

New Suggestion to Measure the Level of Technology Fusion: Technology Fusion Index

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Abstract

This study proposes the technology fusion index as a means to measure the intensity of technology fusion in SME research and development projects on fusion technology. The technology fusion index classifies technologies based on NSTSC (National Science and Technology Standard Classification), analyzes their contributions to the projects and applies Berry-Herfindahl index to measure between 1 and 0. The technology fusion index has the following advantages: First, it enables objective measurement of the level of technology fusion in research and development projects, fair selection of project tasks and effective assessment of project achievements. In addition, it can be combined with national science and technology statistics from NSTSC for more thorough analysis since it is based on NSTSC. The limitation of this study is that it fails to expand technology fusion to the industry level. The Korean government has expanded the concept of technology fusion to the industry level since the enactment of the Industrial Convergence Promotion Act in 2011, and has been making strenuous efforts to foster the industry as one of the country's new growth engines. This study falls short of meeting such government expectations and the issue of technology fusion industry remains open for future research work.

Keywords: technology fusion index, NSTSC (National Science and Technology Standard Classification), Berry-Herfindahl index, Industry Convergence Promotion Act

1. Introduction

Fusion technology refers to the innovative technology that has been developed through interdisciplinary or heterogeneous technology integration to address the economic and social problems of the future. It is drawing much attention as a new growth mechanism, for sustainable economic growth, which is expected to help us overcome the limitations of technology and industrial growth in the existing red ocean market as well as tap into new premium markets and create blue oceans. A case in point is the iPhone from Apple.

As demonstrated with the success of the iPhone, fusing existing technologies can create much more added value than creating whole new innovative technologies. Fusion technology such as IT/BT/NT has infinite potential in creating huge added value and thus is able to manifest itself as an emerging industry, producing highly competitive goods and services.

Major advanced countries have established national fusion technology development plans and provided governmental support for fusion technology development. US government established its NBIC convergence plan to converge nanotechnology, biotechnology, information

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technology and cognitive sciences in 2002 while EU and Japan announced Converging Technologies for European Knowledge Society (CTEKS) and Technology Fusion and Innovation Support Strategy (New Industry Creation Strategy) respectively in 2004. In Korea, multiple ministries also promoted technology fusion research and development projects. However, they had different definitions of fusion technology and conflicting ideas about fusion technology development. (Kim, Jeong and Jeong, 2009) In order to resolve such issues and create new growth engines through fusion technology development, the Korean government enacted the Industrial Convergence Promotion Act in Apr 2011.

Before implementation of Industry Convergence Promotion Act, one of the biggest issues is how to measure industry convergence. If there is no way to measure industry convergence, the performance of various efforts for industry convergence cannot be measured. In the past, Ministry of Education, Science and Technology made a lot of support for the development of technology fusion. However, in the performance evaluation, the convergence level of technology development was not considered but rather patent and the success of commercialization were emphasized. Thus, the effect of government investment on technology fusion is unknown. In order to overcome this limitation, this study proposes technology fusion index that measures the level of technology fusion. The technology fusion index from this study is to objectively measure the level of fusion of the technology that is committed into developing national research and development. In the index, the number and contribution from committed technology are input variables, Herfindahl index which is used as the market concentration index in the field of economics is utilized, and classification of technology is based on NSTSC (National Science and Technology Standard Classification) of Ministry of Education, Science and Technology.

2. Theoretical Background

There exists research on technology classification based on the characteristics of technology fusion

conducted by Hwang, Kim and Lee (2008). Additionally, there are two separate research studies on the technology fusion index: one carried out by Gang, Eom and Kim (2006) and the other conducted by Bae and Lee (2010).

2.1 Fusion Index Based on IPC

Gang, Eom and Kim (2006) defined fusion technology as a technology that “combines technologies from different fields to fulfill market needs or to create new demands” based on the assumption that “technologies from different fields” mean technologies that are classified into different categories based on a particular classification system.

IPC (International Patent Classification) is applied for classification of technologies. That is, technologies are deemed to belong to different fields when IPC subclass for technologies is different under IPC. The number of technology fields is used to measure the level of technology fusion. When IPC are used for economic analysis, the common problem is that the classification method of IPC, which classifies technologies for technological or legal purposes, is not suitable for economic analysis. For example, IPC third-tier B05 adds up the number of patents for sprayers, covering all types of sprayer inventions from insecticide sprays to perfume sprays. If industrial classification was used to classify technologies, insecticide sprays would be classified into the chemical fertilizer industry or the agricultural machine industry and perfume sprays would be classified into either the glass industry or the metal industry, depending on the material of the sprayer.

Schmoch et al. (2003) tried to reconcile 625 IPC classifications with 44 manufacturing classifications, matching IPC up with just one industrial classification. A total of three research institutes – German, French and British research institutes – participated in this process. Dun & Bradstreet documents were used to identify the industries to which a patent application company belongs and, among them, the most important industry was selected as a match. In Korea, Seo (2005) conducted such a matching process and

made a match list, in 2005, which was later utilized by Gang et al. (2006) Gang et al. (2006) to make calculations for the technology fusion index. Taken together, fusion technology can be specifically defined as “a patented technology that has IPC subclass belonging to 44 different industrial classifications”.

“Fusion index” refers to the value indicating to the technology level of convergence with another technology from a different field and is determined by the number of fields a patented technology belongs to. As indicated in (Formula 1), the index is scaled between 0 and 1, where 0 is one technological field for a patented technology and 1 is 44 different technological fields for one patented technology. As most patented technologies’ F_{care} concentrated in the low range, the difference in the raw fusion index in the low range is designed to be large while the difference in the raw fusion index in the upper range is designed to be small.

There is a limit in the fusion index proposed by Gang, Eom, and Kim (2006) since the number of technology committed to technology fusion is only considered while the contribution of committed technology is neglected. These limitations will cause big problem when fusion index is used in selecting research and development projects. For example, let (a) be the situation in which two technologies are given equal contribution (50% each) to be applied to technology development and (b) be the situation in which one technology is given weight of 99% and the other technology is given 1% contribution to be applied to technology development. Then, both (a) and (b) have the same number of applied technology, which is two in these cases. However, when considering the contribution, (b) will be most likely better than (a) but (b) will have difficulty in the process of fusion. Therefore, when only the number of applied technology is considered in the evaluation of the level of fusion, researchers will most likely pay more attention to increasing the number of applied technology rather than putting efforts in technology fusion. Furthermore, when research project is decided by the number of technology, the project will be selected by the amount of fusion rather than the quality of fusion.

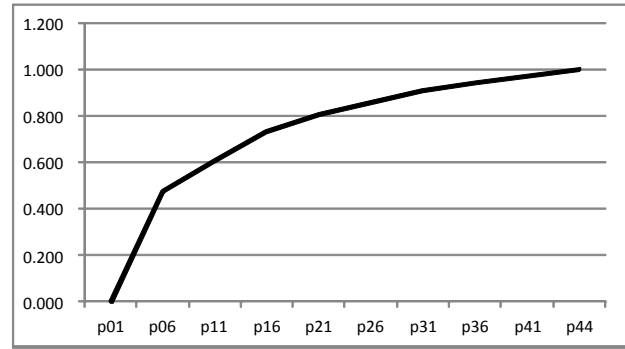


Figure 1 Number of technology vs. Fusion Index (FI_0)

$$FI_0 = F_0 \ln F_c \quad (1)$$

$$F_0 = \frac{1}{\ln F_{\max}} \quad (2)$$

$$FI_{ij} = \frac{FI_{0ij} - \text{Min}(FI_{0j})}{\text{Max}(FI_{0j}) - \text{Min}(FI_{0j})} \quad (3)$$

FI_{ij} : Index in the Row Column i - Normalized Raw Fusion Index Value

FI_0 : Raw Fusion Index

FI_{0i} : Raw Fusion Index in the Row i Column j

FI_{0j} : Raw Fusion Index in the Column j

F_{0ij} : Coefficient that Makes the Maximum Value of FI_0 to be 1

F_{\max} : Number of Total Categories (Fields) under the Classification Standard

F_c : Number of Different Fields a Patented Technology has ($1 \leq F_c \leq F_{\max}$)

2.2 Industry Convergence Index

Bae and Lee (2011) developed their fusion index with the specific purpose of developing an industry convergence index that can assess the value of industrial convergence items. Therefore, they made it clear that the index must take into account the convergence between the same and different manufacturing industries, the convergence between the manufacturing industry and the service industry, the number of technologies contributing to convergence products and the comparison of the intensity of technology fusion in products and in the country of origin. They also emphasized that the index must be expressed in objective numbers.

Bae and Leek (2011) used patent data on tech-

nologies and scored the level of technology fusion based on patents, detailed patented technologies, and on standard industrial classification for patented technologies. Their index based on the assumption that convergence products are developed to add a new function to the existing product and that such a function is associated with patents, detailed patented technologies, and standard industrial classification for patented technologies.

The industry convergence index was measured based on the degree of functional development, the extent of functional convergence and the extent of linkage between industries. The time of product launch and the form of patent development were taken into account when measuring the degree of functional development while the level of convergence between the technology and service fields, which highlights the characteristics of convergence products, was evaluated when measuring the extent of functional convergence. Lastly, the extent of linkage between industries indicated the spillover effects of technological applications to various industries and was thus measured to assess the linkages between technologies and various industries. The extent of linkage between different kinds of industries was measured to be proportional to the potential of industrial convergence and inversely proportional to the level of industrial convergence

Table 1 shows the level of technology fusion in LED TV, iPhone and Nintendo Wii. LED TV earned 71.71 points, the highest score among other target products as it obtained significantly high scores in technology fusion and technology involvement in the industry. LED TV is highly involved in the electric lighting, video display system, and other-electric (television) industries and its technology fusion rate

involving three or more technologies is 39.4%, which is quite high compared with that of other products. Moreover, LED TV technology is fused with service industry functions such as commerce, communications, digital content and broadcasting services.

The iPhone obtained a relatively low score in functional development but was placed first with 30.52 points in terms of technology fusion. iPhone-related technologies are found to be utilized in 15 industry sectors while 70.5% of iPhone-related technologies are concentrated in the top three industries, indicating the low possibility of further technology fusion. iPhone-related technologies earned 16.52 in terms of technology fusion in the manufacturing industry, showing small differences when compared with scores of other products and obtained 14 points in terms of technology fusion in the service industry.

Nintendo Wii obtained a relatively low score in functional development and functional fusion but got a fairly high score of 60.76 in its involvement with the industry, highlighting the fact that Nintendo Wii is a product that meets the definition of a fusion product that creates a new market. Nintendo Wii-related technologies have high potential to be utilized in the entertainment industry, computer peripherals, and electric industries as they are evenly distributed in those industries.

The process of measuring Industry Convergence Index is very complex and difficult. In order to measure Industry Convergence Index, not only patent that is reflected on product has to be identified in order to analyze and evaluate the development process of patent but also technology that is reflected on the patent also has to be identified in order to evaluate the level of technology and also the impact of the product on relevant industry. The problem

Table 1 Examples of fusion index calculation

Ranking	Product	Functional Development (20)	Functional Fusion (40)	Involvement with the Industry (40)	Total (100)
1	LED TV	11.38	23.99	36.34	71.71
2	iPhone	11.81	30.52	24.83	67.16
3	Nintendo Will	11.97	15.6	33.19	60.76

of the evaluation process is that the process reflects lots of the evaluator's subjective. Therefore, Industry Convergence Index is actually difficult to apply and to objectively measure and compare the level of fusion on each product. Thus, as shown in Table 1, Industry Convergence Index should only be used as the means of identifying specific product of level of fusion and characteristics.

3. Development of Technology Fusion Index

3.1 Overview

The technology fusion index is designed to “objectively measure the level of technology fusion in products or services for commercialization”. The technology fusion index is targeted at core technologies, types of technologies and their contribution to products and services. NSTSC (National Science and Technology Standard Classification) is applied for classification of those technologies while the diversification index calculation method is used for index measurements.

3.2 Technology Classification System

‘Fusion technology’ refers to “the merging of technologies from different fields intended to fulfill market needs or create new market demands”. ‘Technologies from different fields’ stands for technologies that are classified into different categories based on an arbitrary classification system. To this end, a classification system is required for index measurements.

The existing research studies classified technologies based on IPC (International Patent Classification) and matched those technologies with industries under the Standard Industrial Classification. The research conducted by Gang, Eom and Kim (2006) is based on Schmoch et al. (2003) and on Seo (2005), which took into account the unique circumstances of Korea. The research defined technology fusion with the primary focus placed on the technology-industry classification system. Bae and Lee (2011) considered three aspects of patent, technology and industry when defining

technology fusion and combined the points for those definitions for evaluation. The classification system is also applied to industry evaluation while ‘relation’ or ‘non-relation’ is not considered for technologies covered by the same patent.

As this study is focused on measuring the level of technology fusion in technology research and development projects, technology-industry or industry classification in the existing research studies are not required and only the technology classification system is needed. Therefore, this study uses the National Science and Technology Classification(‘08) for technology classification. The National Science and Technology Classification is Korea’s national classification system for science technologies designed to facilitate the efficient management of information, personnel and research/development projects and is stipulated in Article 27 of the Science and Technology Basic Act. As all national research and development projects are classified in accordance with the National Science and Technology Classification, it is considered a suitable classification system for technologies in national research and development projects.

Since its establishment in 2002, the National Science and Technology Classification has undergone several restructuring processes and changed to the current system in 2008. The classification system has hierarchical structure, which is composed of main level, second tier and third tier category. The main level category is index marked alphabetically while the second and third tier categories are represented by digits in the decimal system. The last digit is 0(zero) for the second and third tier categories and marked as “XX not otherwise classified”. Depending on the characteristics of the institution using the standard classification system, the institution can make and use their own digits for anything under 4 digits. Similar or overlapping science technologies are classified under the major field while overlapping categories are allowed and marked as cross reference for better understanding.

The National Science and Technology Classification System consists of 34 main categories, 347 second tier categories and 2733 third tier categories. Multiple

selections are allowed for fusion technologies while weights are imposed on categories according to their relative importance in terms of dualistic classification. Table 2 shows information/communications (L) in National Science and Technology Classification System.

3.3 Measurement Method

Gang, Eom and Kim (2006) and Bae and Lee(2011) focused on the number of technologies covered by patents and concluded that the higher the number of technologies covered by patents, the higher the level of technology fusion. They failed to reflect technologies' contribution. This study suggests a method that takes into account technologies' contribution to products and services to overcome the limitations of the existing research studies, which only factored in the number of technologies. The diversification index calculation method is used as a means to calculate the fusion index (Lee et al, 1984).

The simplest measurement method of diversification is to consider the number of industries a particular company is participating in. This method makes

calculating straightforward and is intuitive but falls short of reflecting relative ratios between industries. This method is most similar to the existing fusion index calculation methods.

Another method is RIS (reciprocal of industry specialization). In case of a company manufacturing a single type of product, the value of the index is 1 and the larger is the diversification index, the higher is the index numbers. The maximum value of the index is the same as the number of industries a company participates in. The index is easy to measure, calculate and is a good source for understanding the level of companies' dependence on major industries. However, as in the specialization index, it falls short of demonstrating the distribution of the value of shipments in industries, except for the major industry.

$$RIS = \frac{\text{Total Value of Shipments from Company A}}{\text{Value of Shipments into the Major Industry from Company A}} \quad (4)$$

In order to solve a problem such as the one illustrated above, Gort index was developed to consider both the quantitative and qualitative aspects of

Table 2 National Science and Technology Classification System: L. Information/Communications

Second Tier Category	Third Tier Category
L01 Information Theory	L0101. Computer Theory L0102. Algorithm L0103. Compiler ~ L0110. Cloud computing/Grid computing L0111. Real-Time System L0112. Information Search L0199. Information Theory, Not Otherwise Classified
L02 Software	
L03 Information Protection	
L04 Broadband Convergence Network	
L05 Satellite/Radio Wave	
L06 Mobile Communications	
L07 Digital Broadcasting	
L08 Home Network	
L09 RFID/USN	
L10 U-Computing	
L11 Information Communications Module/Parts	
L12 ITS/Telematics	
L13 Disaster Information Management	
L14 National Defense Information Communications	
L99 Other Information/Communications	L9999. Information/Communications, Not Otherwise Classified

industries. According to Gort index, the index value of a company manufacturing a single type of product is 0 and the larger the diversification index, the higher the index numbers, gaining a value close to the number of industries a company participates in. Although it complements the weaknesses of the two earlier indices, Gort index is still insufficient in measuring the difference in the ratio between industries, except for the major industry.

$$\text{Gort} = \frac{\text{Value of Shipments into Major Industry from Company A}}{1 - \left(\frac{\text{Value of Shipments into Major Industry from Company A}}{\text{Total Value of Shipments from Company A}} \right)} \quad (5)$$

Berry-Herfindahl index is a modified version of Herfindahl index and is easy to calculate and understand. In addition, it also shows the relative ratio between industries a company is participating, making it one of the most influential and widely used indices for diversification. The index is scaled between 0 and 1 and the bigger the index number, the larger the diversification. One weakness of Berry-Herfindahl index is that it cannot show the level of differences between industries a company participates in.

$$\text{BH}^* = 1 - \sum_{i=1}^n x_i^2 \quad (6)$$

x_i : Proportion of Company in a Particular Company's Shipments

Gravity index (Grav) is an enhanced version of Berry-Herfindahl index that combines characteristics of the BH* index and the level of differences between industries. In this index, the more distantly industries are related, the greater the weight is.

$$\text{Grav} = \sum_{i=1}^n \left[x_i \sum_{j=1}^n d_{ij}(x_j) \right] \quad (7)$$

x_i & x_j : Proportion of Industry i and j in A Particular Company's Shipments

d_{ij} : Difference between Industry i and j .

Table 3 The example to calculate weight in gravity index measurement

d_i	d_j	Weight = d_{ij}
31111	31111	0
31111	3111x	1
31111	311xx	2
31111	31xxx	3
31111	3xxxx	4

In equation (7), d_{ij} is the weight showing the distance between industries. Table 3 shows the example to calculate the weights. When the last digit in industrial classification is different, d_{ij} is 1 and when the second last digit and the third last digit are different, d_{ij} is 2 and 3 respectively. However, it is difficult to calculate and understand how diversified it is even when you know the index figures. This study uses the Berry-Herfindahl index, which is easy to calculate and reflects the relative proportions between industries a particular company is involved in, as a method for Technology fusion index calculation.

4. Examples of Technology Fusion Index Calculation

'Technology fusion index' is calculated as follows: Step 1; classifying technologies in accordance with NSTSC (National Science and Technology Standard Classification) as well as identifying and recording their contributions to research and development projects. Six technologies were applied based on the third tier category classification while three technologies were applied based on the main level category classification.

Step 2; multiplying the technology contribution rate (A) based on the main level category classification by A*A and recording the numbers. For instance, the electrical/electronic technology's contribution rate is 0.4, which is then squared to yield 0.16.

Step 3; add up the numbers obtained from Step 2 to get the Herfindahl index value and subtract the Herfindahl index value from 1 to obtain the value for the Berry-Herfindahl index and the technology fusion index.

Table 4 Technology fusion index calculation method: Step 1

Main Level Category		Second Tier Category		Third Tier Category		Technology Contribution Rate	H_Main Level Category
							Technology Contribution Rate(A)
K	Electric/ Electronics	K04	Semiconductor Device	K0402	Compound Device	0.2	0.4
		k06	Home Appliances	K0603	Lighting Equipment	0.2	
L	Information/ Communications	L09	RFID/USN	L0901	RFID Technology	0.2	0.4
				L0903	Mobile	0.2	
J	Chemical Engineering	J02	Nanochemistry Process Technology	J0202	Nanochemistry Process Technology	0.2	0.2
Total Herfindahl						1.0	1.0
Berry-Hefindahl							
Fusion Index							

Table 5 Technology fusion index calculation method: Step 2

Main Level Category		Second Tier Category		Third Tier Category		Technology Contribution Rate	H_ Main Level Category	
							Technology Contribution Rate (A)	A*A
K	Electrical/ Electronics	K04	Semiconductor Device	K0402	Compound Device	0.2	0.4	0.16
		k06	Home Appliances	K0603	Lighting Equipment	0.2		
L	Information/ Communications	L09	RFID/USN	L0901	RFID Technology	0.2	0.4	0.16
				L0903	Mobile	0.2		
J	Chemical Engineering	J02	Nanochemistry Process Technology	J0202	Nanochemistry Process Technology	0.2	0.2	0.16
Total Herfindahl						1.0	1.0	
Berry-Hefindahl								
Fusion Index								

Table 6 Technology fusion index calculation method: Step 3

Main Level Category		Second Tier Category		Third Tier Category		Technology Contribution Rate	H_Main Level Category	
							Technology Contribution Rate (A)	A*A
K	Electrical/ Electronics	K04	Semiconductor Device	K0402	Compound Device	0.2	0.4	0.16
		k06	Home Appliances	K0603	Lighting Equipment	0.2		
L	Information/ Communications	L09	RFID/USN	L0901	RFID Technology	0.2	0.4	0.16
				L0903	Mobile	0.2		
J	Chemical Engineering	J02	Nanochemistry Process Technology	J0202	Nanochemistry Process Technology	0.2	0.2	0.04
Herfindahl $\sum A^2 A$						1.0	1.0	0.36
Fusion Index								
Berry-Hefindahl = 1-Herfindahl								0.64

Table 7 shows the fusion index for four different products. Product 1 is based on the third tier category under NSTSC and only one technology is applied for Product 1. Even based on main level category or second tier category classification, only one technology

is applied and thus the fusion index value is 0. On the contrary, ten technologies are utilized for Product 4, which is also based on the third tier category under NSTSC, meaning that the technology contribution rate is 10% for each technology. Three technologies;

Table 7 Comparison of scores derived from technology fusion index

Main Level Category		Second Tier Category		Third Tier Category		Product 1	Product 2	Product 3	Product 4
K	Electrical/ Electronics	K04	Semiconductor Device	K0402	Compound Device	1.00	0.5	0.2	0.1
				K0403	Semiconductor Materials		0.2	0.2	0.1
				K0407	Design Tool			0.2	0.1
				k0409	Other			0.2	0.1
		K06	Home Appliances	K0603	Lighting Equipment		0.1	0.2	0.1
				k0609	Other				0.1
L	Information/ Communications	L09	RFID/USN	L0901	RFID Technology		0.1		0.1
				L0903	Mobile				0.1
				L0909	Other				0.1
J	Chemical Engineering	J02	Nano chemistry	J0202	Nano chemistry		0.1		0.1
Total						1	1	1	1
Technology Fusion Index						Third Tier Category	0.00	0.68	0.80
						Second Tier Category	0.00	0.48	0.32
						Main Level Category	0.00	0.34	0.00
						Total	0.00	1.50	1.12
							2.14		

electrical/electronics (0.6), information/communications (0.3) and chemical engineering (0.1) are applied on the basis of the main level category classification while four technologies; semiconductor device (0.4), home appliances (0.2), RFID/USN(0.3) and nanochemistry (0.1) are applied on the basis of the second tier category classification.

Product 2 and Product 3 are in stark contrast to each other: For both products, five technologies are used based on the third tier category classification. However, there are significant differences when a classification is made based on the main level category as opposed to the second tier category. Three technologies of electrical/electronics (0.8), information/communications (0.1) and chemical engineering (0.1) are used for Product 2 on the basis of the main level category classification while four technologies, semiconductor device (0.7), home appliances (0.1), RFID/USN(0.1) and nanochemistry (0.1), are used on the basis of the second tier category classification.

By contrast, one technology is used for Product 3 based on the main tier category classification while two technologies, semiconductor device (0.8) and home appliances (0.2), are used based on the second tier category classification. That is, the fusion index

is higher for Product 3 with a uniform distribution when a classification is made based on the third tier category but is higher for Product 2 when a classification is made based on the main level and second tier categories. Therefore, it can be concluded that the technology fusion index is greatly affected by NSTSC.

5. Conclusions

This study suggests the technology fusion index as a means to measure the level of technology fusion in research and development projects. The technology fusion index classifies technologies based on NSTSC, analyzes their contributions to the projects and applies Berry-Herfindahl index to measure the index value between 1 and 0.

The technology fusion index has the following advantages: First, it enables objective measurement of the level of technology fusion in research and development projects, the fair selection of project tasks and the effective assessment of project achievements, making it stand out from other research studies. In addition, it can be combined with national science and technology statistics from NSTSC for a more thorough

analysis since it is based on NSTSC.

The limitation of this study is that it fails to expand technology fusion to the industry level. The Korean government has expanded the concept of technology fusion to the industry level since the enactment of the Industrial Convergence Promotion Act in 2011 and has been making strenuous efforts to foster the industry as one of the country's new growth engines.

This study falls short of meeting such government expectations. Nevertheless, this study, unlike other studies that start with patent, provides a new perspective that connects technology with technology and technology with fusion products, thereby progressing future industry-wide research. In other words, the analysis of this study's output, research and development project, by Standard Industrial Classification makes it easy to measure the level of technology fusion at product level. Furthermore, if the connection between technology and product, like past patent and industry, can be established by expanding the analysis of relation, this application can provide clues that can measure both convergence between products and industrial convergence. In my opinion, if these kinds of research are continually conducted, the situation of industrial convergence can be more systematically identified, thereby helping in making industrial convergence as one of the country's new growth engines.

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