The Role of Organizational Alliance Networks in Successful R&D
— The Case of Toyota's Fuel Cell Development —

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Abstract

This paper focuses on the elements of successful research and development (R&D) in a high-technology field. It asks the question of how openness and involvement in organizational research networks can help innovation. The paper relies on the technological patents of Toyota's fuel cell R&D program up to the unveiling of the first-generation Toyota Mirai in 2014. Through a text analysis of patent contents, the paper gives an overview of how the development has transitioned through different phases. Toyota's research is then compared to other Japanese automakers in terms of the openness of its R&D alliance network. Then, through quantitative analysis, the paper investigates what elements contribute to a successful granted patent. The results show that both open alliance partners (such as overseas partners) and partnership with central actors in the Japanese nanotechnology network contribute to a greater likelihood of gaining a patent grant. The results also suggest that some degree of openness and network involvement in related technology fields are necessary for successful R&D, but the openness itself is not enough.

I. Introduction

The Mirai's first model ended production in 2020, and Toyota released the second generation Mirai. The first model was an important commitment towards fuel cell technology, and Toyota has become a central player in the automobile industry that pioneered the technology. This paper investigates the circumstances of its development and asks how openness and involvement in organizational research networks can help innovation. While Toyota can boast of its capabilities in research and development (R&D), the radical nature of the technology made it necessary to look outside of the well-established Toyota network. While research and development are mainly conducted among key Toyota organizations, the company looked outside domestically and internationally to find unique solutions.

In recent years, concepts such as open innovation and alliance networks have become important. The present study asks what exactly these terms mean in terms of a concrete case and how much impact they have in developing cars with innovative technologies. Toyota has used different kinds of open innovation, maintaining a fine balance. The paper contributes to the literature on open innovation and helps shed light on how domestic companies can benefit from multiple pathways to other fields and networks.

II. Literature review and theory

The concept of open innovation has been introduced by Chesbrough (2003) and has since become ubiquitous in management research. In the past, organizational researchers have looked at organizations as independent, self-contained entities. They did have important connections to their environment, but the environment was vaguely defined, and organizational outcomes were seen as coming from inside the organization. This idea was questioned, and more emphasis was placed on relationships to other organizations, networks, and outside stakeholders (for example, in the early population ecology perspective of Hannan & Freeman, 1977; Powell, Koput & Smith-Doerr's (1996) network perspective; and Chesbrough's (2003) open innovation concept). Chesbrough (2003) and Powell et al. (1996) recognized that innovation does not occur within the organization's limits, but ideas originate from inside and outside of the organization. Development likewise does not take place isolated but is carried out in a network of diverse organizations, especially in the case of small venture companies in high-technology industries.

Open innovation, however, is more than receiving ideas from the outside network. Chesbrough and Bogers (2014) defined it as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries." They point out that there is an intentional, purposive element in the management of these flows across boundaries.

Traditional R&D is built around an in-house R&D center. This center, of course, establishes links to academia and other research organizations and does not act completely alone, but management scholars did not focus extensively on these relationships. In the last two decades, researchers have recognized the importance of these networks around firms.

Powell et al. (1996) emphasized that organizations were embedded in networks, and innovation was a joint effort made possible by the cooperation of various actors. There is a great deal of evidence that ideas and necessary resources can come from outside the network and that the position of the organization within the network influences the quality of these resources.

Organizations are not merely influenced by adjacent members but also by the whole network (Uzzi, 1996a; Uzzi, 1996b). It is also not enough to simply be connected to a network. Different network positions confer different levels of benefits to organizations (Burt, 1992; Baum, Calabrese & Silverman, 2000; McEvily and Zaheer, 1999; Zaheer & Soda, 2009).

There is a consensus that the right open innovation strategy can be theoretically beneficial (Bogers, Chesbrough, & Moedas, 2018). Chesbrough's open innovation can, however, be realized in different ways. Customers can be involved in the idea generation process, or a diverse set of contributors can work on an idea as in open-source software development. In Toyota's case, suppliers have long been involved in incremental innovation and improvements (Dyer & Nobeoka, 2000). This network of Toyota's will be introduced in more detail in the next chapter. However, this case will show that in certain situation firms have to go beyond their established networks.

The aim of the paper is to look at a concrete case and see what elements contribute to successful innovation. This paper looks at several different pathways to innovation. First of all, Toyota group companies work together within their close-knit network. These closed, trust-based alliances are likely to carry benefits. Coleman (1988, 1990), Brown & Duguid (1991), Nishiguchi & Tsujita (2017) predict that a close-knit, high-trust grouping will work together with the best results. Therefore, our base hypothesis is that Toyota group companies will have the highest level of innovation.

> *Hypothesis 1.* Alliances with domestic organizations in the closely-knit Toyota group will have better innovational output (measured in granted patents).

However, the literature on open innovation (Chesbrough, 2003) predicts that alliances with international organizations will also provide benefits. International alliances come with disadvantages (Lavie & Miller, 2008) and while cultural differences and different goals can all contribute to problems, international alliances can also provide much-needed resources or knowledge. Therefore,

> *Hypothesis 2.* Alliances with international organizations beyond the closely-knit Toyota group will have good innovational output (measured in granted patents).

The same literature on open innovation suggests that alliances with domestic organizations in other related industries, such as the nanotechnology industry, are also beneficial. Unique sources of information from other networks can be likewise beneficial

(Burt, 1992, 2004).

Hypothesis 3. Alliances with domestic organizations in related industries are beneficial (as measured in granted patents).

To this, we can add that network theory predicts that organizations in better positions will provide more benefits (Baum, Calabrese & Silverman, 2000).

Hypothesis 4. Network theory predicts that only organizations in powerful positions within the domestic network will be beneficial alliance partners.

In the next section, an overview will be given about Toyota and its R&D network, followed by a simple temporal text analysis about Toyota's fuel cell development process.

III. Case: Toyota's fuel cell development and the Toyota Mirai

Case Background

The paper investigates the case of Toyota Motor Corporation's fuel cell car development. Toyota has been in the center of management research both in Japan and in the US. The Toyota Production System and lean production have been analyzed in-depth (Womack, Jones & Roos, 1990; Liker, 1990). There has been a great deal of research on how Toyota makes strategy and achieves successful innovation (Clark & Fujimoto, 1991; Fujimoto, 1999).

Dyer & Nobeoka (2000) and Clark & Fujimoto (1991) described a learning or knowledge-sharing network between the long-term suppliers and subcontractors of Toyota that provided the basis for Toyota's competitive advantage. Dyer & Nobeoka (2000) describe how these supplier networks are maintained by special organizations such as the Kyohokai in Japan and the TSSC in the US. These organizations foster communication and cooperation with Toyota and enable the firm to exercise control over the supplier through monitoring and feedback.

However, many of the suppliers do not belong to just one organizational pyramid under Toyota, but in many cases supply parts to other car manufacturers as well (Fujimoto, 1999). A review of data by the author from the Nihon Jidosha Buhin Kogyokai revealed that a company supplies parts to at least three companies on average.

These networks contribute direct technical knowledge about the overall product architecture and knowledge about outsourced parts. Dyer & Nobeoka (2000) write that "a fundamental dilemma for a knowledge sharing network is providing assurances to members that proprietary knowledge will be protected while at the same time encouraging members to contribute valuable knowledge to the collective good. Toyota solves this problem by simply eliminating the notion that there is 'proprietary knowledge' within certain knowledge domains (e.g., production, quality, etc.)." The way Toyota creates a community based on trust is described by the authors, "[b]y openly sharing all of the valuable production know-how at its disposal, Toyota creates a norm within the network that very little of the knowledge that a firm possesses is proprietary (with the exception of certain product designs/technology)." Dyer & Nobeoka (2000) explain that "[p]roduction processes are simply not viewed as proprietary and Toyota accepts that some valuable knowledge will spill-over to benefit competitors. […] Toyota creates a norm of reciprocal knowledge sharing within the production network by providing free assistance to suppliers and allowing suppliers full access to Toyota's operations and stock of knowledge (the only exception is the new model design area which is available only to certain key suppliers)." (Dyer & Nobeoka, 2000). It is important to note that new model design is only available to certain key suppliers. The development of radically new technologies, like fuel cells, is likewise not shared openly with most members (though Toyota has opened up its patent portfolio at the end of the development process to help the spread of the technology following American examples).

With newly developing technologies, it is often necessary to go outside the well-established 'network.' In the following sections, I look at Toyota's R&D network for fuel cell research, but first it is necessary to introduce Toyota's existing network for R&D. Dyer & Nobeoka (2000) found that the only kinds of proprietary knowledge not opened up to the supplier network are product technologies and designs. While development is contained within Toyota's core development network, this proprietary knowledge can be protected.

Ku (2011) describes Toyota's R&D network in detail. He found that Toyota tends to outsource parts development, but this outsourcing mostly takes place within its supplier network and its traditional R&D network. This network is built around several key organizations spearheaded by Toyota Motor's technological center. These include Toyota Chuo Kenkyusho, the Higashi-Fuji Technical Center, the Nihon Jidosha Buhin Sogo Kenkyusho (jointly created with Denso), the Konpon Kenkyusho (Genesis Research Institute), and Toyota Technical Development Corp. These are helped along by other research institutes affiliated with main suppliers. In our case, Equos Research would be such a firm affiliated with the Aisin Group. Therefore, it is clear that new product development does not occur in-house. In fact, Toyota has long been collaborating with its suppliers in R&D. However, Toyota's R&D does not simply rely on its supplier network, but the company builds bridges to other entities such as universities and foreign organizations, as shown through our data.

Case Data

In order to look at the field around Toyota, I gathered data from archival records. First, I have collected car parts supplier data to see what the original parts network looks like and what companies belonged to this group. For this, the data books from the Nihon Jidosha Buhin Kogyokai and the members' list of Kyohokai were used.

This was followed by data collection from fuel cell patent data for three different car companies (Toyota, Honda, and Nissan) from available data based on the Japanese Patent Office. This data, for Toyota, consisted of approximately 1400 joint-patents out of more than 10,000 fuel cell related patents of the same company and provided the basis for my analysis as to what extent companies partnered with non-Japanese organizations. I have found a number of patents (see percentages in Figure 2 later in the text) with overseas members, which shows that Toyota could build up a more open network. These patents were also analyzed for keywords through text mining.

Finally, I relied on a dataset of 700 Japanese firms involved in establishing the nanotechnology R&D field (Figure 1). Nanotechnology alliance data was based on joint-patents collected from the Japanese Patent Office and were located through several nanotechnology keywords. Network data was computed from the relationships described in the joint-patents. Company-level data was gathered from company websites, annual reports, and other available data sources[(1)]. Network data was computed with UCINet (Borgatti, Everett & Freeman, 2002). The two datasets were matched to cover the same time periods (the period when the development took place). These were also complemented with magazine and

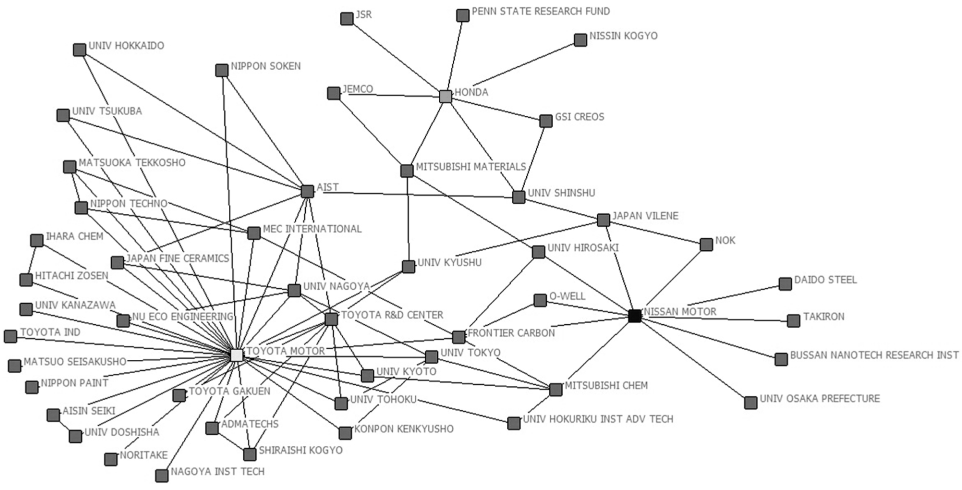

Figure 1 Toyota's central position in the Japanese nanotechnology network

trade journal articles on fuel cells and other case studies in academic journals and books.

Fuel cell development at Toyota and other carmakers

Next, I look at the technology under investigation. A fuel cell can be used to power vehicles from passenger cars to trucks. A fuel cell powers an electric motor, and in Toyota's case, it fits into Toyota's hybrid architecture. Compared to gasoline, hydrogen used in these cells is more considerate to the environment and, provided future development of necessary technologies, there is hope that hydrogen could be manufactured from a wide range of resources in the future.

The idea of a fuel cell was worked out in the nineteenth century, but in real commercial use, they only become common after the 1950s, albeit limitedly.

The first concept of fuel-cell-powered cars appeared in 1991. From the 1980s, Toyota, Honda, and Nissan started limited research into the technology. Toyota and Honda were among the first to sell fuel-cell-powered cars. Our study looks mainly at the development of the Toyota 'Mirai,' its first market model, but through the analysis of joint-patenting, we also followed research by Honda and Nissan. I briefly review these below.

According to the official homepage of Honda, the company started research in the 1980s. These efforts led to the development of the FCX-V1 and FCX-V2 concepts and incremental innovation to its fuel cell stack, making it lighter and usable in low temperatures (-20 degrees Celsius). The Canadian PEM fuel cell company Ballard has contributed to the success of Honda's fuel-cell cars. By 2008, the FCX Clarity was ready. Honda conducted joint research not only with Ballard but also with Stanford University. It is important to note that Toyota did not have alliances with these organizations, according to the data I have collected.

At the same time, Nissan also started working on fuel cell technology and started developing its FCEV technology in 1996. It has already tested its technology in cars in 1999 and created a new type of battery stack in 2011. Through its alliance with Renault, Nissan also started joint-research with Ford and Daimler A.G, companies that had a joint venture with Ballard.

Regarding Toyota's fuel cell research and development, I will describe the process in more detail. To gain more insight into the process, I have analyzed patents and keywords in abstracts filed by Toyota Motor Corp. In the following tables, I show how keywords changed as the development moved forward.

Toyota started developing fuel-cell cars in 1992. Its first concepts, the FCHV-1 and FCHV-2, were tested in 1996 and 1997. These were followed in 2001-2002 by the FCHV-3, FCHV-4, and FCHV-5 concept cars. By 2008, Toyota started working on the FCHV-adv to find solutions for specific problems such as operation in low temperatures. The company also developed buses, the Hino FCHV Bus, powered by fuel cells.

In the first phase, as shown in Table 1, focus was mainly on fuel cell technology. This shifted to a focus on integration into the overall architecture. In the following years, Toyota developed the FCHV3 and FCHV4 based on the Highlander design in the US (90kW with a range of 300 km). Road tests were conducted in Japan with the FCHV-4.

Table 1　Toyota's fuel cell development before 2000

Main technologies in patents (before the year 2000)	
燃料電池	Fuel cell
燃料電池システム	Fuel cell system
燃料電池発電装置	Fuel cell electricity generator system
燃料電池用セパレータ	Fuel cell separator
燃料改質装置	Fuel reformer
個体高分子型燃料電池	Solid polymer fuel cell
燃料電池用セパレータ及びその製造方法	Fuel cell separator and its production method
凹凸形状計測装置及び凹凸形状計測方法	Concave-convex checker device and measuring method
燃料電池を有する直流電池	DC power source with fuel cell
車両の制御装置	Vechicle control device
電源装置及び電気自動車	Power source and electric vechicles

Toyota needed to integrate fuel cells into the hybrid platform. This happened in the second phase, as described in Table 2. The aim was also to improve output and operation. In 2003, Toyota also tested the compact MOVE FCV-K-II.

Table 2　Toyota's fuel cell development between 2003 and 2004

Main technologies in patents (2003-2004)	
燃料電池及びその製造方法	Fuel cell and its production method
燃料電池システム	Fuel cell system
燃料電池スタック	Fuel cell stack
ハイブリッドシステム	Hybrid system
燃料電池の制御装置	Fuel cell control device
燃料電池用セパレータ	Fuel cell separator
チューブ型燃料電池用膜電極複合体	Membrane electrode composite for tube fuel cell
燃料電池搭載車両	Fuel cell-powered vechicles
移動体	Moving body
燃料電池構造	Fuel cell structure

In the next phase, Table 3, nanotechnology research has experienced a boom, and Toyota took a central place in the nanotechnology network, as seen in Figure 1. This is also the period when research projects with overseas universities first appear. Toyota funds research at Georgia Tech. Organizational influences are probably negligible, but successful patents follow.

Table 3　Toyota's fuel cell development between 2004 and 2005

Main Technologies in patents (2004-2005)	
燃料電池及びその製造方法	Fuel cell and its production method
燃料電池システム	Fuel cell system
燃料電池スタック	Fuel cell stack
燃料電池車両	Fuell cell-powered vechicle
燃料電池用ケース	Casing for fuel cell
移動体	Moving body
燃料電池モジュール	Fuel cell module
積層型ガス流路形成装置	Multilayer gas flow path forming device
異常判定装置	Error detection device
燃料電池用消音機	Silencer for fuel cell

In this period (2007-2008), development shifted to production methods and cost reduction. In this phase, much more emphasis was placed on the development of the car. Toyota was also struggling with overcoming narrow, specific problems with the technology. Engineers had to make fuel cells lightweight and relatively inexpensive. Cold-weather performance became important. Precious metals used for the catalyst needed to be reduced, and the proton-exchange membrane needed to be made less expensive. In this period, more overseas collaborations appear to address these difficult-to-solve issues. Evidence is found that these alliances are rather short-term and focus on these specific problems.

Table 4　Toyota's fuel cell development between 2007-2008

Main technologies in patents (2007-2008)	
燃料電池	Fuel cell
燃料電池の製造方法	Fuel cell production method
燃料電池スタック	Fuel stack
燃料電池システム及び移動体	Fuel system and moving bodies
車両	Vechicles
膜電極接合体の製造方法	Production method of membrane electrode assemblies
燃料電池用セパレーター	Fuel cell separator
燃料電池装置	Fuell cell device
燃料電池の洗浄方法	Fuel cell cleaning methods
気液分離器	Gas-liquid separator
燃料電池用触媒の製造方法	Method for producing fuel cell catalyst
燃料電池搭載車両	Fuel cell-powered vechicles

This is the last phase in my analysis, Mirai's actual development proceeded after this period, but much of the information concerning the final phases of the development was derived not from patents but trade journals and other available public information. Patent data from later periods was also used for the statistical test but were not included in the text analysis.

Describing the outside field

Fuel cell research outside Japan was mainly conducted in the United States and Canada, as well as Europe. One of the first fuel cells was assembled in Case Western Reserve University[(2)], and fuel cells were researched in several North American universities.

In North America, two leading companies in the 2000s focused on these technologies: UTC Power and Ballard Power Systems. Daimler AG and Ford had a joint venture with Ballard Power System, the Canadian developer for PEM fuel cells, the Automotive Fuel Cell Cooperation. The same company, Ballard, has collaborated with Honda in its development of fuel cell cars. However, Daimler abandoned fuel cells to focus on battery power, and Ballard acquired the Automotive Fuel Cell Corporation's assets[(3)]. UTC Power was probably the most experienced fuel cell company in the US before its acquisition by ClearEdge (now acquired by the South Korean Doosan Group). UTC developed fuel cells for NASA's Apollo program and the space shuttle.

Overall, it has to be noted that the fuel cell industry is not highly developed, relatively weak, and car companies could have much influence. This is a very different context compared to, for example, the life science industry in Fazekas (2015).

Is there openness in Toyota's fuel cell network?

The first question that needs to be answered before discussing influences is whether Toyota's fuel cell research network had any outside contacts. Figure 2 shows that 20% of Toyota's fuel cell-related patents investigated were filed by more than one company, a little less than 5% included a foreign collaboration partner. While this number is not very large, the percentage is relatively significant compared to the other large automakers in the analysis.

The patents clearly show a number of concrete collaborations. An early research project was with Georgia Tech. Toyota founded research on proton electrolyte membranes for fuel cells between 2003-2008[(4)]. These PEM fuel cells are used in the Mirai. From 2008, Toyota also partnered with UTC Power, and also in 2008, Toyota started collaborating with Ilika Technologies, a UK-based material research corporation. The company's stated first commercial customer was Asahi Kasei in 2004, so they had a strong relationship with Japanese companies from the start. Other outside collaborations include Case Western Reserve University, HZB (Helmholtz Zentrum Berlin), and Sandia National Laboratories.

However, the number of overseas research links is limited. Organizational influences are presumed to be small, but they might provide key boosts to innovational performance.

A quantitative statistical test will investigate whether these different types of partnerships

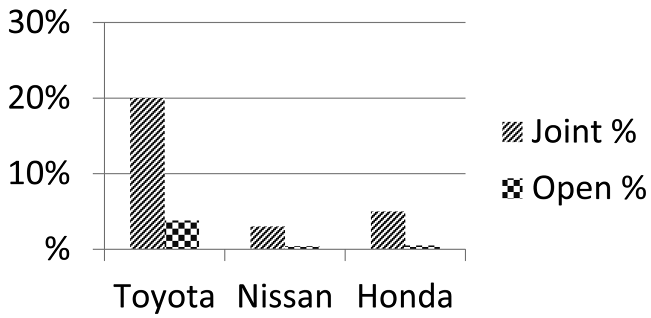

Figure 2 Number of joint patents and open relationships (non-Japanese partners)

were beneficial for innovation (partnerships within the Toyota network, partnerships with domestic, related industries, and partnerships with international organizations).

Quantitative test: which pathways lead to successful innovation?

Variables

Dependent Variable

The dependent variable is a binary variable taking the value of 1 if the given patent was granted and 0 otherwise. I was interested in the success of each innovation. Granted patents here are treated as successful innovational output, though the usual limitations of patent-style innovation studies apply.

Independent Variables

The variable testing hypothesis 1, 'Toyota group company as partner', is a binary variable taking the value of 1 if the partner is in the close-knit Toyota network. This variable is for testing whether partnering within the network is beneficial for successful innovation.

The variable testing hypothesis 2, 'Overseas organization as partner', is a binary variable taking the value of 1 if the partner is an overseas organization. This is to measure whether partnering with outside fields can bring essential benefits to Toyota and to see whether these firms had any major impact on the R&D side.

The variable testing hypothesis 3, 'Partner contained in the nanotech network', is a binary variable taking the value of 1 if the partner is contained in the nanotechnology network. This variable is then complemented with different network measures about the partner's place within the nanotechnology network. The software, UCINet (Borgatti, Freeman & Everett, 2002), was used to calculate different network values: a structural hole measure to see how much unique information the partner has access to, and eigenvector centrality to understand how prestigious the organizations are the partner is connected to. To these measures, a third variable was added to measure the partner's alliance portfolio diversity. This variable measured how many cross-industry (i.e. partners from different industries) alliances the partners had through the Herfindahl index.

Control Variables

A number of controls were added. Partners' average age (averaged if more than one) and size (measured by capital stock), a year dummy, and project complexity (measured by the number of categories the patent belonged to) were added as standard controls.

IV. Results

A simple logistic regression model tested whether there was a link between patent grants and partnering with organizations within the Toyota network (hypothesis 1). We did not find a positive relationship. In fact, a negative relationship was shown, indicating that many in-house innovations did not result in a granted patent.

The other hypotheses were concerned with partnering that went outside the traditional Toyota R&D network. We found some support for hypothesis 2, as seen in Table 5 & 6. Partnering with international organizations was significant on a marginal level, indicating that these partnerships ended in more granted patents. Toyota has sought out these relationships to find solutions for specific problems. Perhaps the specificity, clear goals, and the relatively dominant position of Toyota helped these partnerships overcome the liabilities of international cooperation and find successful solutions for its needs.

Hypothesis 3 was not supported. Partnering with firms that were simply part of the nanotechnology network did not seem to help much.

Network effects were also tested (hypothesis 4) with two models. One with the full sample of 1397 patents, including firms with no ties to the nanotechnology network, and then another with only 406 patents that included organizations in the nanotechnology network. In both models, our model remained significant, though only marginally. Partners that were central firms in the nanotechnology networks seemed to contribute to a successful outcome, but being simply in the nanotechnology network was not necessarily important, even showing an inverse link in model 2. This can probably be understood as a relative lack of importance of nanotechnology in the overall technology, even though nanotechnology was key to overcoming some specific problems. Overall, it seems that access to outside networks is important and beneficial in the R&D process. The size and influence of this access are limited, however.

Finally, control variables need to be interpreted. As the fuel cell industry is relatively young, partnering with younger firms led to somewhat better results. Size, however, was also marginally significant, making this claim a little bit more ambiguous. Project complexity was strongly significant. Interpreting this result is somewhat difficult, and only conjectures can be given. Perhaps more resources are used for complex patents, or these key technologies were perhaps pushed to have wider applications.

Nevertheless, from this and the fact that partnerships with overseas firms were beneficial, it is possible to conclude that Toyota did need to go outside of its network to find solutions

Table 5　Correlations between variables

	1	2	3	4	5	6	7	8	9	10	11	12
1 Grant dummy (dependent variable)	1											
2 Partners' average age	-0.0078	1										
3 Partners' average size	0.033	0.2801	1									
4 Overseas organization as partners	0.0129	0.0824	0.0471	1								
5 PRO or university as partner	-0.0279	0.444	0.2021	0.272	1							
6 Toyota group company as partner	-0.0953	-0.4059	0.0849	-0.2364	-0.3721	1						
7 Toyota motor croporation in the alliance	0.0079	-0.0334	0.0168	-0.3415	-0.1846	0.1766	1					
8 Technological complexity of the patent	0.1167	0.1017	0.0858	0.0571	0.1536	-0.1274	-0.0538	1				
9 Partners' alliance diversity in the nanotech network	0.0292	0.0672	0.6411	0.0179	-0.0547	0.101	0.0706	0.0005	1			
10 Partners' structural hole measure in the nanotech network (inverted constraint)	0.0042	0.1893	0.0793	-0.1172	0.0258	0.1442	0.1075	0.0281	-0.1637	1		
11 Partners' eigenvector centrality in the nanotech network	0.0447	0.0813	0.2465	-0.0022	0.2547	0.0135	0.0414	0.0058	0.2489	-0.0931	1	
12 Partner contained in the nanotechnology network (dummy)	-0.1151	-0.1208	-0.2923	-0.2194	0.0032	0.237	0.1782	-0.0991	-0.2309	0.3538	-0.0129	1

Table 6　Logistic regression analysis: dependent variable measures the number of granted patents, and the analysis looks at the variables that lead to successful grants.

	Model 1 Controls			**Model 2 Full sample**			**Model 3 Reduced sample**		
Partners' average age	-0.0062	+	(0.0032)	-0.0072	*	(0.0034)	-0.0105	**	(0.0040)
Partners' average size	0.0001	*	(0.0001)	0.0001		(0.0001)	0.0000		(0.0000)
Year dummy	あり			あり			あり		
Overseas organization as partner	1.7359	*	(0.8893)	1.627	+	(0.9105)	1.8817	+	(1.0493)
PRO or university as partner	-0.4081		(0.3121)	-0.5075		(0.3569)	-0.4399		(0.3934)
Toyota group company as partner	-0.665	***	(0.1549)	-0.6713	***	(0.1657)			
Toyota motor corporation in the alliance	0.2268		(0.5051)	0.2623		(0.5103)	0.1899		(0.5504)
Technological complexity of the patent	0.246	***	(0.0713)	0.2423	***	(0.0714)	0.1365		(0.1188)
Partners' alliance diversity in the nanotech network				-0.0036		(0.1848)	0.0695		(0.2512)
Partners' structural hole measure in the nanotech network (inverted constraint)				0.2061		(0.1343)	-0.4608		(0.4182)
Partners' eigenvector centrality in the nanotech network				0.4978	**	(0.2013)	0.6333	**	(0.2526)
Partner contained in the nanotechnology network (dummy)				-0.2633	+	(0.1531)	0.3725		(0.4040)
Constant	-2.4656	***	(0.7055)	-2.2889	***	(0.7124)	-3.0331	**	(1.2249)
N	1397			1397			406		
Log likelihood	-881.4727			-876.0808***			-245.1155***		

Notes)　+ p<0.1; * p<0.05; ** p<0.01; *** p<0.001; standard errors in parentheses. Unit is the joint pantent. Values in patents with more than two participants were averaged.

to some of its specific problems and that its closed, domestic network was not enough to overcome these problems within a set timeframe. Open innovation seemed to be essential for successful innovation, but the careful management of this innovation process is pivotal. It is not enough to seek outside links. Multiple pathways to innovation have to be coordinated and carefully managed.

V. Conclusion

Innovation occurs in networks. While ideas often stem from individuals, developing these ideas into concrete technologies is a joint effort. Minor improvements and further radical solutions are gathered together from the network the company is connected to.

This is evident from the present case. Toyota benefits from the multiple networks it is connected to. Not only its traditional supplier network, its core corporate network, its overseas networks, but also its other domestic R&D alliances were vital for the development of the fuel cell car.

Toyota manages multiple pathways to innovation in a complex fashion. Toyota mixes long-term relationships with short-term partnerships to address its problems faced along the innovation process. Its alliances with overseas universities helped it find radical solutions, while its central position in the domestic nanotechnology industry helped it leverage emerging technologies and gain knowledge in fields it lacked. The paper found evidence that these relationships are also beneficial and result in granted patents.

However, as we have seen, just partnering with firms in the nanotechnology network by itself is not enough. It is likely that some network positions are costly to maintain. A central position in the nanotechnology network seems to require some effort that does not pay in innovational terms. This cost can be assumed as a kind of field-building cost. Alliances can help build internal capabilities or contribute to a better position in the overall field. Alliances can give power to the central firm and can provide it with unique sources of information.

Once the central position is established, the organization is better positioned to leverage access to other highly central, prestigious firms. Therefore, not establishing itself as a central organization can lead to lost opportunities and subpar performance. Some cost is necessary to build the right kind of field, and it cannot be expected that every effort should pay off in the form of successful innovation or granted patents.

This study clearly shows that open innovation is a long-term strategy, and there is no one correct way of leveraging the benefits. Toyota has built a multi-layered innovation strategy – one where a number of distinct strategies are combined to deliver innovative products, such as the Mirai.

Notes

(1) Japanese Patent Office, Hitachi High-Technologies Corporation's corporate information database NEXT Yuho Kakumei (now acquired by another company) and Edinet (Electronic Disclosure for Inverstors' Network). More information on the nanotechnology data is available in Fazekas, B. (2021). Inter-organizational Network Effects across Organizational Field Boundaries. Kyoto University, Graduate School of Economics, Doctoral Dissertation.

(2) Case Western Reserve University homepage, technology portfolio, fuel cells. Retrieved 19 Sep 2019 at https://energy.case.edu/research/storage-conversion/fuel-cells

(3) Klippenstein, Matthew (2017). "Is Toyota's hydrogen fuel-cell fervor foolish, or foresighted? (with charts)". Retrieved 19 Sep 2019 at https://www.greencarreports.com/news/1109836_is-toyotas-hydrogen-fuel-cell-fervor-foolish-or-foresighted-with-charts

(4) Meijin Liu personal homepage at Georgia Tech, listing research projects. Retrieved 19 Sep 2019 at http://www.prism.gatech.edu/~ml44/rp.htm

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