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## Article

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RESEARCH

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# Weak signal detecting of industry convergence using information of products and services of global listed companies - focusing on growth engine industry in South Korea -

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## Abstract

The [World Economic Forum 2016, <https://www.weforum.org/events/world-economic-forum-annual-meeting-2016>. Accessed 5 Aug 2017] predicted that the world would face the Fourth Industrial Revolution which means innovative changes through convergence of cutting-edge information and communications technologies (ICTs) such as artificial intelligence, IoT, big data and cloud computing with conventional industries. It was forecasted that such innovation would take place across all industries and services. In particular, the Fourth Industrial Revolution has paid attention to changes in conventional traditional industries. The weak signal analysis is a method which can detect the sign of future changes at an early stage. A weak signal is defined as an advanced indicator in such changes. Therefore, its search and monitoring can be an early warning on threat and great opportunity to be prepared. To overcome the limitation of future prediction which is mostly dependent upon an expert group's intuitive judgment, this study attempted to investigate the weak signal of convergence among industries, using knowledge structure based approaches. As new products and services can lead to convergence between industries, research data has gathered information on the products and services of global listed companies which have been established for the past 11 years. For comparative analysis, they were grouped every 5 years, and product and service trends were compared. And we detected weak signals of convergence with different industries and noticed the changes of existing industries. Historically, the convergence of industries is mainly discussed in relation to science and technology-led industries, so the industrial field that has been studied has chosen Korea's growth engine industries, a high-tech science and technology industries.

**Keywords:** Sharing economy, Global listed companies, Convergence trend, Weak signal, Growth engine industry

## Introduction

Today, businesses are exposed to rapidly changing business environments. Under these circumstances, it is very difficult for them to launch and lead new business just by responding to such changes. Therefore, businesses have pursued open innovation by

monitoring and converging external knowledge to stay competitive in global market. For this, there have been a lot of studies. Many studies such as “Application of Open Innovation to Social Business (Svirina et al., 2016)”, “Effects of Service Innovation on Government Support System (Si-jeoung et al., 2016)”, “A Study on the development of new Innovation Diagram based on three elements - Technology - Business Model (BM) - Market (JinHyo et al., 2016)”, and “Analysis of Core Competency Enhancing Relationship between Innovation Performances and TQM Implementation (Maha, 2016)” have insisted that businesses need to keep monitoring diverse internal and external environments and promoting innovation.

The 2016 World Economic Forum in Davos, experts predicted continued low growth of world economy, increase in the risk of Chinese economy, low oil price, decrease in global productivity and acceleration of industrial competition. As a way to overcome such problems, they suggested that businesses need to well understand the Fourth Industrial Revolution and get fully prepared. 2016 was the year when ‘Sharing Economy’, one of the core businesses of the Fourth Industrial Revolution, had a significant influence on industries. This trend would be called “uberization”. In fact, it brought a sensation to conventional industries while being defined as a new economic term.

This new term originated from the word ‘uber’. It refers to direct transaction between the consumer and supplier through the Internet without any broker. Recently, it has rapidly spread across industries such as lodging industry, finance, law and medicine as well as transportation. In 2015, the Wall Street Journal predicted that ‘uberization’ would be available in all services.

It’s forecasted that diverse ICT platform-based services and business models would increase, and industrial competition would become more intense. In addition, the importance of conventional industries has been re-illuminated. To understand these changes which have spread across industries through convergence with conventional industries based ICT, it is necessary to examine ‘weak signal’, a sign of future changes on industrial products and services.

A weak signal is an advanced indicator on certain phenomena. Monitoring this is essential in assessing timely warning and origin of uncertainty (Sandro et al., 2012). This study targets to suggest implications after analyzing business service trends and investigating a weak signal on convergence services with data on the products and services of global listed companies from 2005 to 2015.

## **Literature review**

### **2. 1. Weak signals**

Ansoff (1975) introduced a concept called weak signals for preventing long-range-planning or strategic-planning problems, and categorized information into two groups: strong signals and weak signals. Weak signals can become clearer and strengthen over time to become strong signals or they might vanish.

Godet (1994) defined it as a sign of a big change near the future even though it is hard to see it at present. In other words, it is deemed as one of the methods to analyze uncertain future. Hiltunen (2008) suggested a 3D spatial model comprised of signal, issue and interpretation as a sign of future changes. ‘Signal’ refers to the number of signals or visibility while ‘issue’ represents the number of issues. Lastly, ‘interpretation’

means a degree of recognition of future signal by information users. As the number of signals and issues increases in a 3D space, and such signal has a bigger influence on information users, a weak signal moves to a strong signal Fig. 1.

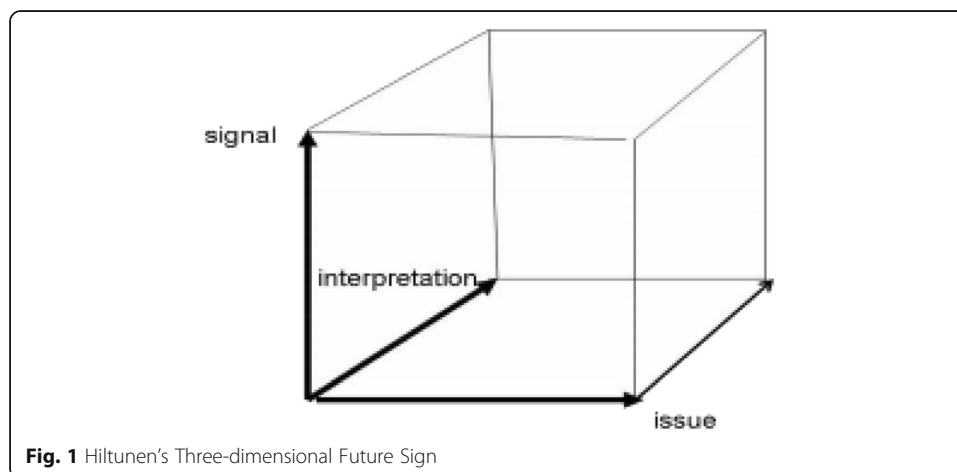
Coffman (1997) stated the 7 different characteristics of ‘weak signal’ and explained it specifically. He insisted that they bring changes in political, economic, technical and social thoughts and inventions. Kuosa (2010) said that a weak signal should bring significant effects in the future, or it would probably end up as a meaningless chatter (cf. Table 1). In fact, it is a critical matter to separate the weak signal from the meaningless chatter.

Coffman (1997) and Brown (2007) applied a concept of ‘weak signal’ to the analysis of business environments in their studies. Kaivo-oja (2012) studied integration with corporate knowledge management theory. In addition, Sandro et al. (2012) added weak signal analysis to the level 6 in a business foresight analysis framework.

In fact, there have been many other studies on weak signal analysis in diverse fields such as R&D environment change monitoring & future studies, international security, politics and communication studies (Sun-Hi et al., 2009). The approach to detect weak signals is mainly based on expert discussions, Delphi methods, and intuitive judgment by experts, which is time consuming and costly.

To solve these problems, researches using a knowledge structure based approach for clustering have been started (Thorleuchter and Van den Poel, 2015). There are qualitative and quantitative approaches to the analysis of knowledge structures. The qualitative approach has the advantage that it is easier to grasp the knowledge structure as a way to obtain opinions from the research field to a small number of experts, but there are disadvantages such as bias or subjective errors of the experts (Law & Whittaker, 1992). Social network analysis, which is widely used as an analysis method of knowledge structure, is an analytical method for constructing a keyword network using keywords as objects, analyzing them quantitatively, and grasping the relationship between keywords. (Newman and Girvan, 2004; Scott, 1991). Key indicator of social network analysis include co-occurrence, centrality, and clustering analysis of keywords.

Tabatabaei (2011) considered environmental scanning of Web as the main way to detect emerging weak signals in the digital media field, and applied web mining, text



**Fig. 1** Hiltunen's Three-dimensional Future Sign

**Table 1** Signals: Probabilities and Effects (Kuosa, 2010, p. 43)

	Small Effect	Big Effect
Small probability of coming true	Meaningless chatter	Weak signal
Big probability of coming true	Original trend	Megatrend

mining, and document clustering to analyze. Janghyeok (2012) studied Internet-based environmental scanning combined with weak signal analysis and used keyword-based text mining using Web news. In contrast to the knowledge structure based approach, research using a semantic clustering approach focusing on the meaning of text has also been conducted (Thorleuchter and Van den Poel, 2015).

## 2. 2. Industry convergence

The convergence started from the research centered on technology convergence, but it is gradually expanding to the study of science, value, market, and industry convergence.

In general, the method for analyzing technology convergence is to analyze the citation information of patents (Trajtenberg et al., 1997) or measure the degree of convergence of technology using ipc co-classification information of patent (Curran & Leker, 2011).

Most scholars have focused on the media, information technology or electronics industry to study industrial convergence, primarily because it relates to high-level industries that are centered on science and technology (Schnaars et al., 2008).

According to Curran and Leker (2011), convergence is a sequential process, and when science, technology, and market converge, it evolves sequentially to the stage of industry convergence. In addition, industry convergence can be achieved through either a new business model or a new product / service.

In this study, we analyzed the trend of industrial convergence using information of products and services of global companies.

## 2. 3. Growth engine industry

Korea's growth engine industry refers to core technologies or products/services which would create new market from a long-term perspective, evolve into new industry and make a big contribution to the improvement of added values and job creation if it is discovered and promoted by the government or national strategy (Seok-in et al., 2014). Under this policy, Korean government has strategically chosen future growth engine industry for economic growth and job creation since April 2015. In fact, such strategic industry growth policy has been the mainstream around the globe. It includes the US government's innovation strategies (the White House, USA, 2011), Japan's Industrial Structure Vision (METI Japan, 2010) and EU's core implementation technology selection & promotion (EU, 2010). The 10 Biggest Startup Opportunities 2016<sup>1</sup> published by CIO Magazine are also considerably matched with the growth engine industries named by Korean government.

According to previous studies on the number of new global businesses by Korea's growth engine industry, even though the number of business startups was declining by

12% from the prior year (2013), the number of businesses from growth engine industry has increased in the Group of 7 (G7) (Lee-Nam et al., 2016).

### **Analysis method**

The methodology of this study is based on a knowledge structure based approach to search for the weak signals of inter-industry convergence. However, it is differentiated method by using keyword network analysis, betweenness centrality for convergence measurement, and minimum spanning tree (MST).

We use keyword network analysis in order to distinguish weak signal and meaningless chatter, and to express related product and service keywords in network, and applied MST to visualize which links in the product and service nodes are important and to show only the backbone of the graph.

This study analyzed the products and services of the global listed companies which have been established for the past 11 years for the purpose of discovering a weak signal and service trends which have been linked with diverse industries in convergence with conventional services.

First, this study attempted to detect intra- or inter-industry service trends and changes by analyzing a keyword network on the business types and products & services of the global listed companies. For this, they were divided into two groups (2005–2010, 2011–2015) by the year of establishment and comparatively analyzed. For analysis data, ORBIS database, a business information database (approx. 154 million items) of the digital publisher 'Bureau Van Dijk (<https://orbis.bvdinfo.com>)' was used.

First of all, data on the business types and products & services of 16,151 global listed companies (excluding 177 firms in which business code is missing) from 2005 to 2015 were extracted. Then, 5626 listed companies in growth engine industry were selected. For target industry, Korea's growth engine industry was chosen. Each industrial sector can be classified under the Korea Standard Industrial Classification (KSIC).

In the ORBIS, U.S. SIC is used for business code. Since the information which can map both U.S. SIC and KSIC is provided, the KSIC code which belongs to growth engine industry can be mapped by the major group (2-digit) of the SIC code. In addition, 'products and services' provided by the ORBIS are mostly the items collected by the analyst or data provider. Therefore, general and simple data are provided. Because data are usually available in phrase, they are good for the analysis of a keyword network. To figure out convergence with other services (or products) under the same industry, a keyword network analysis method was used, and products & services and inter-service connectivity were set with 'node' and 'link' respectively.

The co-occurrence matrix between phrases (keywords) which represent products & services shows the number of the businesses in which different keywords occur at the same time. Therefore, increase in this value means that many companies provide products and services. The actual data format is 'weighted edge list' just like 'source-target-weight'. Here, 'source' and 'target' represent 'products' and 'services' each while 'weight' refers to the value of the co-occurrence matrix. In reality, inverse values were used. An inverse number was used for weight to sort core links in the MST.

The graph consists of node and edge. In the said co-occurrence matrix, the keyword of 'source' and 'target' in 'source-target-weight' form is node while the line which

connects source and target is ‘edge’. Lastly, the weighted value of the edge is ‘weight’. Even though there would be diverse ways to visualize the graph, the force-directed placement (FDP) is a technique to visualize all nodes and links. However, this kind of visualization technique is not preferred because its visibility drops when the number of nodes and edges increases. To visualize a big graph having a lot of nodes and edges, it is preferred to express a graph in backbone. Among these methodologies, MST is basically used.

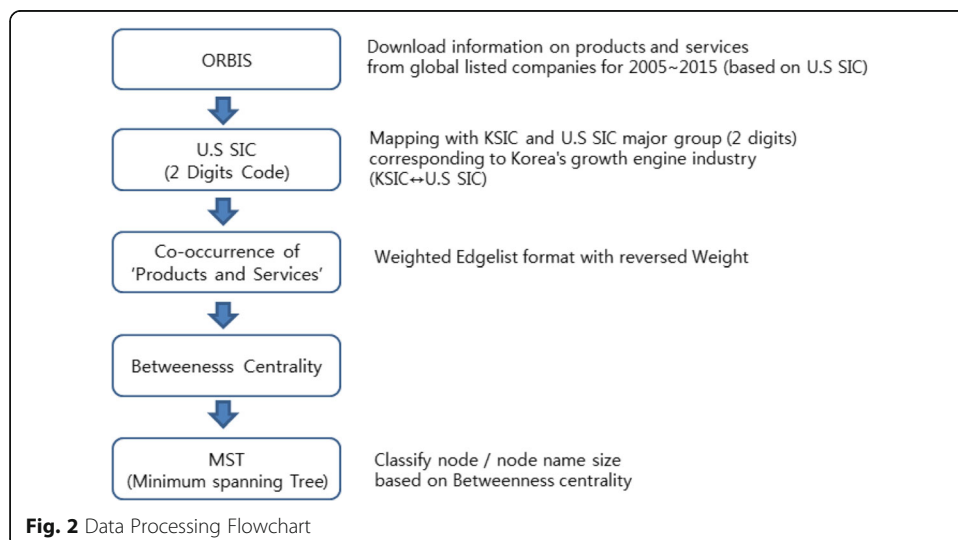
MST is a methodology to visualize the edges which minimizes the weighted sum of all nodes on a network. For example, let’s say the undirected graph  $G = (V, E)$ . Here, ‘V’ is a set of vertex (another name of a node) while ‘E’ represents a set of edges. The weighted value of random edge  $(u, v)$  in ‘E’ is taken as ‘ $w(u, v)$ ’, and sum of total weighted values linking all vertexes is stated as ‘ $w(T)$ ’. Then, the following equation appears:

$$w(T) = \sum_{(u,v) \in T} w(u, v)$$

In the MST problem, it is essential to discover the power set (“T”) of the edge set which minimizes the equation ‘ $w(T)$ ’ Fig. 2. Consequently, the group comprised of the power set ‘T’ and node set ‘V’ is stated as follows ( $G' = (V, T)$ ) Cormen et al. (2001):

Meanwhile, the MST algorithm chooses edges which minimize the weighted value of path. Therefore, the value with lower edge is selected. In co-occurrence matrix used in this study, however, the one with higher weighted value is a more important edge. To select more important edges, hence, this study took reverse weighted values.

In basic MST algorithm, a node size is not considered. From the perspective of information analysis, however, it is useful to visualize what keywords are important. Therefore, this study attempted to differentiate node sizes and express them in the MST figure. For the standards to differentiate a node size, the importance of a node’s mediating role in a whole network was examined. In other words, it was interpreted that if





mediation in a whole network was high, the roles implemented for product-service convergence would also increase. For this, betweenness centrality has been commonly used in social network analysis.

In addition, graph data divided into two periods were overlapped, and new product and service nodes which appeared later were expressed in the MST with different colors. In this manner, the keywords excluded from the industry classification in the products and services marked in a different color (red in this study) were taken as the weak signal of convergence.

According to Hiltunen (2008), weak signals are rarely exposed topics, so we extracted low frequency keywords (small size nodes) from links connected to the network.

This study also used 'R program' in most data analysis projects.

## Results

The U.S SIC is a 4-digit code allocated to companies by the US government to identify their business. This code is arranged in 11 sectors, and it is divided into 83 2-digit major groups and 416 3-digit industrial groups. It is comprised of a total of 1005 4-digit industries.

Appendix 1 reveals that Korea's growth engine industry is mapped to 9 major groups (28, 35, 36, 37, 38, 48, 49, 73 and 87) among the 83 2-digit major groups of SIC. The number of global listed companies by year of establishment in Appendix 2 represents the number of global listed companies (16,151) on the 1st digit of the U.S SIC. Table 2 below states the number of global listed companies in the 2-digit major groups mapped to Korea's growth engine industries by year.

Table 3 below describes the services of the 2-digit major groups mapped to growth engine industries.

The same first digit in the SIC means same an industrial division. Therefore, 9 major groups can be grouped into five major classes (28, 35–38, 48–49, 73 and 87). Figure 3 below reveals the percentages of the five major groups in the same division for the past 11 years.

**Table 2** Number of Global Listed Companies by Year of Establishment

USSIC	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
28	140	136	143	76	80	76	62	47	36	47	26	869
35	71	73	53	41	34	41	36	14	19	19	10	411
36	116	141	112	77	65	74	56	35	28	30	17	751
37	31	23	28	19	8	23	15	8	12	12	8	187
38	39	65	45	42	19	28	16	20	18	25	14	331
48	65	61	56	35	28	32	26	19	13	23	8	366
49	77	67	66	29	28	42	26	16	16	23	10	400
73	236	241	224	143	133	182	150	99	92	116	59	1675
87	72	92	87	69	51	54	59	42	55	36	19	636
Total	847	899	814	531	446	552	446	300	289	331	171	5626



**Table 3** U.S SIC Major Group Mapped to Korea's Growth Engine Industries

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73 - Business services
87 - Engineering, accounting, research, management, and related services
28 - Chemicals and allied products
35 - Industrial and commercial machinery and computer equipment
36 - Electronic and other electrical equipment and components, except computer equipment
37 - Transportation equipment
38 - Measuring, analyzing and controlling instruments; photographic, medical and optical goods; watches and clocks
48 - Communications
49 - Electric, gas and sanitary services

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The five groups mapped to growth engine industries accounted for more than 50% in the same industrial division. In particular, the number of companies in Group 73 stayed over 70% for the past 11 years. In terms of the number of global listed companies, Group 73 is the highest among the total major groups.

#### 4. 1. Products and services of the SIC 28 major group

Major Group 28 is a group of chemicals and allied products. This major group includes establishments producing basic chemicals, and establishments manufacturing products by predominantly chemical processes. Establishments classified in this major group manufacture three general classes of products: (1) basic chemicals, such as acids, alkalies, salts, and organic chemicals; (2) chemical products to be used in further manufacture, such as synthetic fibers, plastics materials, dry colors, and pigments; and (3) finished chemical products to be used for ultimate consumption, such as drugs, cosmetics, and soaps; or to be used as materials or supplies in other industries, such as paints, fertilizers, and explosives.

From 2005 to 2010, chemicals, chemical products and pharmaceuticals were the mainstream. However, they shifted to cure, drugs, pharmaceuticals and healthcare products during 2011–2015.

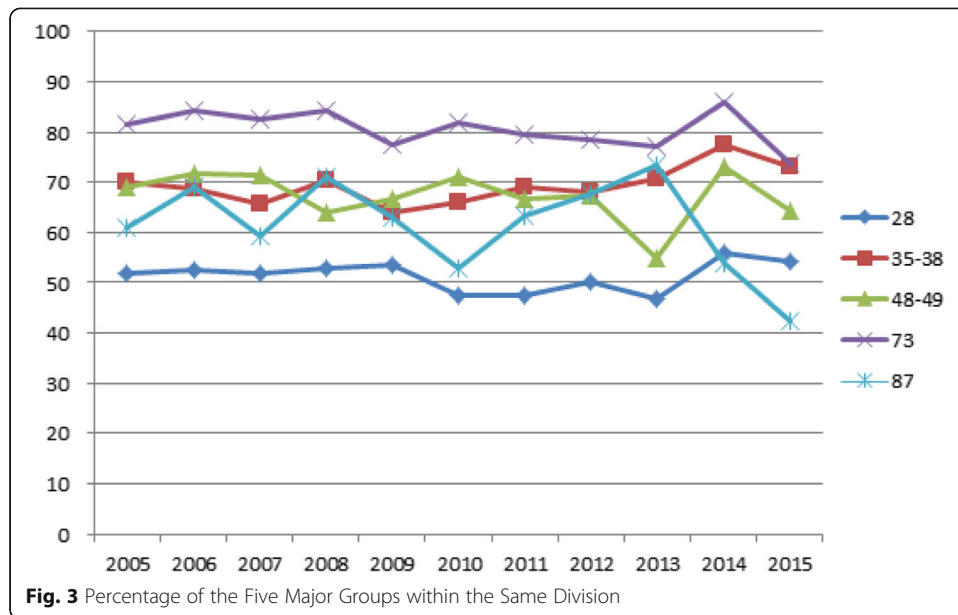
The Weak signal appears as the smallest node in the connection line of the keyword network, and we extracted keyword that does not belong to the same industry to detect weak signals of convergence with other industries.

The product keywords under a weak signal included own healthcare product, medical device, cancer treatment, complementary product candidate, rare disease and commercial technology.

This can be interpreted as a signal that the chemical industry is converging with the healthcare and medical equipment industries as well as the medical and pharmaceutical industries Fig. 4.

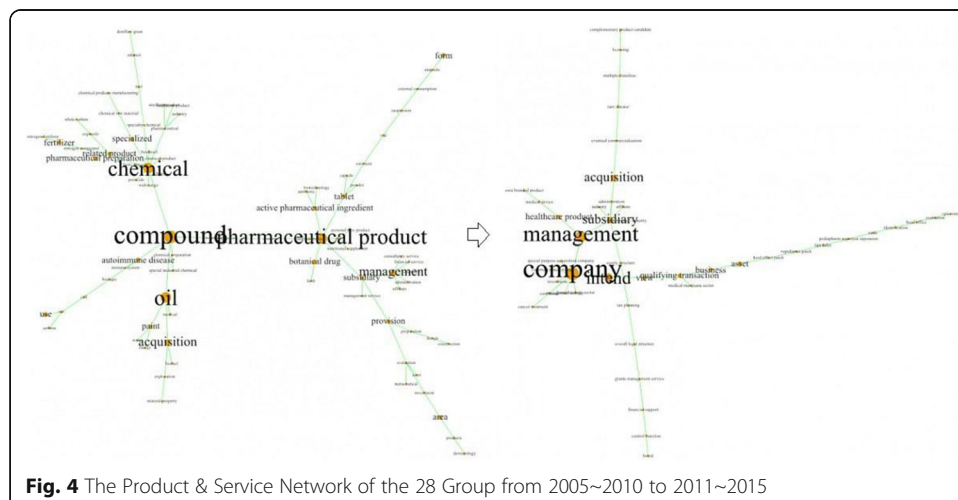
#### Products and services of the SIC 73 major group

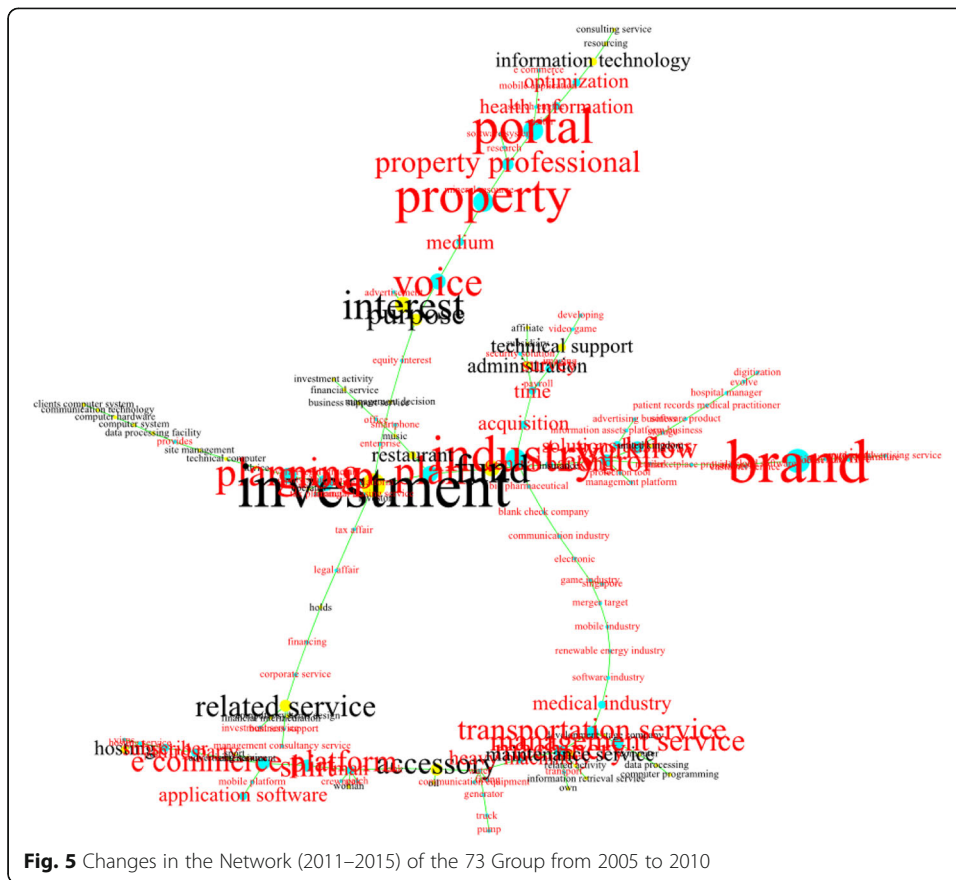
The Major Group 73 is a business services group based on ICT. This major group includes establishments primarily engaged in rendering services, not elsewhere



classified, to business establishments on a contract or fee basis, such as advertising, credit reporting, collection of claims, mailing, reproduction, stenographic, news syndicates, computer programming, photocopying, duplicating, data processing, services to buildings, and help supply services.

According to analysis results, this major group has continuously provided diverse services (e.g., information technology, investment & financial management, finance, business support, etc.) for the past 11 years. From 2005 to 2010, computer system, hardware, web services, online ads, mobile phone, business support, Internet platform and consulting were primary services. During 2011–2015, investment services were further accelerated. Then, service configuration shifted to applied software, portal services, client-oriented, voice, brand, smartphone, e-commerce platform, information protection & security solution, cloud software,





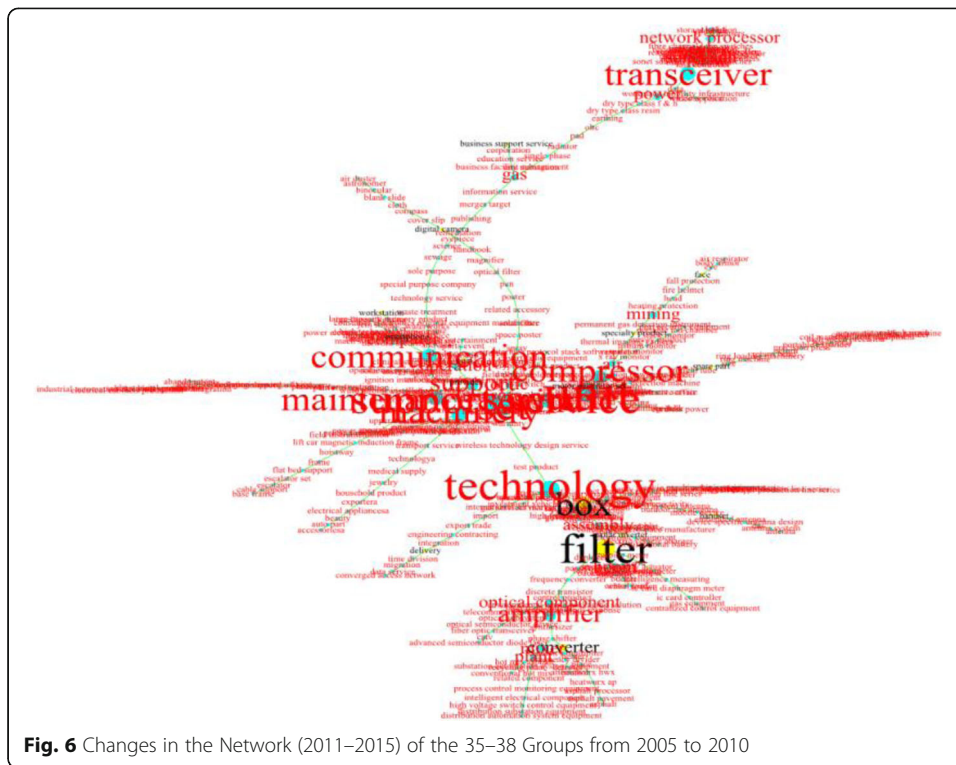
transportation and property services. In addition, centrality has expanded in health-related services Fig. 5.

What matters is that compared to the past in which particular services were specified, service keywords relating to diverse industries (e.g., medicine, game, communication, mobile, renewable energy) have emerged. The words under a weak signal include patient records, bio pharmaceutical, hospital manager, imaging, restaurant, tank, entertainment, water, mineral resource and blank check.

This can be interpreted as a signal that ICT industry is converging not only in medicine, bio, health, energy, transportation industry but also in entertainment, finance, defense, food industry etc. and can be seen that ICT industry is the main industrial field in the Fourth industrial revolution.

### Products and services of the SIC 35–38 major groups

In Major Groups 35–38, the number of global listed companies in each group is small, and they belong to the same manufacturing division. Therefore, all service keywords were analyzed together. Major Groups 35–38 are related with machine and equipment. They are manufacturing industry-based groups which include the parts and products relating to industrial machine, transportation equipment, computer and measuring & analysis instruments.

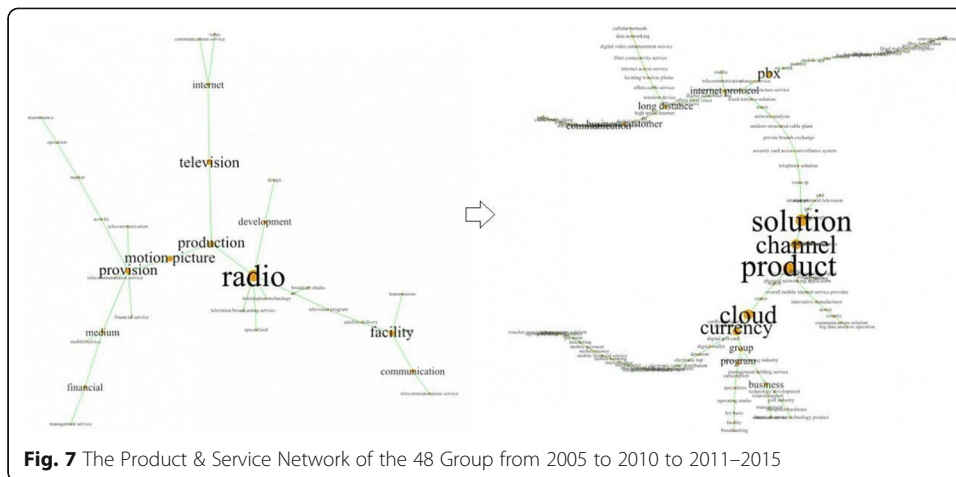


In terms of product configuration from 2005 to 2010, machine parts (e.g., generator, display, assembly, wheel, lamp, motor, panel, power supply, USB, lense, corgresistor, fixture, converter, etc.) accounted for a great portion. From 2011 to 2015, there was a shift to technology-oriented services including diverse machine. Product composition includes communication service, transceiver, network processor, amplifier, compressor, optical component, mining and maintenance service. Just like Group 73, investment and corporate management support services were further accelerated. The words under a weak signal include voice, water, gas, medical device, security, software solution, education and smart home. This can be interpreted as a signal that the mechanical and manufacturing industries are converging with medical equipment, security, education, smart home and environmental industries Fig. 6.

#### Products and services of the SIC 48–49 major groups

Major group 48 includes establishments furnishing point-to-point communications services, whether intended to be received aurally or visually; and radio and television broadcasting. This major group also includes establishments primarily engaged in providing paging and beeper services and those engaged in leasing telephone lines or other methods of telephone transmission, such as optical fiber lines and microwave or satellite facilities, and reselling the use of such methods to others.

The major services from 2005 to 2010 were telecommunication, radio, television, broadcasting, the Internet, motion picture and equipment. They shifted to channel,



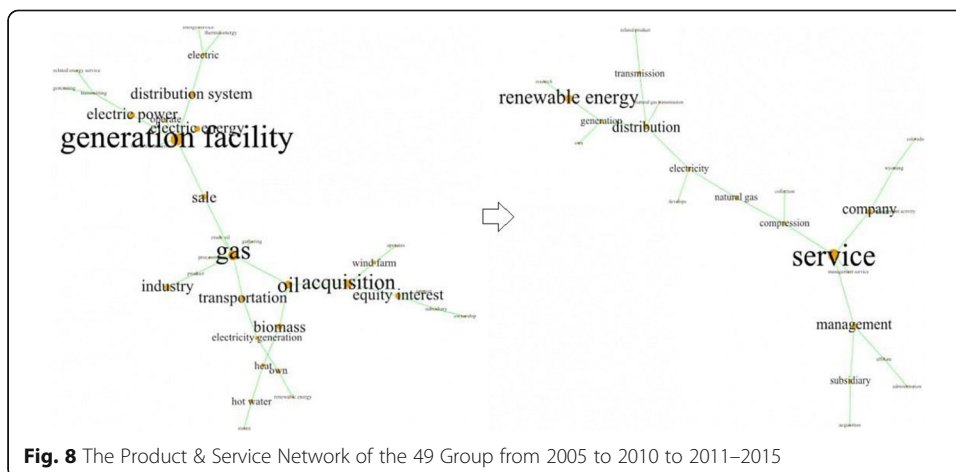
**Fig. 7** The Product & Service Network of the 48 Group from 2005 to 2010 to 2011–2015

broadband, pbx, high-speed internet, cloud and currency (digital wallet, digital gift card) during 2011–2015. The words under a weak signal converged with other industries include big data analysis, innovative manufacturer, mobile payment/banking, local voice, fixed wireless, digital video entertainment, security card access and surveillance system.

This can be interpreted as a signal that the telecommunication industry is converging with big data, mobile, security and entertainment industries Fig. 7.

Major Group 49 represents the field of electric, gas and sanitary services. This major group includes establishments engaged in the generation, transmission, and/or distribution of electricity or gas or steam. Such establishments may be combinations of any of the above three services and also include other types of services, such as transportation, communications, and refrigeration. Water and irrigation systems, and sanitary systems engaged in the collection and disposal of garbage, sewage, and other wastes by means of destroying or processing materials are also included.

The major services from 2005 to 2010 were generation facility, electric power & energy, gas, oil, biomass, distribution system and transportation. During 2011–2015,



**Fig. 8** The Product & Service Network of the 49 Group from 2005 to 2010 to 2011–2015

almost sale services were provided, but centrality expanded in services and renewable energy Fig. 8.

### Products and services of the SIC 87 major group

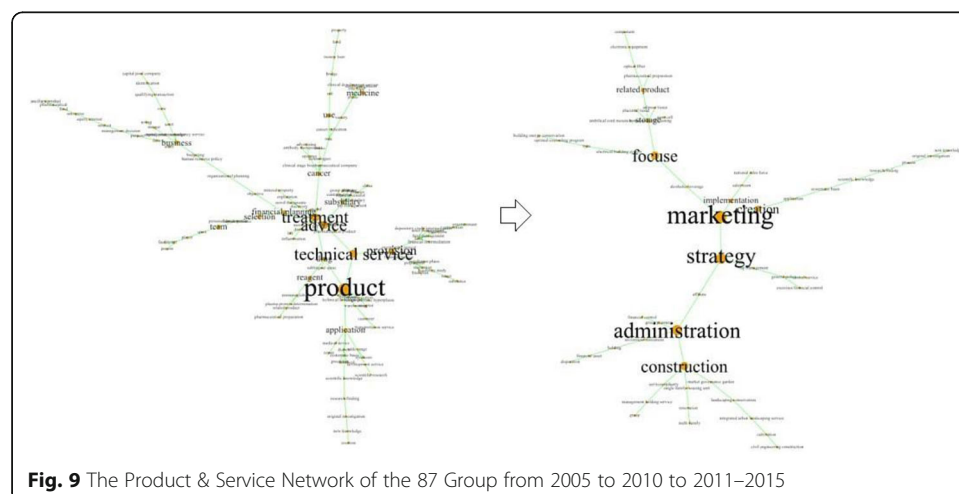
Major Group 87 represents engineering, accounting, research, management, and related services. This major group includes establishments primarily engaged in providing engineering, architectural, and surveying services; accounting, auditing, and bookkeeping services; research, development, and testing services; and management and public relations services.

The major service keywords from 2005 to 2010 were consulting services relating to business management activities and investments and pharmaceutical products (e.g., disease, cancer, treatment, drug, reagent, etc.). In terms of changes in service keywords during 2011–2015, keyword centrality in marketing, strategy, administration and construction as well as pharmaceutical products (e.g., disease, treatment, etc.) further expanded. As a weak signal of convergence with other industries, the following words were found: single family housing unit, cultivation urban landscaping conservation, renovation, service industry, market governance garden and building energy conservation.

This can be interpreted as a signal that the engineering industry is converging with the construction, energy, and service industries Fig. 9.

### Conclusion and future work

This study analyzed Korea's growth engine industries with the products and services of global listed companies which have been established for the past 11 years (2005–2015). These global listed companies represent growing businesses, and products and services are an indicators which represents the related industries. In addition, Korea's growth engine industry is the hottest industrial sector which should be strategically developed. Therefore, the study results have great implications. To examine the weak signal of inter-industry convergence, the keywords relating to the products and services from other industries were derived. The





results of the analysis on the U.S SIC's five major groups mapped to Korea's growth engine industries found the followings:

Major Group 73 is a group which is most converged with diverse industries such as medicine, energy and communication. The keywords under the weak signal for the convergence also varied from diverse fields including bio-health, entertainment, environment and finance. In Major Group 28 as well, changes from chemical products to more specified products such as drugs and health-related products were found. Under a manufacture-based business type, Major Groups 35–38 shifted from machine, equipment and parts services to technology-oriented services. The weak signal of convergence such as education, smart home, environment, medicine and security services occurred. Major Groups 48 and 49 also found a weak signal such as big data analysis, mobile payment/banking, security card and renewable energy, slightly different from industry services. In Major Group 87 as well, there was a shift from traditional consulting services to marketing and strategy services which reflect trends (e.g., single family, service industry, building energy).

This study showed the possibility of detecting weak signals of industrial convergence to prepare for the Fourth industrial revolution era by using product and service information of global listed companies. The proposed method is advantageous in that it can detect weak signals more efficiently than time-consuming and expensive expert methods.

In this study, five major groups were grouped and analyzed every 5 years. Therefore, there should be a more specific analysis on Major Group 73 in which convergence with diverse industries has occurred. In addition, it is necessary to analyze connectivity with technology trends by analyzing patents and papers and examine the products and service trends of global listed companies in 11 industrial divisions.

The limitation of this study is that only the information of products and services of listed companies is used to detect weak signals of industrial convergence. The proposed methodology should be applied not only to BM patent information including new business model information but also to information on products and services of unlisted companies. In addition, since the study has been limited to the fields of the growth engine industry being promoted in Korea, future research needs to be studied in the whole industry field. For more accurate analysis, however, it appears that there should be a Delphi survey which acquires opinions from expert groups based on the study results.

This study is expected to provide businesses a hint for the development of products and services by recognizing the weak signal of convergence with other industries in addition to service trends. Furthermore, global listed companies' analysis results would be useful in analyzing business environments for predicting and being prepared for the future.

## Endnotes

<sup>1</sup>1. Wearables in the enterprise, 2. Consumer IoT and 'smart home', 3. Consumer privacy protection, 4. Counterterrorism technologies, 5. Cybersecurity services to protect enterprises, 6. Financial tech in emerging markets, 7. Digital health and Big Data, 8. The 'Uberization' of manufacturing, 9. Autonomous cars, 10. Space exploration.



## Appendix 1

**Table 4** US SIC Code and KSIC Mapping of Growth Engine

Growth Engine	U.S SIC Code	KSIC	Business Type
Smart car	3812	27211	Manufacture of wireless navigation devices and measuring instruments
	3663	26429	Other wireless communication equipment manufacturing
	3711	30121	Car and other passenger vehicle manufacturing
	No Mapping	30320	Automobile body parts manufacturing
	No Mapping	30392	Automobile electric system manufacturing
5G mobile communication	3714	30399	Other auto parts manufacturing
	3663	26429	Other wireless communication equipment manufacturing
	7372	58222	Development & supply of application software
	No Mapping	61220	Wireless communication
Deep-sea / extreme-environment offshore plant	4899	61299	Other electric communication
	3561	29131	Liquid pump manufacturing
	3731	31119	Other vessel manufacturing
High-speed vertical take-off & landing unmanned aerial vehicle	No Mapping	42136	Underwater construction
	8711	72129	Other engineering services
	3721	31310	Aircraft, spacecraft and auxiliary system manufacturing
Intelligent robot	No Mapping	29280	Industrial robot manufacturing
Wearable smart device	3661	26422	Mobile phone manufacturing
	3663	26429	Other wireless communication equipment manufacturing
	3845	27112	Electric diagnosis & treatment system manufacturing
	7372	58221	Development & supply of system software
Tangible contents	7372	58222	Development and supply of application software
	No Mapping	59114	Production of broadcasting programs
	No Mapping	70121	Electrical & electronic engineering R&D
	No Mapping	63991	Supply of database and online information
Smart bio-production system	3822	27215	Automatic measurement & control system manufacturing
	3823	27216	Manufacture of industrial process control equipment
	No Mapping	27112	Electric diagnosis & treatment system manufacturing
	No Mapping	27213	Manufacturing of inspection, measurement and analysis equipment
	3829	27219	Manufacture of other measuring, testing, navigation, control and precision equipment
Virtual training system	7372	58222	Development and supply of application software
	7371	62010	Computer programming service
	3721	31310	Aircraft, spacecraft and auxiliary system manufacturing
Customized wellness care	7372	58222	Development and supply of application software

**Table 4** US SIC Code and KSIC Mapping of Growth Engine (*Continued*)

Growth Engine	U.S SIC Code	KSIC	Business Type
	7371	62010	Computer programming service
	3845	27112	Electric diagnosis & treatment system manufacturing
	7379	62,090	Other information technology & computer operation-related service
Smart public safety management system	3669	26410	Wire communication equipment manufacturing
	3663	26429	Other wireless communication equipment manufacturing
	No Mapping	61220	Wireless communication
	7371	62010	Computer programming service
	7373	62021	Computer system integration-targeted advisory & construction service
	No Mapping	63991	Provision of database and online information
Hybrid new & renewable energy system	3621	28111	Motor & power generator manufacturing
	3677	28112	Transformer manufacturing
	No Mapping	28202	Battery manufacturing
	4931	35119	Other power generation businesses
	7373	62021	Computer system integration-targeted advisory & construction service
Direct-current transmission & distribution system	3677	28112	Transformer manufacturing
	3613	28121	Electric circuit switch and protection & connection device manufacturing
	3625	28122	Switchboard and control panel manufacturing
Supercritical CO <sub>2</sub> power generation system	3511	29119	Other engine and turbine manufacturing
	3564	29176	Manufacture of distillation units, heat exchangers and gas generators
	4931	35119	Other power generation businesses
Intelligent semiconductor	3674	26110	Electronic integrated circuit manufacturing
	7372	58222	Development and supply of application software
	8731	70121	Electrical & electronic engineering R&D
Convergence materials	No Mapping	20111	Manufacture of basic petrochemicals
	2865	20119	Manufacture of other basic organic chemicals
	2819	20129	Manufacture of other basic inorganic chemicals
	2816	20131	Manufacture of inorganic pigment and other metal oxides
	2821	20302	Manufacture of synthetic resin and other plastic materials
Intelligent Internet of Things (IoT)	7372	58222	Development and supply of application software
	No Mapping	61220	Wireless communication
	7379	62090	Other information technology & computer operation-related service
Big data	7372	58222	Development and supply of application software
	7371	62010	Computer programming service
	7379	62090	Other information technology & computer operation-related service
		63991	Supply of database and online information

**Table 4** US SIC Code and KSIC Mapping of Growth Engine (Continued)

Growth Engine	U.S SIC Code	KSIC	Business Type
	No Mapping		
Advanced material processing system	No Mapping	29176	Manufacture of distillation units, heat exchangers and gas generators
	No Mapping	29221	Manufacture of electronically applied machine tools
	No Mapping	29222	Metal cutting machine manufacturing
	3541	29223	Metal forming machine manufacturing
	3542	29229	Other processing machine manufacturing

## Appendix 2

**Table 5** Number of global listed companies by year of establishment

USSIC	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
0	32	17	39	22	14	32	28	6	9	8	3	210
1	394	467	449	192	181	262	217	89	64	56	52	2424
2	270	259	276	144	149	160	131	94	77	84	48	1694
3	367	440	363	254	197	252	178	113	109	111	67	2454
4	206	178	171	100	84	104	78	52	53	63	28	1121
5	162	184	181	145	137	151	128	77	78	69	40	1357
6	488	579	602	339	255	326	299	233	284	173	186	3770
7	289	286	271	170	172	222	189	126	119	135	80	2066
8	118	133	147	97	81	102	93	62	75	67	45	1028
9	6	15	10	7	4	5	2	4	4	1	5	72
Total	2332	2558	2509	1470	1274	1616	1343	856	872	767	554	16,151

## Appendix 3

**Table 6** Search Strategy of ORBIS (From 2005 to 2010)

Product name	Orbis		
Update number	158		
Software version	129.00		
Data update	15/04/2017 (n° 15,804)		
Export date	19/04/2017		
		Step result	Search result
1.	All companies	201,609,707	201,609,707
2.	Status: Active companies	161,008,585	161,008,585
3.	Accounting template: Industrial companies, Exclude branches	105,935,764	81,007,724
4.	Year of incorporation: on and after 2005 up to and including 2010	37,882,576	20,007,446
5.	Listed/Unlisted companies: Publicly listed companies, Formerly publicly listed companies	102,807	11,883
	Boolean search: 1 And 2 And 3 And 4 And 5		
		TOTAL	11,883

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### Availability of data and materials

All data can be obtained by manually querying the ORBIS system.

### Authors' contributions

LNK, BRL, JHP, and YHM carried out a systematic literature review. LNK, BRL, YHS, and YKK collected data and programmed algorithms to analysis the data. LNK and YKK wrote and revised the final manuscript. All authors read and approved the final manuscript.

### Competing interests

The authors declare that they have no competing interests.

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