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RESEARCH

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Configuring an alliance portfolio for eco-friendly innovation in the car industry: Hyundai and Toyota

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Abstract

Purpose: This study aims to examine the strategic alliance portfolio and the characters of focal firm partners in the eco-friendly car market, and also suggest the important managerial implications and suggestions for firms' managers and policy-makers using the patent information of Toyota and Hyundai as examples. This study identifies the fundamental differences in Hyundai's strategic partnerships through the comparison with Toyota's alliance portfolio.

Key literature reviews: This study analyzes the configuration of alliance portfolio using the patent citation information and various patent citation indexes. Many previous studies use patent citation information to analyze the flow of technological knowledge and the relative importance of the technology that companies produce (Hall, Jaffe, & Trajtenberg, 2005). Patents contain a lot of information, which researchers use to derive multiple properties related to technological innovation or technological excellence (Ernst, 2003). Especially, the Current Impact Index (CII), the Technology Strength (TS), the Technology Independence (TI) and the Science Linkage mean the technological innovation of companies (Chang, Chen, & Huang, 2012; Z. Huang et al., 2003; Sung, Wang, Huang, & Chen, 2015).

Design/ methodology/ approach: The paper employs patent data for collection of partnership data for both Hyundai and Toyota using joint patent filings, and the alliance portfolios are configured by using co-assignees as partners. In addition, we use patent citation indexes to analyze the relationship between firms' technological alliance and innovation capability.

(Expected) findings/results: The results of this study show that; 1) Toyota is actively developing joint R&D activities but, Hyundai is not. Because of this, Toyota has the advantageous position to obtain knowledge and technology than Hyundai due to the high centrality in alliance portfolio. 2) The alliance portfolio of Toyota and Hyundai can be categorized four groups by the degree of collaboration and patent quality. 3) There are differences in the properties of four groups of Toyota's alliance portfolio and Hyundai's alliance portfolio.

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Research limitations/ implications: This study has several limitations. First, patent information indicates only the cross-section of the company's innovation. Second, joint patents are not the only outcome of joint R&D, and comprise only a very small part of the output from joint R&D activities. In spite of these limitations, the findings suggest how firms can catch up to access the automotive bioplastic market, and offers contributions to theories related to portfolios.

Keywords: Automotive bioplastic, Alliance portfolio, Joint patent, Configuration, Pattern

Introduction

In recent years, the car material industry rapidly changes from petroleum-based to biomass-based materials to solve global environmental problems and natural resource depletion, including petroleum (European Bioplastics 2015; Harris 2011). Bioplastic produced from biomass which is the renewable biological resources, requires a fusion of chemical and biotechnology. Strategic alliances are absolutely necessary in bioplastic sector to secure original technology and raw materials (Chen 2012; Álvarez-Chávez et al. 2012; Park et al. 2013). The collaborative innovation network of focal firms like Toyota and Hyundai is an alliance portfolio (Duysters et al. 1999; Hoffmann 2007; Kim et al. 2012). An alliance portfolio consists of the strategic alliances of the focal firm. Some analyze it from a corporate strategy perspective in terms of various businesses (Wassmer 2010). In this study, alliance portfolio is defined as the strategic network of a firm and its partners. This study investigates the dynamics of strategic innovative network in the Asian eco-friendly car market and shows the configuration of an alliance portfolio to access this market using Toyota and Hyundai as examples. Previous studies emphasized the importance of open innovation through cooperation between individuals, companies, universities, institutions, and governments (Douglas 2015; Kwon et al. 2015; Patra and Krishna 2015; Theinsathid et al. 2009; Yun et al. 2016), and discussed the challenges of market access and sustainability (Álvarez-Chávez et al. 2012; Iles and Martin 2013; Rudge et al. 2005). However, there are no previous studies into innovation in collaborative innovation networks and the innovation capability of a firm in the bioplastic industry.In this study, we first identify the difference of the collaboration network between the leading company and the follower in the automotive bioplastic market. This study aims to fill the gap in the literature related to leading companies and fast-followers by analyzing their alliance portfolio in the automotive bioplastic domain and contribute to the theoretical research on R&D collaborations using the case of Toyota and Hyundai. This study shows the difference in the alliance portfolio of the leading company (Toyota) and the fast-follower (Hyundai). Because alliance portfolio reveals information to competitors focusing on a similar technology domain as the focal firm, the analysis of a firm's alliance portfolio is very important.

We collected partnership data for both Toyota and Hyundai using joint patent filings, and we configured the alliance portfolios using co-applicants as partners. Our study joins previous studies using patent statistics as measures of technology innovation performance and regards patent statistics as a measure of the results of technology innovation performance (Kapoor et al. 2015; Kim and Lee 2015; Picard 2012; Yun et al. 2010). Additionally, we analyze the relationship between R&D collaboration and technology performance through business innovation using joint patents.This rest of the paper is structured as follows. Section 2 summarizes the relevant research, and section 3 describes data source and methodology. Section 4 presents the results and analysis of the alliance portfolio configurations, and discusses the differences in the alliance portfolio configurations and characteristics of the partners involved in various portfolio patterns classified according to the degree of R&D collaboration and technology innovation performance. The final section concludes the paper with a discussion of the implications and the limitations of our study.

Literature review

Configuration of alliance portfolio

Many previous studies analyzed the configuration and properties of alliance portfolios using the quantitative indexes as the number of partners, partner diversity, intensity of partnership (repeated partnerships) and technological similarity (Frankort et al. 2012; C. Kim and Song, 2007; Kim and Choi 2014; Ma et al. 2013). However, this study analyzes the configuration of alliance portfolio using the patent citation information and various patent cation indexes.

Many studies use patent citation information to analyze the flow of technological knowledge and the relative importance of the technology that companies produce (Hall et al. 2005). Patents contain a lot of information, which researchers use to derive multiple properties related to technological innovation or technological excellence (Ernst 2003). Tseng et al. (2011) analyze the trends and technological strategies in the amorphous silicon thin-film solar cell industry using patent citation indexes. David W.L. Hsu and Yuan (2013) identify knowledge creation and diffusion in Taiwan's universities utilizing forward citations, backward citations, and Science Linkage (SL).

There are various patent citation indexes. Current Impact Index (CII) is an index that represents technological excellence measured by the number of citations of one patent by other patents in the previous five years. A higher CII indicates that a patent has high technological capability (Chang et al. 2012; Chen et al. 2007; Chiu and Chen 2007). Technological Strength (TS) demonstrates the excellence of technology by indicating the scale of a company's influence in a specific technological field. A higher TS means that the company has higher market competitiveness. Therefore, a company with the higher TS in its alliance portfolio may enjoy a dominant position in the market. Another index is Technological Independence (TI) that implies technological innovation is the degree of citations of internal patents developed in an alliance portfolio. In other words, it indicates that an alliance portfolio with the higher TI actively uses the technologies developed by internal actors (Huang et al. 2003).

Lastly, Science Linkage (SL) represents technological innovation. SL indicates that actors in an alliance portfolio actively develop science-based technologies and lead scientific technology in the market. Sung et al. (2015) classify four companies with a higher SL by analyzing the results for the top 20 companies in the Computers and Communication (C&C) field. They emphasize that a higher SL does not mean that a company has the low technological competitiveness, but that it has technological innovation capability.

Previous studies measured the degree of collaboration between a focal firm and their partners using the number of joint patents. However, it is difficult to determine the extent of cooperation between enterprises for technological innovation accurately using this method. Salton's index compensates for this disadvantage by providing information about the scale of cooperation between companies using the relative rate of joint patents in all patents (Lu and Feng 2009). Lee et al. (2016) measure the extent of cooperation between large firms and small-medium firms using Salton's index.

This study uses the CII, TS, TI, and SL indexes, which represent technological innovation and technological excellence to measure patent quality, and Salton's index to measure the degree of cooperation between a focal firm and its partners. The present study thus differs from previous research because it uses patent citation indexes for analyzing the configuration of alliance portfolio.

Bioplastic industry

Bioplastic is the polymer produced with bio-mass, a bio-resource based on the fermentation process (Jegal 2012; Ministry of Environment 2014). Its renewable properties have focused attention on bioplastic as an eco-friendly material that can reduce CO_2 emissions.

The global bioplastic market was at $ 1.9 billion, formed initially by the US, Europe, and Japan, which have strong environmental regulations in 2011. Europe accounts for 60% of the entire bioplastic market (European Bioplastics 2016). Leading countries such as the US, Japan, and some in Europe focused early on R&D in environmental packaging technology. These countries completely supported R&D and investment costs in the bioplastic industry at the early stages, led by the government (Iles and Martin, 2013). Strategic alliances between traditional chemical companies and start-up bio-companies have expanded in the industry. In the automobile industry especially, companies have expanded the use of bioplastic materials for to enhance their eco-friendly image (European Bioplastics 2015).

In the Japanese automobile business, Toyota has actively used bioplastic to produce eco-friendly cars. In 2009, Toyota produced a new eco-friendly hybrid vehicle using plant-based bioplastic for 60% of the vehicle's inner areas. Additionally, after taking over the PLA production factory from Shimadzu in 2002 through a strategic alliance, Toyota expanded PLA production to produce eco-friendly cars and supplied other companies with the material. Moreover, Toyota engages in active research to improve PLA's material properties (Jegal et al. 2008), with many patents related to bioplastic because they vigorously cooperate with other companies in R&D.

In Korea, after a set of government-mandated tasks related to bioplastic R&D in 1993, companies such as SK chemical, LG Chemical, and so on engaged in bioplastic R&D. Although many firms' manufacturing technology for bioplastic reached a relatively high standard, most commercialization stopped due to excessively strict regulations (Han 2011). Domestic bioplastic in Korea is produced mainly by big chemical companies such as LG chemical, GS Caltex, and CJ. In 2009, Hyundai was the first to use PLA to produce an eco-friendly hybrid car.

Methodology

Measurements

We use patent statistics to measure the firm's innovation capability and R&D collaboration since they provide useful information about the flow of technology development with objective and standardized indexes containing the latest technology trends. In addition, because patents are an objective and formal innovation measurement result, many previous studies use patent statistics to measure firms' innovation capability.

We define a joint patent as that consisting of two of more assignees affiliated with different organizations through information contained in patents. We use these joint patents to measure and analyze R&D collaboration activity, a common methodology employed in earlier research (Y.-S. Chen & Chen 2011; Hoffmann 2007; Huang et al. 2012; Lee and Lee 2013; Lin et al. 2012; Motohashi and Muramatsu 2012; Tseng et al. 2011; Yun et al. 2015). We thus adopt this method to measure the relationship between R&D collaboration and innovation capability.

It is possible to create an alliance portfolio from joint patents resulting from R&D collaboration. Although alliance portfolios can be categorized as alliance portfolio emergence, configuration, and management, this study focuses on alliance portfolio configuration, measured by the size and intensity of the R&D collaboration network.

The firm's innovation capability is measured with a patent citation analysis. Previous studies showed that patents with high numbers of citations in patents filed by other firms have a high technology value. Through a patent citation analysis, many researchers analyzed technological skill and market power, and also measured a firm's innovation capability.

This study analyzes co-assignees in joint patents to create an alliance portfolio for the focal firms and measure its technological skill according to the alliance portfolio. Furthermore, we conduct a comparative analysis about the degree of R&D collaboration among partners and the level of technological skill.

Data

We use data from the Thomson Innovation Database because it supplies a variety of the information required for this study, such as inventors, application year, and assignees' affiliations. We can also select only bioplastic patents because this database provides patent information supplemented by expert reviews since patents may differ in their actual contents when assignees do not want to publish their patent information openly. We searched this database including USPTO (United States Patent and Trademark Office), EPO (European Patent Office), JPO (Japan Patent Office) and KIPO (Korean Intellectual Property Office) for patents from 1984 to 2013 related to bioplastic for Toyota and Hyundai. We identified 45,240 bioplastic patents and classified the patents of Hyundai and Toyota from the entire bioplastic patents (see Fig. 1). Toyota has 233 joint patents of their total of 415 patents, and Hyundai has 71 joint patents of their total of 165 patents. Additionally, Toyota collaborated in R&D with 34 partners, while Hyundai collaborates with 26 partners.

Patent citation analysis indexes

This study analyzes firm's innovation capability through the number of partners and the degree of cooperation using the patent citation information of joint patents of both companies. Joint patents are analyzed through the patent citation indexes suggested by CHI research Inc. (Narin 1999).

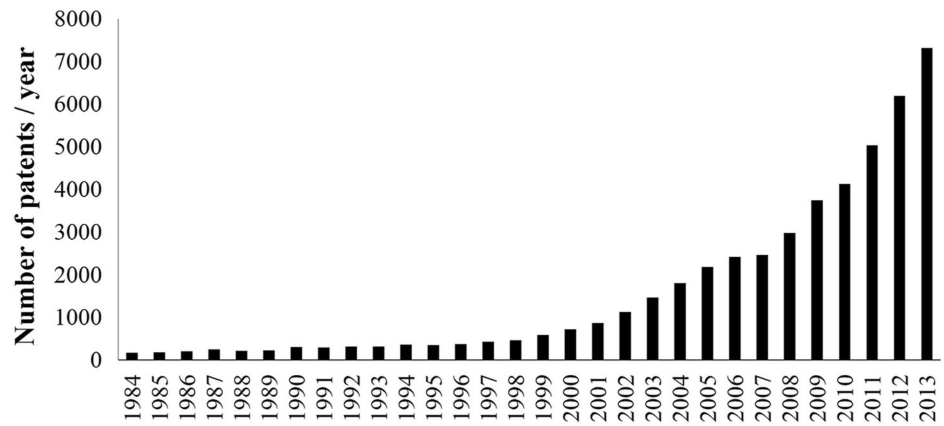

Fig. 1 Number of bioplastic patents registered per year (1984-2013)

Citations Per Patent (CPP) means the average number of times that the patent is cited from other patents as an index to evaluate the quality of the patent's technical capabilities. Patents with more citations are considered an important invention useful for future inventors. Additionally, companies holding patents with high CPP values are more advanced than other firms.

$$\mathrm{CPP} = \frac{\text{Number of citations}}{\text{Number of patents}}$$

CII indicates the degree of citations in other patents over the previous five years. Higher CII values indicate that firms have a high technology impact and shows active R&D in the technology field. CII shows the technological skills of specific assignees in same industry sectors through correlations among companies. If the CII value is 1, the technology impact is average, but a CII of 2 represents a patent cited twice as much as the average by backward patents.

$$\mathrm{CII} = \frac{\mathrm{C_{ij}}/\mathrm{K_{ij}}}{\sum_{\mathrm{t}=1}^{5}\mathrm{C_{ij}}/\sum_{\mathrm{t}=1}^{5}\mathrm{K_{ij}}}$$

t: the past 5 years based on current year

$\mathrm{C_{ij}}$: Number of the cited patents in a certain year

$\mathrm{K_{ij}}$: Number of patents

$\sum_{t=1}^{5}\mathrm{C_{ij}}$: Number of cited patents of company i in industry j from the previous five years

$\sum_{t=1}^{5}\mathrm{K_{ij}}$: Number of patents of company j produced in industry j during the previous five years

Technological Strength (TS) is the number of patents multiplied by CII. TS means the qualitatively weighted evaluation of firms using patent quality and quantity. A higher TS value implies a short industrial circulation cycle or a highly competitive market.

$$\mathrm{TS} = \text{Number of patents} \times \mathrm{CII}$$

Technology Independence (TI) indicates the degree of firms' self-citations. A higher TI means that firms conduct R&D using their own technologies in a relevant field, and a lower TI value indicates that the firm increases their technologies using both its own in-house technology and that of other firms.

$$\mathrm{TI} = \frac{\text{Number of self} - \text{citations}}{\text{Number of citations}}$$

Lastly, we measure the degree of joint research cooperation (R) using Salton's index (degree of collaboration) because the collaboration relationship shown by the number of joint patents cannot represent the relative degree of cooperation. The number of joint patents simply describes the quantitative information about R&D collaboration, but Salton's index (degree of collaboration) represents the relative ratio of joint inventions considering the overall number of the patents, and thus represents the degree of cooperation among comparison targets.

$$\mathrm{R} = \frac{\mathrm{P_{ij}}}{\sqrt{\mathrm{P_i} \times \mathrm{P_j}}} \times 100$$

P_{ij}: Number of i and j joint patents
P_i: Number of joint patents of company i
P_j: Number of joint patents of company j

Results

According to Fig. 2, the number of the joint patents rapidly increased from 2000 to 2005, showing that Toyota actively collaborated with their partners in bioplastic R&D. The total number of bioplastic patents rapidly increased, while the number of joint patents steadily increased from 2007 to 2011.

On the other hand, the number of the total patents and joint patents increased since 2009. This is especially true in the case of Hyundai, which shows that the size of Hyundai's alliance portfolio gradually increased.

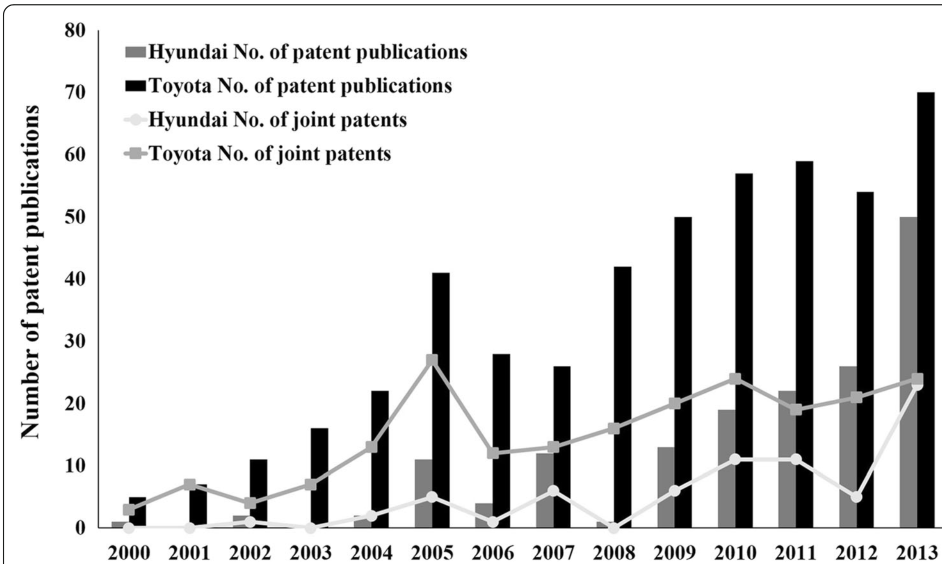

Fig. 2 Joint patents related to total patent activity

Figure 3 illustrates CII, which for Toyota is 1.27 meaning that its patents were cited by other patents 27% more than the expected number. Thus Toyota's patents have a bigger technological impact than other firms. Hyundai's CII for all patents is 0.7, and is 0.6 for joint patents. As for Toyota, its CII for joint patents is higher than that for exclusive patents. This could be because Toyota has high technological skills in R&D collaboration.

Figure 4 and 5 show TS of total and joint patents over time. Toyota has higher TS in R&D collaboration, except for 2012. In 2011, Hyundai had the most total and joint patents, as well as a higher TS value. However, Hyundai does not actively collaborate with other partners as Toyota does. Because Toyota and Hyundai have different alliance portfolio characteristics, Toyota has high TS through R&D collaboration, while Hyundai does not improve their technological skills through R&D collaboration. We therefore analyzed both firms' alliance portfolios in view of partner and size.

Alliance portfolio configuration and properties of partners

Figure 6 shows the relationship between the degree of collaboration and patent quality in Toyota's alliance portfolio. We classified four groups according to the degree of the relationship between the degree of collaboration and patent quality. 'Key partners' have a high value for the degree of collaboration and patent quality and 'Potential partners' have a high value for patent quality and a low value for the degree of collaboration. 'Nominal partners' have a low value for the degree of collaboration and patent quality and 'Diligent partners' have the high value of degree of collaboration and a low value for patent quality.

Table 1 reports the results of the analysis. Patents of 'Key partners' are cited by other patents very frequently and are related R&D based on science. 'Nominal partners' focused on R&D based on science as did 'Key partners'. 'Diligent partners' has the high TI value, meaning that these firms use external technology more than other groups.

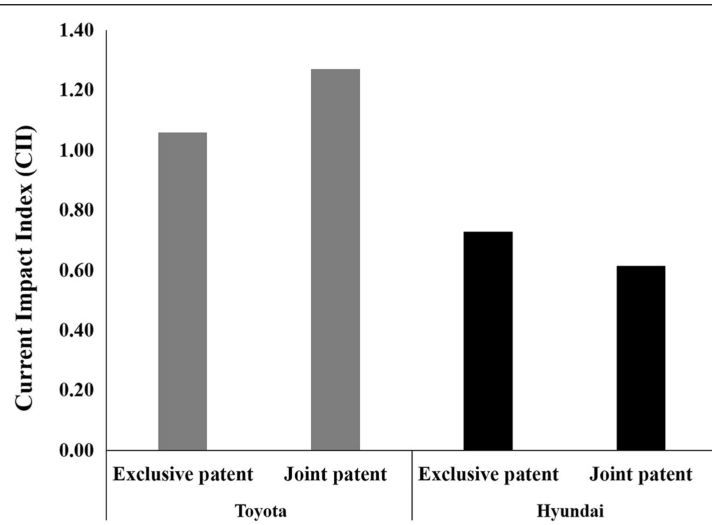

Fig. 3 Current Impact Index (CII) of exclusive and joint patents

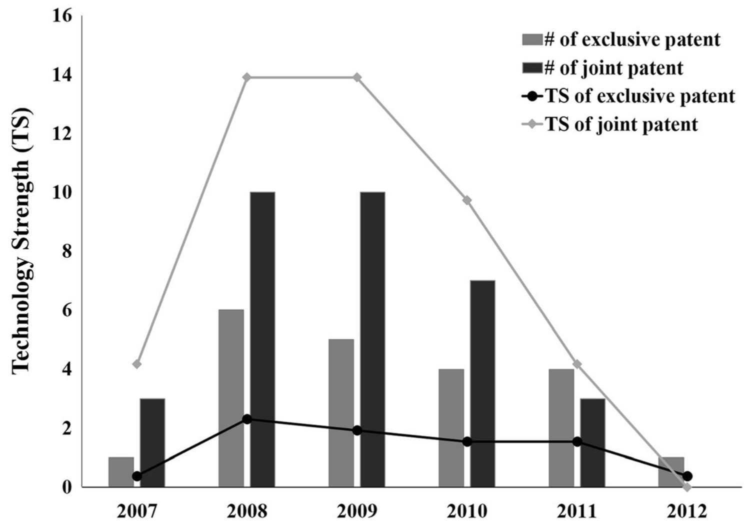

Fig. 4 Technological Strength (TS) in Toyota's alliance portfolio

Figure 7 shows the relationship between the degree of collaboration and patent quality in Hyundai's alliance portfolio. Table 2 shows the properties of the four groups. The patents of 'Key partners' are cited very frequently by other patents, and 'Diligent partners' cite many more patents than other groups. 'Potential partners' focus on R&D based on science and use external knowledge more often. 'Nominal partners' patents are cited more often by other patents than for the other groups except 'Key partners'. 'Diligent partners' has a high value for TI, meaning that these firms use external technology more than other groups.

Typical collaboration patterns

In this section, we perform in-depth analysis of patterns by categorizing an affiliate portfolio according to the partner and patent quality for both Toyota and Hyundai. We

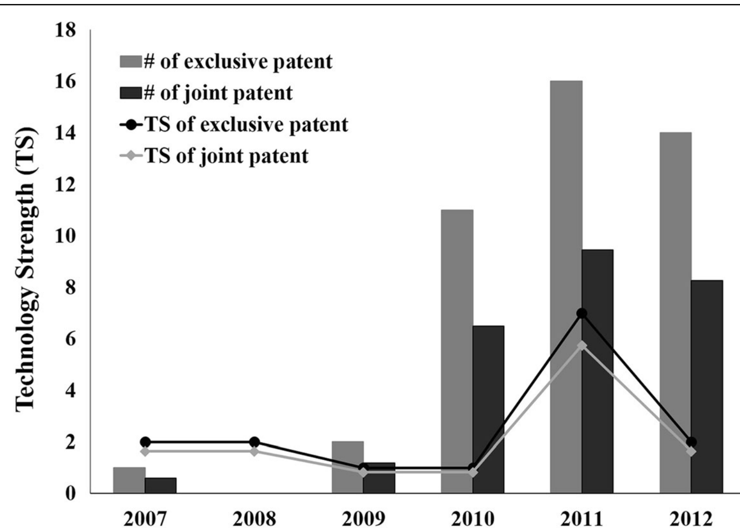

Fig. 5 Technological Strength (TS) in Hyundai's alliance portfolio

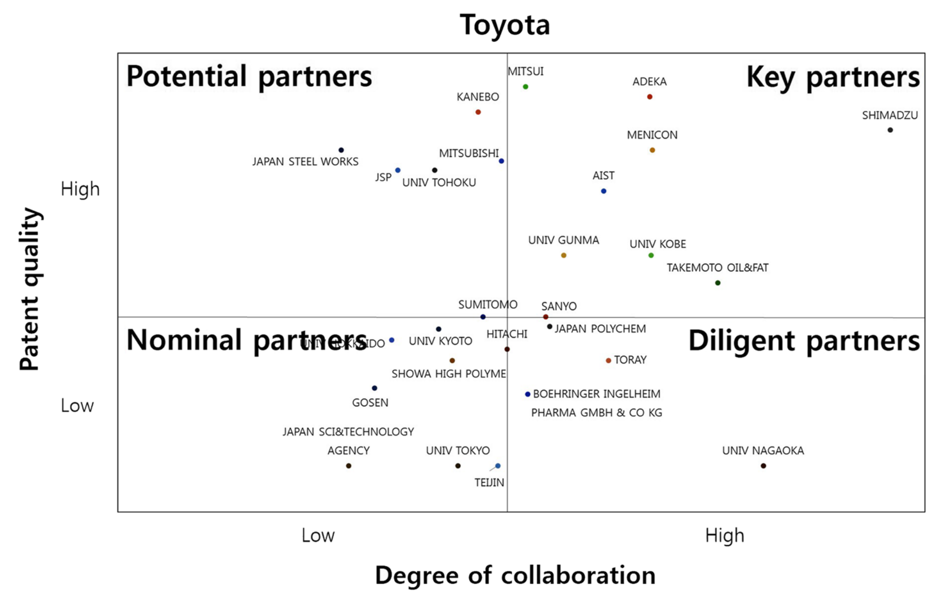

Fig. 6 Relationship between degree of collaboration and patent quality in Toyota's alliance portfolio

then obtain information about the partners using search engines and partner company web sites. Finally, we determine the characteristics of the partners within an affiliate portfolio to investigate the impact of the focal firms' innovation and analyze the cooperation activities and each company's activities in the bioplastic industry. Tables 3 and 4 summarize the analysis.

As shown in Table 3, companies belonging to 'Potential partners' have a lower degree of joint research cooperation with Toyota, though have a significant impact on securing Toyota's source technology. For example, Mitsubishi has technology to enhance heat resistance, since this is a disadvantage of PLA, though Toyota's R&D aims to improve the physical properties of PLA. In addition, Kanebo is the other partner with an annual production capability of 500 tons of PLA fiber in Japan's best PLA textile company.

The representative partners in 'Key partners' are Shimadzu and Mitsui. Shimadzu is a fine chemical manufacturing company, and also an excellent Japanese PLA production company. Toyota cooperated with Shimadzu steadily from 1994 to 2002, and then acquired the PLA production plant in 2002, later producing and selling its own PLA to other companies. The cooperation between Toyota and Shimadzu is a good example from Lin et al. (2012)'s finding that an alliance for product development is better than one based on technological cooperation. Mitsui Chemicals that is another partner of Toyota established a bioplastic production plant with the US chemical company Dow

Table 1 Properties of four groups in Toyota's alliance portfolio

Group	Degree of collaboration	Patent quality	Forward citation	Backward citation	TI	SL
Key Partners	9.36	1.39	49.24	2.33	0.05	1.56
Potential Partners	1.79	1.40	4.95	2.67	0.06	0.19
Nominal Partners	1.77	0.61	1.45	5.02	0.1	1.46
Diligent Partners	5.69	0.38	4.62	6.31	0.2	0.85

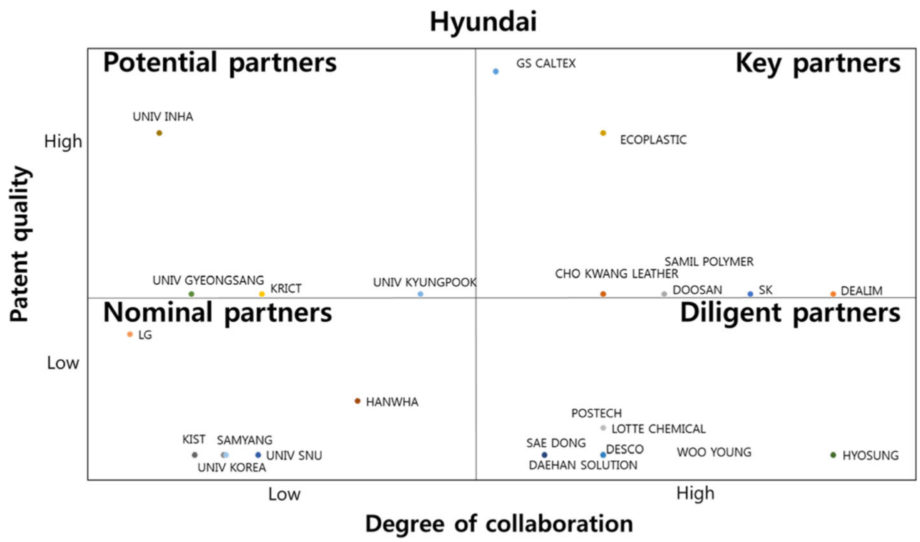

Fig. 7 Relationship between degree of collaboration and patent quality in Hyundai's alliance portfolio

in Brazil, and cofounded a joint venture with Toyota called bio-Indonesia to sell Toyota's bioplastic in Indonesia.

'Nominal partners' are characterized by low joint research cooperation to acquire the simple knowledge where the source technology development level is also low. Unitika has its own production facilities and produces engineering plastics derived from biomass, R&D objectives, and other directions from Toyota. Thus, cooperation for simple knowledge acquisition had the lowest cooperative partnership to improve Toyota's patent portfolio quality. Gosen, another typical example, is a company manufacturing sporting goods in Japan. Recently, the trend of adding a bio-derived plastic has increased in response to the supply of the PLA from Toyota, as indicated by the high degree of cooperation. However, Gosen does not engage in R&D related to bioplastic, so it does not have a significant effect on patent quality.

'Diligent partners' have the highest degree of collaboration as a cooperative group with high joint research cooperation, though this group has low patent quality. In addition, Hitachi has recently expressed an interest in bioplastic production and has less expensive bioplastic manufacturing technology than Toyota's, but has thus not improved patent quality in cooperation with Toyota. In other words, partners belonging to 'Diligent partners' are either receiving a supply of bioplastic or having bioplastic manufacturing technology to produce independently of Toyota.

Table 4 shows the properties of Hyundai's representative partners in four groups. KRICT (Korea Research Institute of Chemical Technology) is the institution

Table 2 Properties of four groups in Hyundai's alliance portfolio

Group	Degree of collaboration	Patent quality	Forward citation	Backward citation	TI	SL
Key Partners	7.56	1.84	1.28	3.58	0.00	0.16
Potential Partners	2.70	1.11	0.67	3.44	0.14	0.53
Nominal Partners	1.65	0.29	1.09	2.90	0.00	0.13
Diligent Partners	6.01	0.07	0.50	2.68	0.17	0.00

Table 3 Properties of representative Toyota's partners involved in four groups

Groups	Characteristics of alliance portfolios		Representative Toyota's partners	
	Patent quality	Degree of collaboration		
Potential partners	HIGH	LOW	Mitsubishi	- Blending PLA with other biodegradable plastics to improve heat resistance
			Kanebo	- Japan's best PLA textile company and acquisition of PLA processing facilities that can produce 500 tons annually
Key partners	HIGH	HIGH	Mitsui	- Establishment of bioplastic plant with US chemical company Dow in Brazil - Establishment of "Toyota bio Indonesia", joint venture of Toyota and MISUI to sell bioplastic produced by Toyota
			Shimadzu	- Toyota took over bioplastic production plant from Shimadzu in 2002
Nominal partners	LOW	LOW	Gosen	- Japanese companies (sports equipment manufacturing) selling fishing supplies and rackets (such as tennis, soft tennis, and badminton)
			Unitika	- Commercialization of "Jekoto", an intensively developed biomass plastic business. This is a polyamide-based engineering plastic using a raw material derived from biomass - Acquired production capacity of 500 tons annually from the factory in Uji City in Kyoto prefecture in July 2012 and completed testing the Jekoto plant
Diligent partners	LOW	HIGH	Hitachi	- In 2010, developed an epoxy with heat resistant resin with lignin in the main raw material - Hitachi recently expressed an interest in the production of biomass-derived plastic

representing 'Potential partners'. KRICT opened the Bio-Chemical Commercialization Center in 2016, focusing on bioplastic R&D.

GS Caltex represents a 'Key partners'. The company is developing bio-nylon made from biomass. This material has very similar mechanical properties as existing products.

LG belongs to the 'Nominal partners', which has a higher number of joint R&D partners in addition to Hyundai. LG, conducted joint research with KAIST in 2009,

Table 4 Properties of representative Hyundai's partners involved in four groups

Groups	Characteristics of alliance portfolios		Representative Toyota's partners	
	Patent quality	Degree of collaboration		
Potential partners	HIGH	LOW	KRICT	- In 2016, Bio-Chemical commercialization center open for production of bioplastic
Key partners	HIGH	HIGH	GS Caltex	- Development of bio-nylon made from biomass
Nominal partners	LOW	LOW	LG	- Joint development of PLA production technology using bacteria with KAIST in 2009
Diligent partners	LOW	HIGH	Hitachi	- Supply environment-friendly fiber (PTT BCF) to make yarn from corn to produce environmentally friendly car mats for the "Kia Soul EV"
			Desco	- Hyundai's subcontractor - Inactive R&D in bioplastic

developed PLA production technology using bacteria. Thus, 'Nominal partners' in Hyundai's portfolio promote more joint R&D with other partners.

Desco and Hyosung are classified as 'Diligent partners' because these partnerships have a higher level of joint research cooperation. Hyosung offers a fiber created to make yarn from corn for materials for the KIA "Soul EV". However, since Desco does not conduct R&D related to bioplastic, it had no significant effect on patent quality.

Conclusions

This study analyzed alliance portfolios and identified the four groups in Toyota and Hyundai's portfolio.

Toyota conducted bioplastic R&D through cooperation with partners in the early stages. Toyota did joint R&D for securing original bioplastic technology through collaborations with partners. As a result, Toyota's patents are cited 40% more than Hyundai's.

On the other hand, Hyundai focused on independent R&D, so both exclusive and joint patents were cited about 20 ~ 40% less than Toyota's. Thus, Hyundai has secured less source technology in bioplastic domain through R&D collaboration. The CII of exclusive patents is 0.6, and that of joint patents is 0.7, so R&D collaborations have a slight positive effect on the company's source technology. Therefore, in the long-term perspectives, when Hyundai collaborates with other partners in bioplastic domain, they will be in an advantageous position to secure original bioplastic technology.

We categorized four groups according to the degree of collaboration and patent quality and analyzed the properties of the representative partners in each group.

In case of Toyota, 'Potential partners' have the low degree of research collaboration and enhances patent quality through joint R&D. They are active in bioplastic R&D and production. 'Key partners' collaborate to obtain critical technological knowledge. For example, Shimadzu conducts continuous joint R&D with Toyota from 1994 to 2002, and then Toyota acquired its PLA production plant in 2002. Now Toyota becomes a supplier of PLA to more than 60 companies to date. Partners of 'Nominal partners' have a low degree of collaboration and patent quality. These partners have their own production facilities and actively conduct bioplastic R&D. However, they have a purpose different from Toyota, and focus on joint R&D with other partners besides Toyota. Lastly, partners of 'Diligent partners' purchase PLA from Toyota or have lower level of technology than Toyota. They have a high degree of R&D collaboration with Toyota but they do not affect Toyota's innovation through R&D collaboration.

In case of Hyundai, most of partners have lower technological skills than Toyota's partners and less science-based R&D activity.

These results show the different strategic alliances between Toyota and Hyundai. Toyota acquired the equipment and the related production techniques in the bioplastic domain. In addition, Toyota collaborated with other institution with bioplastic production facilities and obtained diverse knowledge through collaboration with partners focusing on R&D in PLA rather than for other kinds of bioplastic. Eventually, Toyota produced its own PLA in multiple companies.

On the other hand, Hyundai focuses on bioplastic production through independent R&D. As a result, Hyundai has a low degree of concentration in cooperation with partners, because they just want to acquire knowledge rather than securing original technologies.

The bioplastic field requires an integration of biological and chemical technology, so research in a single discipline makes it difficult to acquire bioplastic source technology. Though research into bioplastic materials is not currently active, interests in automotive bioplastic will emerge in the eco-friendly automobile market.

This study's findings are useful both firms' managers and policy-makers interested in innovation in the eco-friendly automotive and materials industries. Companies promoting innovation must preferentially adopt open innovation strategy. In particular, companies should maintain a long-term cooperative partnership with a clear goal of technology acquisition, reduce alliance portfolio management costs and produce positive effects from a long-term innovation perspective. However companies should have an interest in absorbing knowledge about various fields through collaborations partners in other areas to gain the flexibility to react to internal and external environmental changes. Policy-makers should assist by making it easier to form and develop an innovation network through changes in the system and companies participating in the bioplastic industry. Policy-makers can consider developing such systems and offer subsidies to maintain this cooperation.

However, despite these contributions, this study has several limitations. First, many researchers use patent data for research, but patent information indicates only the cross-section of the company's innovation. Therefore, future studies should introduce more indexes to measure the potential of a company's innovation. Second, joint patents are not the only outcome of joint R&D, and comprise only a very small part of the output from joint R&D activities. Therefore, to measure the results of innovation through joint R&D activities for a focal company and its partners, future studies should conduct surveys or interviews targeting experts participating in contract for technical commercialization or joint R&D.

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All authors read and approved the manuscript.

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The authors declare that they have no competing interests.

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