Technological Forecasting & Social Change 103 (2016) 142–155

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The relationship between technology, business model, and market in autonomous car and intelligent robot industries☆,☆☆

JinHyo Joseph Yun [a,*], DongKyu Won [b], EuiSeob Jeong [c], KyungBae Park [d], JeongHo Yang [e], JiYoung Park [f]

[a] Daegu GyeunBuk Institute of Science and Technology (DGIST), 50-1 Sang-Ri, Hyeonpung-Myeon, Dalseong-gun, Daegu 711-873, South Korea
[b] Korea Institute of Science and Technology Information (KISTI), Hoegi-ro 66 Dongdemun-gu, Seoul 130-741, South Korea
[c] Korea Institute of Science and Technology Information(KISTI), Hoegi-ro 66 Dongdemun-gu, Seoul 130-741, South Korea
[d] Department of Business Administration, Sangji University, 660 Woosan-dong, Wonju, Kangwon-do 220-702, South Korea
[e] Daegu GyeunBuk Institute of Science and Technology (DGIST), 50-1 Sang-Ri, Hyeonpung-Myeon, Dalseong-gun, Daegu 711-873, South Korea
[f] YeongNam University, 280 University-Ro, KeungSan City, KyeungBuk Province 712-749, South Korea

ARTICLE INFO

Article history:
Received 11 August 2014
Received in revised form 9 November 2015
Accepted 13 November 2015
Available online 29 November 2015

Keywords:
Technology–BM–market causal loop diagram
Open innovation
Autonomous car
Intelligent robot

ABSTRACT

This study develops a new innovation diagram based on three elements — technology–business model (BM)–market — for characterizing the knowledge-based economy and open innovation. It identifies the relationship between technology, business model, and market through analysis of in-depth interviews with Korean firms that belong to the autonomous car and intelligent robot industries at first.

It develops the Casual Loop Diagram based on the dynamic relationships between technology–BM–market. In developing this diagram, regulations, standards, and leading firm effects were considered which were caught at the interviews. The technology–BM–market system causal loop diagram was proven through the analysis of technology, and business model patent statistics, and the reference and citation networks among these patents from worldwide in 2 industries.

It identifies the importance of the business model in addition to 3 factors identified in this research, the leading firm effect, standardization, and regulation. The research suggests new market increase strategies and policies which are based on technology–BM–market diagram in technology intensive industries such as autonomous car and intelligent robot industries.

1. Research questions

1.1. Research questions

Many IT-related industries are emerging in the second information revolution based on mobile information technology, sometimes called the third industrial revolution (Rifkin, 2011, p. 14). In particular, IT-based autonomous vehicles and intelligent robots are the most prominent areas of the newly emerging sector. In these newly emerging industries, the relationship between technology and market as well as their combination are expected to become the key drivers for establishing future corporate strategies and industrial policies.

This study attempts to obtain answers to the following research questions with respect to the autonomous vehicle and intelligent robot areas: What are the relationships between technologies, business models and markets? Additional questions to be answered include: 1.) During the growth process of the two industries, what is the driving force of the growth, technology, business model, and market? 2.) Where are the bottlenecks of growth in the two industries? 3.) As the determining factor for the growth process of the two industries, where is the delay phenomenon taking place? 4.) How is the growth process being developed in the short, medium, and long term?

1.2. Scope and methods of research

The technology sectors that serve as the research subject of this study are the autonomous vehicle (or car) and intelligent (autonomous) robot industries. The two industries have not yet fully matured, and so come under the category of emerging industry or growing industry. At present, there are no definitions of the two industries that the main industry, academic world, and research communities can agree on. The autonomous car, also known as a driverless car, self-driving

☆ This paper looks into the relationship between technology, business model, and market in autonomous car and intelligent robot industries.

☆☆ This paper was presented at System Dynamics 2014 Conference at Delft, Netherlands and revised based on honorable professors' comments. And this paper was supported by DGIST R&D Program of the Ministry of Science, TCT & Future Planning of Korea (15-IT-05). This time, we totally developed again this paper based on honorable anonymous reviewers' comments from TFSC.

* Corresponding author.
E-mail addresses: jhyun@dgist.ac.kr (J.J. Yun), dkwon@kisti.re.kr (D. Won), esjng@kisti.re.kr (E. Jeong), kbpark@sangji.ac.kr (K. Park), greatmind85@dgist.ac.kr (J. Yang), heytree@gmail.com (J. Park).

http://dx.doi.org/10.1016/j.techfore.2015.11.016
0040-1625/

car, or robot car, is an autonomous vehicle capable of fulfilling the human transportation capabilities of a traditional car (Göhring et al., 2013; Milanés et al., 2010). Also according to the Wikipedia (2014), an autonomous (intelligent) robot performs behaviors or tasks with a high degree of autonomy, and is particularly desirable in fields such as space exploration, floor cleaning, lawn mowing, and waste water treatment (Hsu and Fu, 2000; Schöner et al., 1995).

As a research method, this study first establishes the Dynamic Innovation Model, which is used in analyzing the dynamic technology-innovation process of specific industries through the analysis of research papers. This is used to establish a conceptual model of the relationships of the technology and the market of the two industries.

Second, this study randomly selected five firms, each from Korea's autonomous car and intelligent robot industries. An examination was conducted of the manufacturing of their representative mass-produced products (products that are being manufactured now or will be in the not so distant future) and the relationships between relevant technology, market, and business model. This was accomplished through an analysis of interviews in both industries, analysis of media materials, and analysis of Web sites. The interviews were conducted for 1–1.5 h using the half-structured questionnaire, with firms in Taegu and Seoul between February and March, 2014. The findings of the interviews are posted on the Google blog, Korea Open Innovation Center <Appendix 1>. In addition to these, we did brainstorming about findings from interviews at 2 industries with focus group. These groups included experts, researchers, and developers from relevant industries, and many others.

Third, we developed the causal loop model of the two industries.

Fourth, The SD model was validated by the analysis of the technology and business model patents of major countries in the two industries (the U.S., Europe, International, Japan, France, Germany, Canada, China, and Korea). The validation of the two industries' causal model was secured by analyzing technology patents and business model patents pertaining to G06Q, and search results using the names of the two industries as keywords, namely, autonomous vehicle (or car) and intelligent (autonomous) robot.

Lastly, we add implications which were caught by interviews, confirmed by causal loop model, and validated by patent analysis.

2. Review of existing research and establishing the research model

2.1. Review of existing research: Technology push, demand pull, and business model

Lotti and Santarelli analyzed the industry dynamics and the distribution of firm sizes, trying to assess the empirical implications of different models of industry dynamics. These included the model of passive learning, the model of active learning, and the evolutionary model (Lotti and Santarelli, 2001). In the model of industry evolution, the dynamics are driven by the process of endogenous innovations followed by subsequent embodiments in physical capital (Lach and Rob, 1996). The field of innovation studies finally came to the conclusion that both were important for the innovation and development of product (Dosi, 1988; Mowery and Rosenberg, 1979; Van den Ende and Dolfsma, 2005).

However, the field of innovation studies has gained renewed attention with the emergence of the solar industry, wind power generation industry, the electric car industry, home intelligent robot industry and many others. Such industries have not yet been able to develop their business models or mature because of market factors, but are attracting the attention of the market despite their technological immaturity.

One of the traditional theories on technological innovation is the Technology Push Theory (Nemet, 2009). The core of the science and technology push argument is that advances in scientific understanding determine the rate and direction of innovation (Nemet, 2009). The theory focuses on technology as the source of innovation, or as the motivation for innovators. Thus, this theory, as the starting point of technology innovation is an enterprise had been the main logic of the closed innovation until the 1990s during which the importance of enterprises' own technological developments were emphasized (Almirall and Casadesus-Masanell, 2010; Chesbrough, 2004; Chesbrough, 2006).

Another traditional technological innovation theory is the Demand Pull Theory. The concept of the theory can be illustrated by what happened during the Middle East Energy Crisis of the 1970s: the price changes of the traditional energy sources triggered technology innovations in new energy sources, which are today's alternative energy sectors (Popp, 2001). The theory stipulates that demand steers firms to work on certain problems (Rosenberg, 1969). However, while the Demand Pull Theory is adequate when explaining incremental innovation, it has limitations when explaining destructive and radical innovation (Abernathy and Utterback, 1978; Dewar and Dutton, 1986).

The traditional innovation theories above have been developed into an integrated technology innovation theory that takes both technology and market into consideration like Fig. 1 (Pinch and Bijker, 1987; Williams and Edge, 1996). In this model, technology directly gives effects to market, and market also directly gives effects to technology. But recently, in addition to that integrated technology innovation theory, numerous further discussions and analyses have been appearing which also take the integration of technology and market into consideration. Such is the case with biosensors, which have been expected to play a significant analytical role in medicine, agriculture, food safety, homeland security, and environmental and industrial monitoring. The technology's commercialization has significantly lagged behind research output because of rising costs and some key technical barriers (Luong et al., 2008). In other words, a significant portion of biosensor technology commercialization is being delayed by both technology and market factors.

In another example, a case study on one of Germany's biggest and most successful software development and information technology service providers revealed how market pull and technology push activities within the corporate technology and innovation management can be integrated (Brem and Voigt, 2009). That particular case demonstrated how technological innovation and the commercialization of enterprises can succeed through the integration of technology and market.

Another study (Nemet, 2009), investigated how a strong government policy that stimulates demand pull can fail if non-incremental technological changes don't accompany it. It was determined that such failure can occur for the following reasons: (1) when the rapid convergence on a single dominant design limits the market opportunity for non-incremental technical improvements; (2) when implemented policies stimulate demand, but uncertainty in their longevity dampens the incentives for inventions that were likely to take several years to pay off; and (3) as a result of declining R&D funding, weakening presidential engagement on energy, and other circumstantial reasons. In other words, even a government policy based on demand pull cannot succeed unless sufficient consideration is paid to the technology push aspect. Policies that maximize the effects of both technology and market integration are required.

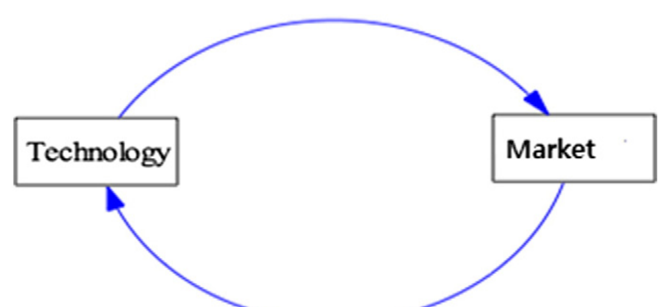


Fig. 1. Technology–Market relation in traditional innovation theory.

Examples of integrated technology innovation cases that are determinants of eco-innovations include technology, market, firm specific factors, and regulations (Horbach et al., 2012). In the cases of regulations, as they are materialized in the market, they can be substituted by the market. In the cases of firm-specific factors, they correspond to the integration of the technology pertaining to the manufacturing of specific products of different firms and the market.

Fig. 1 summarizes the integrated theory of technology push, demand pull, and technology demand. In brief, technology innovations are taking place continuously through a circulation loop in which technologies affect markets and markets again affect technologies. See Table 1.

However, a new theory, which proposes a business model that combines technologies and markets, suggests that business models as well as technologies and markets are emerging as the new factors in enterprise-level innovations (Henry Chesbrough, 2007). The business model provides a coherent framework that takes technological characteristics and potentials as inputs and converts them through customers and markets into economic outputs (Henry Chesbrough and Rosenbloom, 2002). The same idea or technology taken to market through two different business models will yield two different economic outcomes (Henry Chesbrough, 2010). A business model is a mediating construct between technology and economic value. It is what every company employs to perform two important functions: value creation and value capture. The role of the business model in innovation is to connect the captured value (Henry Chesbrough and Rosenbloom, 2002).

Source: (Brem and Voigt, 2009; Bush, 1960; Chesbrough, 2010; Chesbrough and Rosenbloom, 2002; Chesbrough and Schwartz, 2007; Horbach et al., 2012; Luong et al., 2008; Nemet, 2009; Popp, 2001; Rosenberg, 1965; Rosenberg, 1982; Vernon, 1966).

The technology innovation theories above provide significant value in explaining the main aspects of technology innovation. However, with the advent of the knowledge-based economy, the amount of skills and knowledge has increased exponentially and a new paradigm of innovation has emerged, one of open innovation, that utilizes technologies and knowledge without corporate boundaries. As a result, the validities of the existing individual innovative theories have been significantly reduced (Brem and Tidd, 2012; Chesbrough, 2003, p. 24; Chesbrough, 2006; Foray and Lundvall, 1998; Yun and Mohan, 2012; Yun et al., 2013a,b, 2015). Currently, nonlinear dynamics, not linear, are increasingly used with the feedback loop for opportunities and methods by which new technologies meet the markets (Warren, 2008, p. 51; Zajac et al., 2000). In other words, the increasing speed of feedback from technologies and markets due to the development of the mobile Internet, in addition to the online Internet, has produced a rapid increase in the speed of technology innovation. Thus, the importance of the business model as a means of innovation is rising steadily (Chesbrough, 2010; Johnson et al., 2008; Teece, 2010). As a consequence, it is necessary to formulate new corporate innovation theories or models that reflect the rapid increase in the importance of all factors — the knowledge-based economy, open innovation paradigm, steadily rising innovation dynamics as well as the feedback loop — and business models are required more than ever.

2.2. Composition of research framework

Basically, the model is a configuration of feedback loop and time lag center around the relationships between Technology, Business Model (BM), Market, and additional explanatory variables, which affect these main variables. The main elements of the model are presented along with existing research which established the corresponding elements. In the model, technologies do not affect markets directly but rather affect the markets through the business model (Chesbrough, 2010). In addition, a separate positive feedback loop structure exists between the technologies and business model, as well as between the business model and markets (Abdel-Rahim and Quaicoe, 1996; Chesbrough, 2007; Chesbrough and Schwartz, 2007; Leeson, 1966). 3 boxes at this causal loop diagram, Fig. 2 will be stock variables at system dynamics modeling. So Fig. 2 is a kind of hybrid causal loop diagram (Rabelo et al., 2005).

While these two small loops exhibit relatively short-time delays, a relatively long-time delay exists in the direct loop between technologies and markets (Davenport and Short, 1990; Hagedoorn and Schakenraad, 1994; Kokko, 1994; Narver and Slater, 1990; Osterwalder and Pigneur, 2005; Reich and Benbasat, 2000; Sterman, 2000, p. 409; Zott and Amit, 2008). While the long-time delay existing in this model tends to be a material delay in nature, the short-time delay tends to be an information delay (Sturges, 1972). Also, each technology and business model exhibits different degrees of openness to any new technology and business model, according to the open innovation index of each (Chesbrough, 2003, 2004, 2006, 2007, 2010, 2012, 2013; Enkel et al., 2009). A business model could become the new driving force of innovation but usually receives negative effects (Grabowski, 1976; Jaffe and Palmer, 1997). In addition, as the roles of the leading firm grow bigger, the regulation index itself receives bigger negative effects (Admati and Pfleiderer, 2000; Harris, 2002; Rahman et al., 2002; Jaffe and Palmer, 1997). Markets also receive positive effects from the standardization index (Banz, 1981; Gallagher and Park, 2002; Oum et al., 2006). In other words, the larger the standardization, the bigger the markets will grow.

We build research framework as Fig. 2. Basically, we will analyze the relationship between technology, business model, and market. In addition, we will find out the role of regulation, leading firm, and standardization which are outside the relationship between technology, business model, and market to find out manifestly the relationships between three factors.

3. Qualitative analysis of 2 industries

3.1. Autonomous car

The technology, business model, and market have two levels (high and low) based on AHP analysis by interviewee firms, author group, and focus group. Interviews with small- and medium-sized firms and focus group meetings revealed that firms working in the autonomous car sector have amassed various and advanced technologies by accumulating experiences from existing complete unit manufacturing, especially IT-based machineries and engineering, which have been recently added. However, these technologies cannot be connected to the development of various autonomous car business models because of the absence of regulations, standards, and certification systems. Nonetheless, it was found that the small- and medium-sized firms are working actively to develop the autonomous car market within the framework of the existing automotive market.

Four out of five companies in Table 2 have been developing key technologies within the automotive industry to pursue market expansion within the existing automotive market. However, in spite of the efforts that firms have made in developing various business models for partial autonomous operation, there are no legal standards or criteria on autonomous driving available in Korea. Even Hyundai Motor Company, the leading car manufacturer in Korea, with its advanced research on autonomous operation and testing, has not been able to establish Korean autonomous car industry standards or play the leading role in abolishing existing regulations. This is in contrast to the efforts of Google regarding autonomous car operation in the U.S., which includes the abolition of regulations at the state level and leading the setting of new standards.

In Korea, numerous technologies have been developed for autonomous operations, such as Adaptive Cruise Control (ACC), Lane Departure Detection (LDD), Parking Assist, Remote Park Assist, and Blind Spot Information System (BLIS). However, these technologies cannot be established as business models as they cannot pass existing regulations, standards, and test certifications — the related components or systems are instead being adopted and used in foreign countries. The

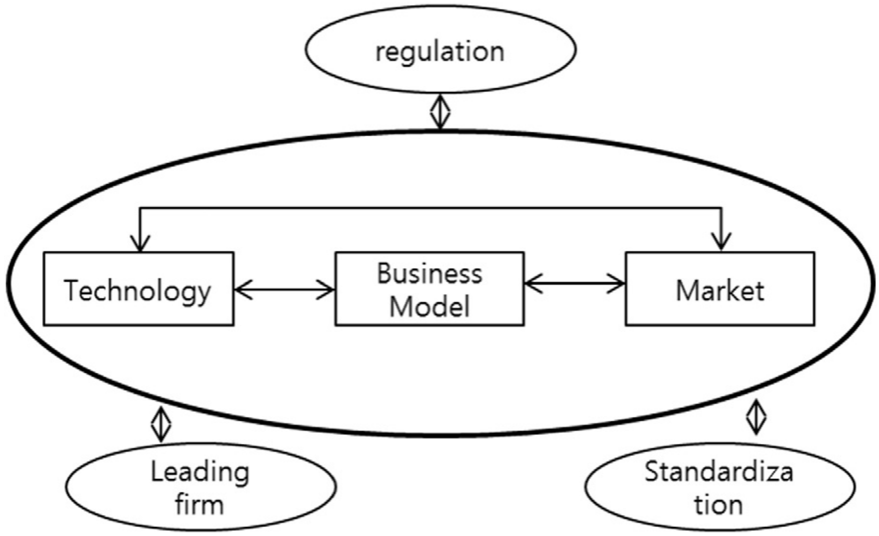


Fig. 2. Research framework.

Korean domestic car industry cannot adopt various soft ware(SW)-related business models for autonomous operation because they do not conform to regulations, certification, and standards.

In spite of this, currently, a sizeable market involving partial autonomous operation has been adopted into the traditional car market and is being expanded in Korea. Firms are fully aware of the sizes of the SW-related markets in Korea which are presently dominated by foreign part markets business models, and are strategically focusing on developing various SW-based business models. It should be noted that CammSys, which is the world's leader in the development of the smartphone camera module, also leads the development of vision systems for the autonomous car, and the SW module business model for autonomous operation, and is strategically working to establish a new business model for the self-controlled car. Significantly, our other car manufacturers were optimistic about the future of the autonomous car market and are strategically focusing on the autonomous operation business model in spite of the difficult regulations and certification processes associated with it.

However, the business model of the Korean autonomous car market, like that for the electric car market, has not been properly established yet because of matters such as the leading car manufacturer's inability to lead on the global stage, unresolved regulations, absence of relevant standards, etc.

3.2. Intelligent robot

Technology, business model, and market have two levels (high and low) based on AHP analysis by interviewee firm, author group, and focus group.

Based on the interviews with the case study firms in Table 3 and the focus group meetings, it can be understood that Korean intelligent robot firms are striving to survive through the diversification of business models, while focusing on the limited technology base. Also, in this small market, it is a reality that most small- and medium-sized robot firms are faced with individual markets of small quantity batch production.

As shown in Table 3, the activities of the Korean firms in the intelligent robot industry are restricted to industrial machine equipment automation or robotic industry automation support. It is also true that the domestic robot market targeting various household activities is very limited, apart from its floor vacuuming application. Nonetheless, the Korean government has expanded investments in research and development in robotic industrial sectors to approximately KRW 1 trillion during the past five years, and many small- and medium-sized machine equipment firms have been able to accumulate technologies in the mechatronics fields by adding SW and control capabilities to their own existing technologies. However, they have not been able to acquire original technologies.

At present, domestic robot firms are not trying to advance the technologies they have accumulated in existing business fields, but are trying to diversify their business models into different areas. As the results of the interviews show, they have developed their business models into various areas while their technologies are limited.

However, in the case of industrial robots, which was the target of this interview, participants revealed that the market is not sufficiently big because of the concentration in the limited and nonstandardized markets. In addition, according to the results of the focus group, the market for professional and specialized robots, such as domestic household robots, medical equipment, and many others, has not been standardized

Table 1
Theories on technology innovation.

Theory	Main factors for innovation	Sample literatures
Technology Push Theory	Technology	Bush (1960)
Demand Pull Theory	Market	Rosenberg (1965, 1982), Vernon (1966)
Joining of technology and market for innovation theory	Concurrence of technology and market	Popp (2001), Luong et al. (2008), Brem and Voigt (2009), Nemet (2009), Horbach et al. (2012)
Business model theory	Business model	Chesbrough and Rosenbloom (2002), Chesbrough (2010), Chesbrough (2007), Chesbrough and Schwartz (2007)

Table 2
Summary of interview results about the autonomous car-related firms.

Firm	Technology		Business model		Market	
	Level	Example	Level	Example	Level	Example
Contela	2	UMTS small cell solution →LTE small cell solution →M2M solution	1	Autonomous car Government approvals and standards on the interior small cell Solution have not been established.	2	Emergence of smart solution markets for the control of car interior and communication inside a car
DiSen	2	BOARD →LCD module ASS'y F/P module →Audio video network →Etc.	1	Failed to come up with concrete business models because of the regulations concerning the LCD used to control the car interior or side view mirror substitutes LCD.	2	Incorporating various entertainment functions in the LCD for the GSP and addition of LCD in the rear passenger compartment
ATT R&D	2	Invita and completed electric car Low-speed electric car Autonomous car platform development	1	Electric car certification and resolutions concerning the completed unit are unresolved. Autonomous and test run are unresolved.	2	Low-speed electric car market High-speed electric car market Partial autonomous electric car, etc.
CammSys	2	Mobile camera module Car black box Vehicle-mounted camera vision and control system	1	Regulations concerning the camera vision and the control to achieve autonomous car are unresolved.	2	Smartphone camera module Car black box Car camera vision
Dong-Ah	2	Car heat controller HVAC control head Motor speed controller	1	Approvals and regulations concerning the controller and system for the autonomous run control are unresolved.	2	Car heating system Car audio and video Car speed system

and has not matured, hence remains limited. However, this is not the case with the household robot: the market for cleaning robots, where standardization is possible, continues to expand. It has also secured sizable markets at home and abroad.

Despite the immaturity of the Korean intelligent robot industry, leading firms have emerged because of the involvement of several large corporations, and the results of the robot industry development policy of the Korean government. Hyundai Heavy Industries, Doosan Heavy Industries, and a few other large corporations are leading industrial robot production. However, even growth in the industrial robot sector is not being developed sufficiently, as it is restricted to an import substitution market. It supplies industries whose finished products are sold globally, such as cars, integrated circuits, and home appliance industries, to fulfill their manufacturing needs. In other words, it is not leading the global market in intelligent robot technology development. It is not able to forecast demand for intelligent robots in the global market, in either the industrial or household sectors. Thus, the progress of several major domestic firms is stagnant and they are only able to supply the Korean market, which is a small and individual market.

The household robot industry of Japan as well as the medical and specialty robot industries of Germany lead the development of newly conceptualized robots, standards setting, regulations maintenance, and certification globally. Samsung Electronics and LG Electronics are emerging as the global leaders in the household robot sector because of expanding demand for robot vacuum cleaners and a limited number of household application robots in the global marketplace. However, even in the household robot market, these firms are not able to play leading roles among other firms in the global marketplace.

3.3. Minor conclusions

First, through the case analyses of small- and medium-sized firms, which are the incomplete unit firms of Korea's autonomous car and intelligent robot industries, actual cases have been identified where technologies are being led to the markets through business models. By identifying that small- and medium-sized firms connect technologies to markets through business models, the validity of the technology–business model–market model adopted in this study is ensured.

Second, it has been identified that regulations and standards have significant impact in determining the business model, the scope, and the scale of the market. Although the effects of regulations on business models and standards on markets could not be divided precisely, case study analyses confirmed that regulations and standards greatly affect the business models and market expansions of the two industries.

Third, it has been identified that the leading firms of the two industries play very important roles, as confirmed by interviews with small- and medium-sized firms. It was revealed that Google's effect on the autonomous car industry is not limited to the simplification of regulations, establishment of a certification system, and formulation of standards. However, such activities leverage the development of new business models and technologies. The interviews with firms, expert-focused group meetings, and questionnaire surveys have revealed that in Japan, the leading firms in the industrial robot, specialty robot, and household robot sectors play the same roles that Google plays in the autonomous car industry.

Table 4 shows the results of AHP analysis conducted during interviews with firms and seminars with experts. In the case of Korea's autonomous car industry, it has been revealed that the firms leading roles are very meager: the industry is excessively regulated in the absence of relevant laws and is relatively well standardized within the framework of the existing car industry. On the other hand, the situation with the intelligent robot industry is somewhat different. Hyundai Heavy Industries and Doosan Heavy Industries, the leading firms of the industrial robot sector, and Samsung Electronics and LG Electronics, the leaders of the household robot sector, play strong roles. The industry is loosely regulated in the absence of relevant laws as it has not had

Table 3
Summary of interview results about intelligent robot-related firms.

	Technology		Business model		Market	
	New tech	Example	New BM	Example	New market	Example
IDEAR System Co., LTD.	1	Agricultural products nondestructive testing equipment Grain rougher Moisture measurement device signal processing Container net system Pellet manufacturing method Rice hull carbonization system	2	CCD color sorter applying DPS Compact net system Coating drying system Bag filter Continuous dryer	1	Restricted to grain handling market: Grain processing, storage, post-processing. (Currently expanding into global market from the present Southeast Asian market)
DaisoCell	1	Accumulation load cell of engineering to measure the load of large structures or power	2	BC type S type LC type RT type BS type BS type CC type and Various load cells such as special order	1	Limited to industrial load cell market. (At present, participating in research and development business of intelligent robot and manufacturing load cells)
YuJin Mechatronics	1	Mechanism design Motion control Intelligent robot-engineering sensor application software programming	2	Industrial machinery Steel manufacturing equipment Automation-system Robot system Laser vision inspection Cutting robot Gantry robot Welding rail cars LNG spraying Safety fence	1	Limited markets, such as industrial equipment and industrial robot. (Diversification strategy of source-technology based business model as markets for products are small because of the lack of standards.)
Samik Tech	1	Automated tool changer Goods transport assembly Uniformly distributing system and heating system	2	Automated tool changer Automated materials changer Wireless communication transporting robot AGV robot Distributed microwave drying and heating system	1	Restricted to individualized machine tool market, such as tools and machine tools, controller systems, and robots. (Focusing on the individualized market of tool or machine tool that controls its parts automatically)
Creative Space	1	Training program logic Logic circuit control circuit and many others — Basic circuit and sensor system	2	Educational robot DODDEE DARO TRS UCR Hands-on professional training materials Eco-navigation Creative personality, integrated science, engineering educational program, etc.	1	Restricted to educational market products, such as robots and science education related devices (simple robotic systems included). (Related market is fragmented into separate markets so there is a need to expand into various business models from the educational market.)

chance to mature yet. The standards are not well established as the markets are relatively small.

4. Causal model of dynamic relationship between technology, BM and market

4.1. Causal loop diagraming of the relationship among technology, BM, and market

Technology innovation brings BM development, BM development again brings Market development and growth, sales and profits from market finally can be used for investment for further technological innovation. As important policy variables, we have found 3 important variables through in-depth interview, a. leading firm, b. regulation, c. standardization. We captured these variables as industry policy variables. Government support concentration to nurture leading firm as 'Nurturing leading firm', deregulation related to the emerging business model in new industry, i.e. autonomous car, intelligent robot, as 'BM deregulation', and standardization in market aspect rather than technology aspect, or customer preference concentration, as 'Standardization (market concentration)'. Such a customer preference concentration can come from various sources, like network effect, efficiency in learning and communicating new tech, cost down from economies of scale, technological standards, and as so on.

Table 4
The characteristics of Korea autonomous car and intelligent robot industry.

Factor	Autonomous car	Intelligent robot
Leading firm	Weak	Strong
Regulation	Strong	Weak
Standardization	Strong	Weak

We described 4 types of major variables in the relationship such as technology factor, business model factor, market factor, and industry policy variables. First, technology factor consists of technology innovation, technology investment, technology variety, and concentration of government support to leading firm. Second, business model factor consists of new BM development: connection of technological innovation into market or trial to do so, and BM deregulation. Third, market factor consists of market potential remained, market size (number of adopters), industry sales (sales sum of all firms in the industry), industry profit (profit sum of all firm in the industry), economy efficiency

Table 5
Major feedback loops in causal diagram of the relationship between technology, BM and market.

Major feedback	Feedback effect	Path
R1: Basic relation, (Reinforcing)	Basic influencing loop of reinforcing between tech, BM, and Market	Tech innovation↑ → New BM development↑ → Market size↑ → Industry sales↑ → Industry profit↑ → Tech investment↑ → Tech innovation↑
R2-1: Reinforcing	Positive effect of nurturing leading firm (The effect comes by accelerating the reinforcing effect of R1)	Nurturing leading firm↑ → Tech investment↑ → Tech innovation↑ → New BM development↑ → Market size↑ → Industry sales↑ → Industry profit↑ → Tech investment↑
R2-2: Reinforcing	Positive effect of market standardization (The effect comes by accelerating the reinforcing effect of R1)	Standardization↑ → Economic efficiency↑ → Industry profit↑ → Tech investment↑ → Tech innovation↑ → New BM development↑ → Market size↑ → Industry sales↑ → Industry profit↑
R2-3: Reinforcing	Effect of BM development as new market potential creator (The effect comes from the base of basic loop R1)	New BM development↑ → Market potential remained↑ → Market size↑ → Industry sales↑ → Industry profit↑ → Tech investment↑ → Tech innovation↑ → New BM development↑
B1: Restricting	Restricting negative effect of excessive nurturing leading firm	Nurturing leading firm↑ → (Delay) → Tech variety↓ → Tech innovation↓ → New BM development↓ → Market size↓ → Industry sales↓ → Industry profit↓ → Nurturing leading firm↓
B2: Restricting	Restricting negative effect of market concentration that comes from excessive standardization	Standardization↑ → (Delay) → Cost of using alternative tech↑ → Tech variety↓ → Tech innovation↓ → New BM development↓ → Market size↓ → Industry sales↓ → Economic efficiency↓ → Standardization↓

which comes from various sources like early setting up the related complementary infrastructure, reduction of consumer learning cost, network effect, economies of scales and etc., cost of using alternative technology; cost occurring from using not-most-used standard (stand can be product type, technology type, format, and etc.)., and standardization in the market aspect not in the technology aspects(customer concentration to each competing standard and format). Fourth, industry policy variables consist of concentration of governments support to leading firm, BM deregulations, and standardization in the market aspect not in the technology aspect. 3 policy factors are included each in technology factor, business model factor, and market factor.

4.2. Major influencing loops in the causal model

4.2.1. Basic loop; basic relationship between technology, BM, and market

Technology innovation brings BM development, BM development again brings Market development and growth, sales and profits from market finally can be used for investment for further technological innovation. This basic relationship was found from literature review and interview result of this study. We captured it through R1 at Table 5 and Appendix 5. R1 is Basic influencing loop which reinforce between tech, BM, and market like R1, 'Basic influencing loop' in Fig. 3 and Appendix 5. This basic loop means there are strong dynamic mutual reinforcing relationships between technology, business model, and market.

4.2.2. Reinforcing loops

A positive effect of nurturing leading firm (reinforcing effect of leading firm) occurs at R2-1, 'Positive effect of nurturing leading firm' like Table 5 and Appendix 5. R2-1 comes by accelerating the reinforcing effect of R1. At the early stage of emerging high tech such as, autonomous car or intelligent robots, existence of technology leading firm can contribute to start reinforcing loop between technology, BM and market. As a result, leading firm can significantly contribute to early setting up the industry and early market growth. Good example of this is Apple in early stage of smart phone industry as a strong leading firm.

In addition, a positive effect of market standardization occurs also at R2-2 like Table 5 and Appendix 5. R2-2, 'Positive effect of market standardization' too comes by accelerating the reinforcing effect of R1. At early stage of emerging high tech (autonomous car, intelligent robots), market standardization, or customer concentration, can increase economic efficiency and profit level of the industry. Starting from increased industry efficiency and profit, market standardization will stimulate technology investment and entire reinforcing loop between technology, BM, and market (R1). Thus, early setting up of market standard in emerging high industry can be good policy leverage to make that industry grow faster.

And, the BM development give positive effect to this diagram as new market potential creator at R2-3, 'Effect of BM development as new market potential creator' like Table 5. R2-3 too comes by accelerating the reinforcing effect of R1.

4.2.3. Balancing loops

A restricting negative effect of leading firm occurs at B1 in Fig. 3 and Appendix 6. B1, 'Restricting negative effect of excessive nurturing leading firm' is a restricting negative effect of leading firm with delay effect. At the early stage of emerging high tech (autonomous car, intelligent robots), existence of technology leading firm can be helpful. But in the long-term, sole dependency on leading firm can harm technological variety. The lacking of technological variety can damage long-term technology innovation and, can harm long-term industry growth. Because of delay effect, this restricting negative effect cannot be caught at first, but in the end, the negative effects become dominant.

The restricting negative effect of market concentration occurs also at B2 in Fig. 3 and Appendix 6. B2, 'Restricting negative effect of market concentration' is a restricting negative effect of market concentration with delay effect. At early stage of emerging high tech (autonomous car, intelligent robots), market standardization, or customer concentration into single standard, can be helpful in increasing industry efficiency. But in the long-run, it can harm cost of using alternative technology and technology variety. As results, too much excessive market concentration onto single, or just few, standard can damage long-term growth ability. One good Example of B2 is Microsoft(MS) in late stage of desk top Operation System(OS), Window. MS does not show any technological innovation in desk top OS. But people are still using it because there are no or few alternatives.

4.3. Evidence of causal loop diagram from patents citation network analysis of two industries

Even though many modelers speak of model "validation" or claim to have "verified" a model, in fact, validation and verification of model is impossible (Sterman, 2000, p 846). But an "objective" model-validation procedure rests eventually at some lower level on a judgment or faith that either the procedure or its goals are acceptable without objective proof (Forrester, 1961, p. 123).

The G-Pass (http://gpass.kisti.re.kr) (LexisNexis) is a worldwide patent database built by the Korea Institute of Science and Technology Information (KISTI) based on a database provided by LexisNexis. Through an analysis of each keyword in the G-Pass, the patents of the two

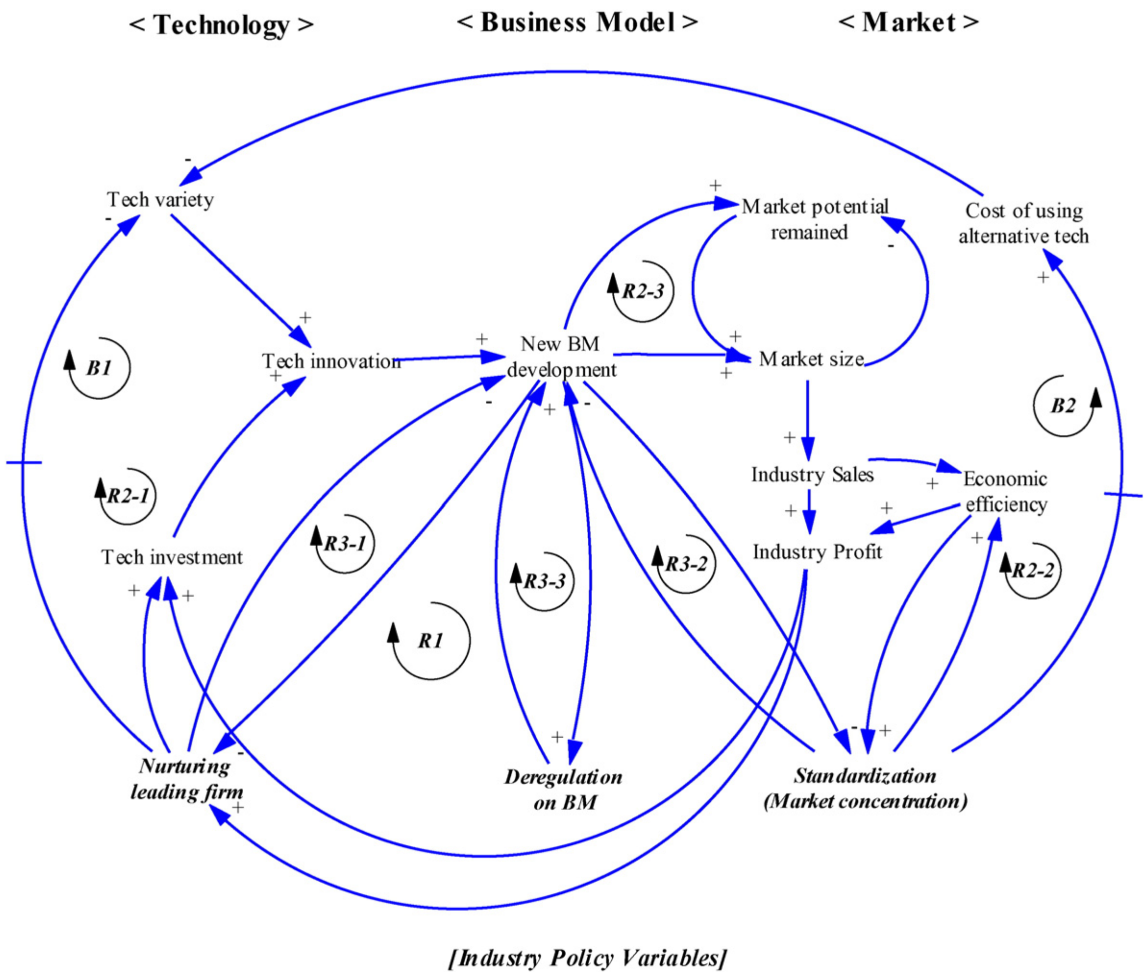


Fig. 3. Causal model of the relationship among technology, business model, and market.

industries were extracted, centering on autonomous car or autonomous vehicle and intelligent robot or autonomous robot from 1960 to 2013. The totals are shown in Tables 5 and 6 below. This patent DB coverage includes all major countries, such as the U.S. (United States), EP (Europe), WO (International), CN (China), JP (Japan), KR (Korea), GE (Germany), FR (France), GB (Great Britain), and CA (Canada).

Through Table 6, it has been found that more technologies have been quantitatively developed in the autonomous car industry than in the intelligent robot industry. In addition, even in the areas of citations and references, which are indicators of the spread of technology innovation, it has been identified that the activities in the autonomous car industry are progressing much more vigorously. Technology innovation in n−1 time as reference becomes technology innovation in n time which is target patent after one round of causal loop, and becomes technology innovation in n + 1 time after another round of causal loop as patent which cited patents in n time like path of patent usage in Table 6. As shown in Tables 2 and 3, this also coincides with the results of interviews with the two industries of Korea. Basically citation and reference show us open innovation level of technologies in 2 industries. From Table 6, the existence of basic and reinforcing causal loops for technology innovation can be proven with evidences.

In Table 7, the number of business model patents of the two industries, and the citation and referencing of the business model patents in 2 industries are very few. This means that autonomous car and intelligent robot industries are emerging industries. The number of BM patents in intelligent robot is bigger than in autonomous car like Tables 2, and 3. And, from Path of Patent Usage of business model patent at Table 7, the existence of evidences of causal loops having connected with technology innovation and BM can be found. 74 intelligent robot business model patents referred to 240 technology patents. Those 74 intelligent robot business model patents were in turn cited by 414 technology patents.

Table 7 shows the existence of the causal loop by which technology is passed to a business model to form the initial process loop, and back to technology.

In the case of the autonomous vehicle, where 42 business model patents refer to 322 technology patents, the number of autonomous vehicle business model patent citations was very low, at 52. This is because the leading firms' roles as a whole are still quite weak. This also coincides

Table 6
Technology patents in autonomous car and intelligent robot.

Industry	Numbers of reference usage (Record)	Numbers of technology patents in autonomous car or intelligent robot	Numbers being cited (Record)
(Path of patent usage)	Tech patent→	Tech patent→	Tech patent
Autonomous car	13,047	5,557	11,180
Intelligent robot	8,708	2,994	7,404

Table 7
Business model patents in autonomous car and intelligent robot.

Industry	Numbers of reference usage (Record)	Numbers of BM patents	Numbers being cited (Record)
(Path of patent usage)	Tech patent →	BM patent →	Tech patent
Autonomous car	322	42	52
Intelligent robot	240	74	414

with the Korean phenomena shown in Table 4. Table 7 points out the existence of the loop of technology–BM–market directly. In addition, on average 7.7 technology patents are referenced by each autonomous vehicle business model patent, and 3.2 technology patents are referenced by each intelligent robot business model patent: this provides manifest and concrete evidence about the role of the business model as a bridge between technology and markets (Chesbrough 2010).

In addition, autonomous car technology patents are referring nearly half themselves according to the Appendix 2. It is opposite to intelligent robot technology patents which are referring outside than themselves 5 times. These mean directly that autonomous cars are strongly standardized than intelligent robot like Table 4. Citation of business model patents of intelligent robot is much bigger and diverse than that of autonomous car according to the Appendix 3. Maybe intelligent robot industry has leading firms which are appearing as triggering identities of new technologies from business models opposite to autonomous car industry. According to Appendix 4, even though the volume of technology patents of autonomous car industry is larger nearly 1.5 times than intelligent robot industry, the amount of business model patents of autonomous car industry is smaller than intelligent robot industry. This means that regulation in autonomous car industry is much higher than that of intelligent robot industry objectively.

The levels of Standard, Leading firm and Regulation in 2 industries are proven by Appendices 2, 3, and 4 which are comparative analysis of patent citation network between 2 industries in addition to Table 4. These network analysis results were similar to the interview results as Table 4.

If we summarize the evidences of causal loop model in Fig. 3 they are as follows. First, Tables 6, and 7 are showing real loops between technology, business model and market. Second, the roles and loops of standardization, leading firm, and regulation in 2 industries are proven by interview results in Tables 2, 3, and 4, and patent citation network analysis in Appendices 2, 3, and 4.

5. Discussion and conclusion

5.1. Policy leverage

To allude to the effects of negative feedback loops of Fig. 3, BM development and government support for new BM, continuous trial for connection between technology and market, can be good strategy. We can find BM development is at the heart (center) of whole causal loop. If we can change BM development, we can change whole structure. Catalyst role of BM is basically reinforcing relationship between tech, BM, and market at R1 in Fig. 3, Table 5, and Appendix 5.

Moreover, with continuous trial to build new BM, we can create new market chance and sometimes we can profoundly increase market potential itself. We can find entirely novel usages of current product and technology with new BM such as Baking Powder as kitchen abstergent, or Auto bike not as instrument of transport but instrument for weekend recreation, and etc. Ansoff defined such a role of BM as 'New market development'. BM has a role of new market creator like R2-3 in Fig. 3, Table 5, and Appendix 5.

BM can also reduce sole dependence on leading firm and market standardization like R3-1 in Table 8. With more new BM, sole dependency on leading firm will be reduced, and technology variety and technology innovation will increase.

In addition, BM can reduce excessive market concentration like R2 in Table 8. With more new BM, excessive market concentration will reduce. Accordingly, decreasing cost of using alternative technology allows that technology variety and innovation increase.

Such a role of BM as new market creator and sound cure for negative effect of leading firm and excessive market concentration can be promoted by policy effort of deregulation on BM like R3-3 in Table 8. Such an effort can be accomplished through continuous and sustained effort of deregulation.

5.2. Implications and future research topics

Through this study, it has been confirmed that the technology innovations of the autonomous car and intelligent robot industries are being progressed as a part of a dynamic feedback process between technology, business model, and market. Through specific case studies, the relationships between the three partial factors have been confirmed. Through the patent analysis, the existence of the three-factor feedback loop has been indirectly confirmed. Lastly, through the causal loop modeling, changes of the dynamic relationships of the three-factors could be estimated.

In addition, through causal loop modeling, we could manifest the role of business model. It appears that if we increase the business model level, even though the technology level is not high, the market size increases through positive feedback loop.

Therefore, firms should consider that their own technology innovation strategies are the results of the dynamic interactions of three factors, which include technology, business model, and market, and so should establish strategies that include both technology and business model together. Also, the government should not restrict its involvement to either technology- or market-driven approaches, or a combined two-approach strategy, but should definitely consider adopting the results of the business model analysis.

Most of all business model developing strategies and policies with technology increase strategy and policy can result in bigger increase in market. So, companies should keep in mind that developing a business

Table 8
Policy leverages to overcome major restrictions in the dynamics between technology, Bm and market.

Policy leverage	Feedback effect	Path
R3-1: Restriction cure (Reinforcing)	Effect of BM in reducing sole dependency on leading firm (The more BM development, reinforcingly the less restricting effect of excessive nurturing leading firm)	New BM development↑ → Nurturing leading firm↓ → New BM development↑
R3-2: Restriction cure (Reinforcing)	Effect of BM in reducing excessive market concentration (The more BM development, reinforcingly the less restricting effect of excessive market concentration)	New BM development↑ → Standardization (Market concentration)↓ → New BM development↑
R3-3: Restriction cure (Reinforcing)	Effect of deregulation on BM and BM development	Deregulation on BM↑ → New BM development ↑ → Deregulation on 2BM ↑ → New BM development↑

model is one way to increase markets without the large investment required to increase the state of technology. Governments also motivate an increase in business models when they trigger new industries, such as autonomous car or intelligent robots industries.

In future, it will be necessary to develop System Dynamics Model and conduct concrete simulation research on the policy leverage including the pattern and size of market growth. Such research should further explore how market growth is dependent on the specific level of open innovation of the technology and business model selected by firms in the market. The dynamic SD model based on the causal loop diagram between technology, BM and market should be applied to new innovation strategy, and policy development.

Appendix 1. Half-structured questionnaire and interviewers list

1.1. Half-structured questionnaire

This interview is to check the current state of technology development and market formations of new industry sectors, and to figure out what the firms' understandings of the markets are, and the characteristics of technologies.

1) Industry overview.
 - Achievement history.
 - Sales.
 - Main products.
 - Investments in patent and research and development, research staff, etc.
2) Changes in your firm's main products or diversification history and agents.
3) Sources of new products and process innovation of firms.
4) (Own R&D, collaboration with universities, collaboration with institutions, cooperation with firms that purchase products from you, firms that sell products to you, etc.)
5) Market trends and outlook of this industry sector and requirements for market vitalization.
6) Status and prospects of technologies of this industry sector and requirements for technology development.
7) The biggest obstacle to the development of this industry sector.
8) Policy changes the government has to make to develop this industry.
9) Characteristics of entrepreneurship, corporate culture, etc.
10) The value and potential of your firm's current business model.

1.2. Interviewee list

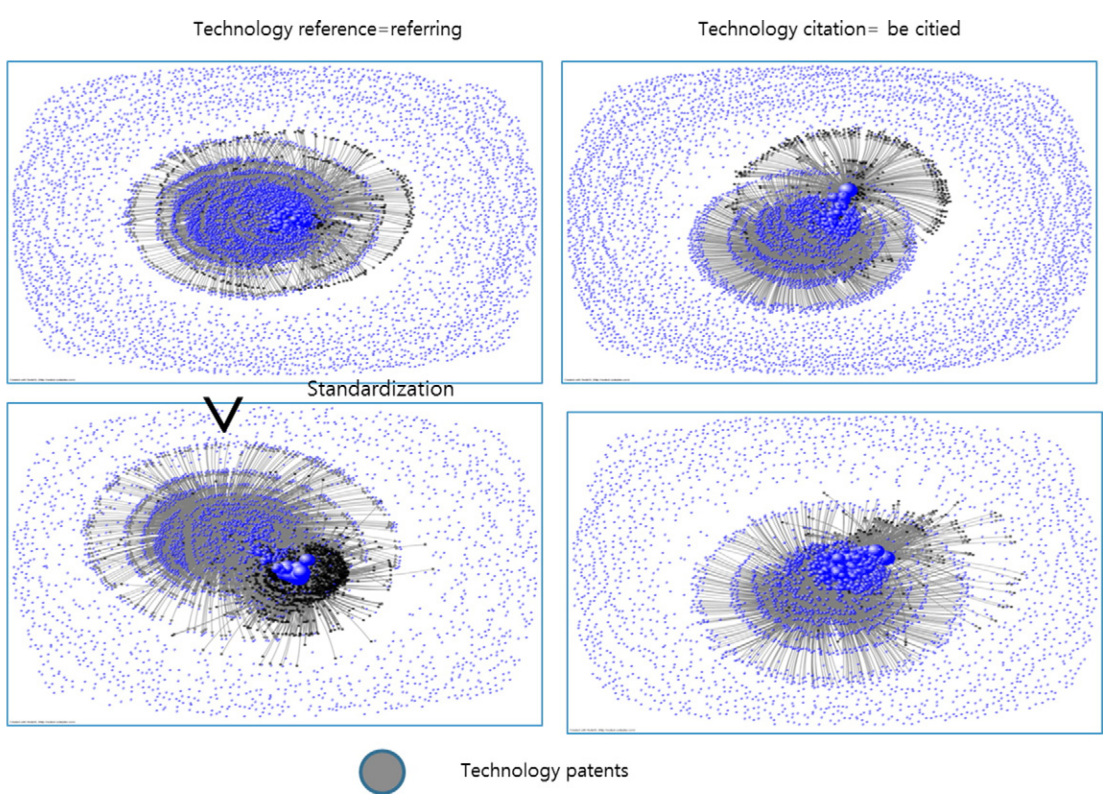
Sector	Date	Firm's name	Interviewee	Characteristics
Autonomous car	2014.2.13	Contela	Kim Jungmin, Managing director	Gateway system Management system Evolved into small cell system Pursuing autonomous car small cell system
	2014.2.14	DiSen	Lee Hun, Research Center director	Car LCD module localization, the first in Korea Expanding into audio video navigation system technology business Expanding into AVN for autonomous car
	2014.2.24	ATT R&D	Kim Mansik, CEO	Production of electric vehicles as well as slow speed and hybrid electric car electric vehicle consulting Expansion into autonomous car platform
	2014.2.25	CammSys	Sung Sungu, General manager	Mobile camera module Intelligent black box Developed camera for autonomous car and expanding to control sensor
	2014.2.28	Dong-Ah	Cho Bongnam, Managing director	Car heater and air conditioner controller Motor speed controller Real view system Expand into controller for audio equipment
Intelligent robot	2014.03.05	IDEAR System Co., LTD. (Manufacturing of crop processing equipment)	Choi Byeongjo, CEO	Grain dryer, processor, and storage facilities Color sorter Rice processing complex Expand into eco-energy facilities
	2014.03.05	Diaos Cell (Manufacturing of industrial load cells)	Cho Heedong, CEO	Concentrate on various industrial load cells, such as BC type S type LC type
	2014.03.06	YuJin Mechatronics (Industrial robots)	Eun Jongok, CEO	Submission equipment Industrial robots

(continued on next page)

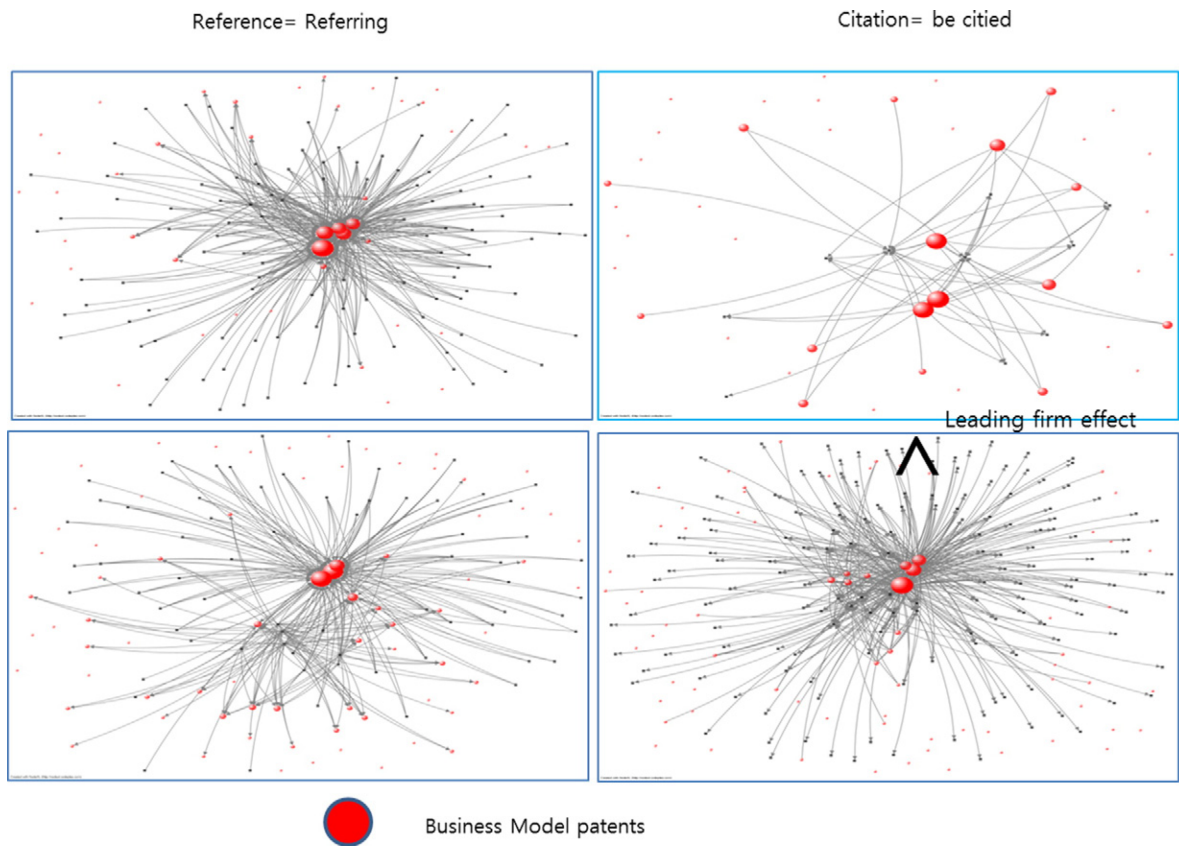
(*continued*)

Sector	Date	Firm's name	Interviewee	Characteristics
	2014.03.07	SamIk Tech (Robot machine tool)	Choi Kyeongsu, CEO	Sense application Expand soft programing Tower-automated tool changer Wireless communication transport robot Expand into distributed microwave drying and heating system
	2014.03.07	Creative Space (Robot education and teaching materials)	Lee Eunkyeong, CEO	Educational robotics and intelligent robot R&D Develop integrated science programs
Focus Group	2014.03.03	ETRI Electronics and Telecommunications Research Institute Autonomous car industry specialist	Jeon Hwangsu, PhD	Pointed out that due regulations and business model development are blocked.
	2014.03.03	KIET Korea Institute for Industrial Economics and Technology Intelligent Robot Specialist	Jeong Mantae, PhD	Pointed out that due to immaturity of standards, industrial and household robot industry cannot be developed efficiently.
	2014.03.20	Korea Delpai	Park SangChul R&D Planner	Pointed out that there are not leading firms in autonomous car industries and there are a lot of technologies for autonomous car already.
	2014.04.11 (Scheduled)	DGIST Intelligent robot System research specialist	Lee SangChoul Ph.D.	Pointed out that there are not high standards in intelligent robots which are becoming bottlenecks in this industry.
	2014.04.12. (Scheduled)	DGIST Autonomous car Vision research specialist	Son JunWou Ph.D.	Pointed out that there are high regulations in autonomous car and electronic car all together.

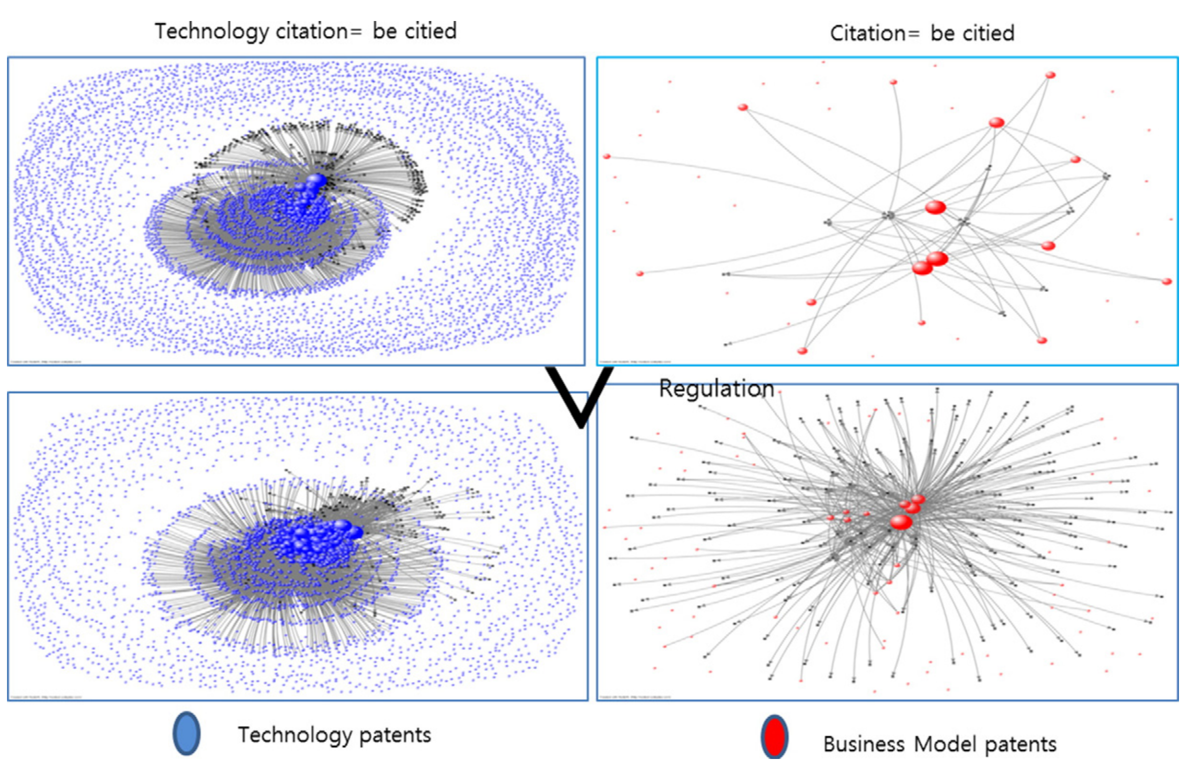
Appendix 2. Validation of standardization from comparing of technology patent reference between 2 industries



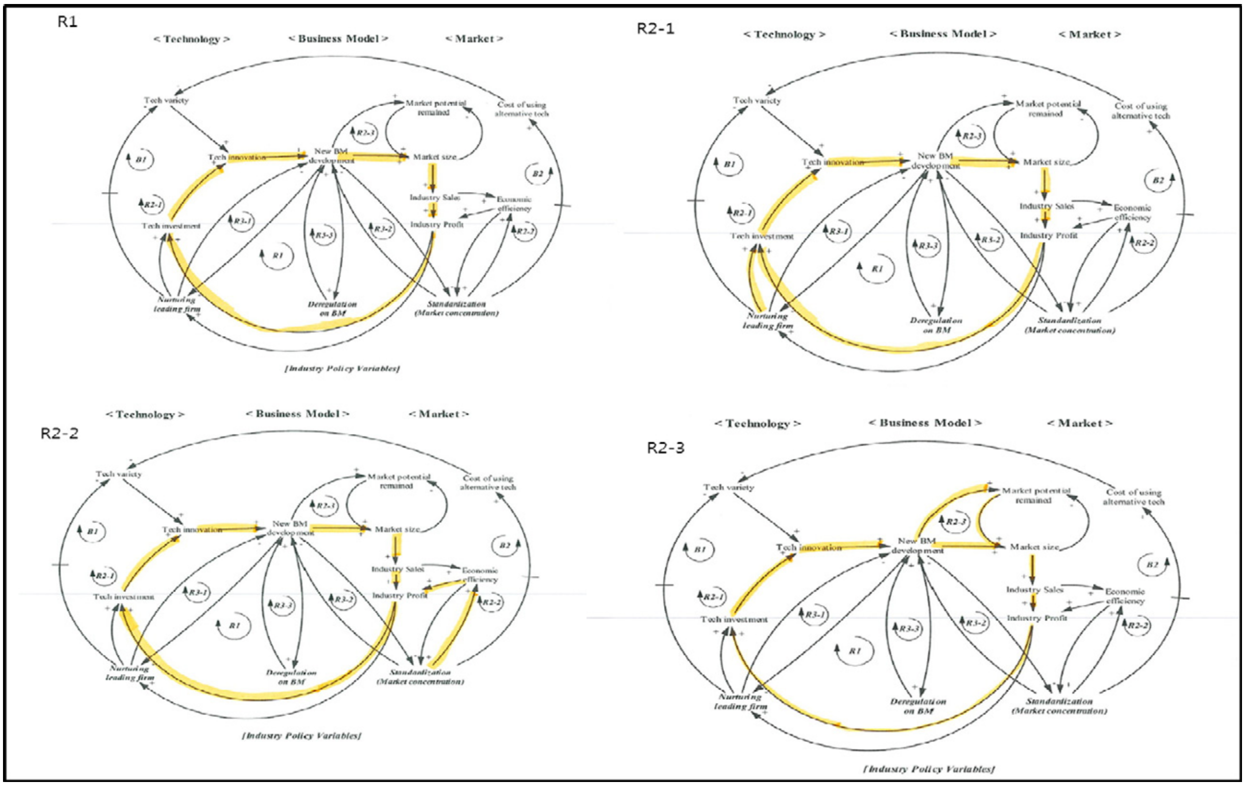
Appendix 3. Validation of leading firm effect from comparing of BM patent citation between 2 industries



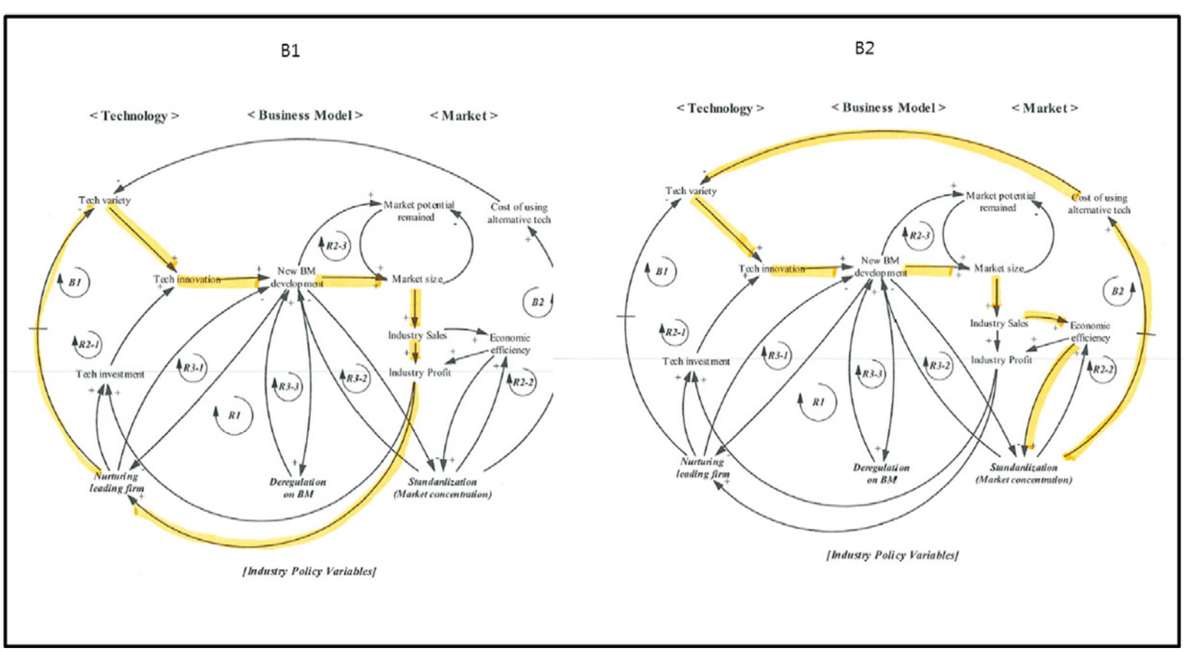
Appendix 4. Validation of regulation from comparing of technology patent, and BM patent citations between 2 industries



Appendix 5. Basic Causal Loop and Reinforcing Causal Loops



Appendix 6. Balancing Causal Loops



Appendix 7. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.techfore.2015.11.016.

References

Abdel-Rahim, N.M., Quaicoe, J.E., 1996. Analysis and design of a multiple feedback loop control strategy for single-phase voltage-source UPS inverters. IEEE Trans. Power Electron. 11 (4), 532–541.
Abernathy, W.J., Utterback, J.M., 1978. Patterns of industrial innovation. Technol. Rev. 64, 254.228.
Admati, A.R., Pfleiderer, P., 2000. Forcing firms to talk: financial disclosure regulation and externalities. Rev. Financ. Stud. 13 (3), 479–519.
Almirall, E., Casadesus-Masanell, R., 2010. Open versus closed innovation: a model of discovery and divergence. Acad. Manag. Rev. 35 (1), 27–47.
Banz, R.W., 1981. The relationship between return and market value of common stocks. J. Financ. Econ. 9 (1), 3–18.
Brem, A., Tidd, J., 2012. Perspectives on Supplier Innovation: Theories, Concepts and Empirical Insights on Open Innovation and the Integration of Suppliers Vol. 18. World Scientific.
Brem, A., Voigt, K.-I., 2009. Integration of market pull and technology push in the corporate front end and innovation management—insights from the German software industry. Technovation 29 (5), 351–367.
Bush, V., 1960. Science, the Endless Frontier. National Science Foundation, Washington, DC.
Chesbrough, H.W., 2003. Open Innovation: The new Imperative for Creating and Profiting from Technology. Harvard Business Press.
Chesbrough, H., 2004. Managing open innovation. Res. Technol. Manag. 47 (1).
Chesbrough, H.W., 2006. The era of open innovation. Manag. Innov. Chang. 127 (3), 34–41.
Chesbrough, H., 2007. Business model innovation: it's not just about technology anymore. Strateg. Leadersh. 35 (6), 12–17.
Chesbrough, H., 2010. Business model innovation: opportunities and barriers. Long Range Plan. 43 (2), 354–363.
Chesbrough, H., 2012. Why companies should have open business models. MIT Sloan Manag. Rev. 48 (2).
Chesbrough, H., 2013. Open Business Models: How to Thrive in the New Innovation Landscape. Harvard Business Press.
Chesbrough, H., Rosenbloom, R.S., 2002. The role of the business model in capturing value from innovation: evidence from Xerox corporation's technology spin-off companies. Ind. Corp. Chang. 11 (3), 529–555.
Chesbrough, H., Schwartz, K., 2007. Innovating business models with co-development partnerships. Res. Technol. Manag. 50 (1).
Davenport, T.H., Short, J.E., 1990. The new industrial engineering: information technology and business process redesign. Sloan Manage. Rev. 31 (4).
Dewar, R.D., Dutton, J.E., 1986. The adoption of radical and incremental innovations: an empirical analysis. Manag. Sci. 32 (11), 1422–1433.
Dosi, G., 1988. Sources, procedures, and microeconomic effects of innovation. J. Econ. Lit. 1120–1171.
Enkel, E., Gassmann, O., Chesbrough, H., 2009. Open R&D and open innovation: exploring the phenomenon. *R&D Manag.* 39 (4), 311–316.
Foray, D., Lundvall, B.-A., 1998. The knowledge-based economy: from the economics of knowledge to the learning economy. The Economic Impact of Knowledge, pp. 115–121.
Forrester, J.W., 1961. Industrial Dynamics. MIT Press, Cambridge (Currently available from Pegasus Communications: Waltham, MA).
Gallagher, S., Park, S.H., 2002. Innovation and competition in standard-based industries: a historical analysis of the US home video game market. IEEE Trans. Eng. Manag. 49 (1), 67–82.
Göhring, D., Latotzky, D., Wang, M., Rojas, R., 2013. Semi-Autonomous Car Control Using Brain Computer Interfaces. Intelligent Autonomous Systems 12. Springer, pp. 393–408.
Grabowski, H.G., 1976. Drug Regulation and Innovation: Empirical Evidence and Policy Options. American Enterprise Institute for Public Policy Research, Washington DC.
Hagedoorn, J., Schakenraad, J., 1994. The effect of strategic technology alliances on company performance. Strateg. Manag. J. 15 (4), 291–309.
Harris, L., 2002. Small firm responses to employment regulation. J. Small Bus. Enterp. Dev. 9 (3), 296–306.
Horbach, J., Rammer, C., Rennings, K., 2012. Determinants of eco-innovations by type of environmental impact—the role of regulatory push/pull, technology push and market pull. Ecol. Econ. 78, 112–122.
Hsu, F.-.Y., Fu, L.-.C., 2000. Intelligent robot deburring using adaptive fuzzy hybrid position/force control. IEEE Trans. Robot. Autom. 16 (4), 325–335.
Jaffe, A.B., Palmer, K., 1997. Environmental regulation and innovation: a panel data study. Rev. Econ. Stat. 79 (4), 610–619.
Johnson, M.W., Christensen, C.M., Kagermann, H., 2008. Reinventing your business model. Harv. Bus. Rev. 86 (12), 57–68.
Kokko, A., 1994. Technology, market characteristics, and spillovers. J. Dev. Econ. 43 (2), 279–293.
Lach, S., Rob, R., 1996. R&D, investment, and industry dynamics. J. Econ. Manag. Strateg. 5 (2), 217–249.
Leeson, D.B., 1966. A simple model of feedback oscillator noise spectrum. Proc. IEEE 54 (2), 329–330.
Lotti, F., Santarelli, E., 2001. Industry Dynamics and the Distribution of Firm Sizes: A non-Parametric Approach.
Luong, J.H., Male, K.B., Glennon, J.D., 2008. Biosensor technology: technology push versus market pull. Biotechnol. Adv. 26 (5), 492–500.
Milanés, V., Llorca, D.F., Vinagre, B.M., González, C., Sotelo, M.A., 2010. Clavileño: evolution of an autonomous car. Paper presented at the Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on.
Mowery, D., Rosenberg, N., 1979. The influence of market demand upon innovation: a critical review of some recent empirical studies. Res. Policy 8 (2), 102–153.
Narver, J.C., Slater, S.F., 1990. The effect of a market orientation on business profitability. J. Mark. 54 (4).
Nemet, G.F., 2009. Demand-pull, technology-push, and government-led incentives for non-incremental technical change. Res. Policy 38 (5), 700–709.
Osterwalder, A., Pigneur, Y., 2005. Clarifying business models: origins, present, and future of the concept. Commun. Assoc. Inf. Syst. 16.
Oum, Y., Oren, S., Deng, S., 2006. Hedging quantity risks with standard power options in a competitive wholesale electricity market. Nav. Res. Logist. 53 (7), 697–712.
Pinch, T.J., Bijker, W.E., 1987. The social construction of facts and artifacts: or how the sociology of. The social construction of technological systems: New directions in the sociology and history of technology 17.
Popp, D., 2001. Induced innovation and energy prices: National Bureau of Economic Research.
Rabelo, L., Helal, M., Jones, A., Min, H.-.S., 2005. Enterprise simulation: a hybrid system approach. Int. J. Comput. Integr. Manuf. 18 (6), 498–508.
Rahman, A., Perera, H., Ganesh, S., 2002. Accounting practice harmony, accounting regulation and firm characteristics. Abacus 38 (1), 46–77.
Reich, B.H., Benbasat, I., 2000. Factors that influence the social dimension of alignment between business and information technology objectives. MIS Q. 81–113.
Rifkin, J., 2011. The third industrial revolution: how lateral power is transforming energy, the economy, and the world. Macmillan.
Rosenberg, M., 1965. Society and the adolescent self-image.
Rosenberg, N., 1969. The direction of technological change: inducement mechanisms and focusing devices. Econ. Dev. Cult. Chang. 1–24.
Rosenberg, N., 1982. Inside the black box: technology and economics. Cambridge University Press.
Schöner, G., Dose, M., Engels, C., 1995. Dynamics of behavior: theory and applications for autonomous robot architectures. Robot. Auton. Syst. 16 (2), 213–245.
Sterman, J.D., 2000. Business Dynamics.
Sturges, P.T., 1972. Information delay and retention: effect of information in feedback and tests. J. Educ. Psychol. 63 (1), 32.
Teece, D.J., 2010. Business models, business strategy and innovation. Long Range Plan. 43 (2), 172–194.
Van den Ende, J., Dolfsma, W., 2005. Technology-push, demand-pull and the shaping of technological paradigms—patterns in the development of computing technology. J. Evol. Econ. 15 (1), 83–99.
Vernon, R., 1966. International Investment and International Trade in the Product Cycle.
Warren, K., 2008. Competitive Strategy Dynamics. John Wiley & Sons.
Williams, R., Edge, D., 1996. The social shaping of technology. Res. Policy 25 (6), 865–899.
Yun, J.H.J., Mohan, A.V., 2012. Exploring open innovation approaches adopted by small and medium firms in emerging/growth industries: case studies from Daegu–Gyeongbuk region of South Korea. Int. J. Technol. Policy Manage. 12 (1), 1–19.
Yun, J.H.J, Nadhiroh, I.M., Jung, W.Y., 2013a. The relationship between open innovation, entrepreneurship, and introduction of new business models in Korean and Indonesian information technology enterprises. Korean Soc. Sci. J. 40 (2), 81–99.
Yun, J.H.J., Ryu, G.W., Jung, W.Y., 2013b. Is there any difference in the effect of open innovation according to the product life cycle?: Revisiting the relationship between product life cycle and trade. J. Int. Trade Dipl. Commerce 9 (2), 17–46.
Yun, J.H.J., Avvari, M.V., Jung, W.Y., 2015. Unraveling the relationship between entrepreneurship and open innovation: A Study on one of Modern Technology Evolution Channel.
Zajac, E.J., Kraatz, M.S., Bresser, R.K., 2000. Modeling the dynamics of strategic fit: a normative approach to strategic change. Strateg. Manag. J. 21 (4), 429–453.
Zott, C., Amit, R., 2008. The fit between product market strategy and business model: implications for firm performance. Strateg. Manag. J. 29 (1), 1–26.