The Partnership Network Structure of Automakers under Radical Technological Change

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Abstract

Background: Traditionally, dense network structures have dominated partnerships in the automotive industry. On the other hand, previous research in other industries has shown that network structures suitable for radical innovation include weak ties, structural holes and betweenness centrality. **Objective:** The purpose of this research is to empirically analyse the effect of the ongoing and radical change in the business environment within the automotive industry, referred to as CASE (connected, autonomous/automated, shared, and electric), on the network structure of the partnerships of automobile manufacturers. **Methods/Approach:** The methodology of this study is based on the use of real data on partnerships of car manufacturers around the world, analysed using social network analysis methods. **Results/Findings:** The analysis confirms that there is a significant correlation between the degree of the CASE approach, the number of weak ties and the size of structural holes. In addition, several cases showed significant differences in the network structure between new technology ventures and existing legacy technology firms. The findings highlight the insight that the network structure of the automotive industry is likely to change significantly in the future due to technological innovation.

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Introduction

The aim of this study is to empirically analyse the impact of rapid technological change on the network structure of corporate partnerships. The network structure involved in corporate partnerships depends on the industrial characteristics and product structure to which the firm belongs. Technological changes affect the industrial characteristics and product structure, such as the composition of components, and the optimal partnership changes. In this study, we focus on the automotive industry, which is currently facing a dramatic technological change called CASE (Connected, Autonomous, Shared & Services, and Electric) (Houdek et al., 2017). The term CASE was originally coined by Daimler AG, but is now widely used in the automotive industry.

In the traditional automotive industry, a network structure of closed and strong partnerships with specific groups of companies has been chosen. When consumers choose a car, the customer value of that car is heavily influenced by characteristics such as concept and brand value, which naturally vary from car to car. A single car is made up of tens of thousands of parts and materials. In order to realise a car's concept and design, it is important to coordinate the many components and materials in an integrated way.

For this reason, each car manufacturer works closely with specific component and material manufacturers in the development, design and production of its products. Each car manufacturer needs to exchange important intellectual property, development and design information in a flexible manner, while preventing it from being passed on to non-partners. To this end, they have strengthened their human and capital relationships with a limited number of unique partners and have formed strong partnerships over time. The result is a closed and cohesive ecosystem in the automotive industry, vertically integrated around the car manufacturers.

On the other hand, in the IT industry, for example, a relatively open and ad hoc network structure of weak partnerships has been chosen. Interface specifications for computers and the Internet have been standardised, many of them are available free of charge, and components are increasingly modular. This has allowed a wide range of players to enter the market and has given rise to countless ventures specialising in particular technologies. Furthermore, it is easy to improve the performance of products, add new functions and reduce costs, making them rapidly more cost-effective for customers. In addition, so-called platform leaders have emerged, specialising in a limited number of technologies, expanding their alliances with various companies and dominating certain business areas. in the IT industry, platformers have taken the lead in forming an open, horizontally linked ecosystem.

However, the development of CASE, the subject of this research paper, is causing a radical change in the traditional automotive product and industry structure, and may foreshadow that the product structure of the automobile will resemble that of IT products. For example, "connected" means that the car will be transformed into an information and communication device." Autonomous driving" means that the core technology of the car will be IT, and the traditional value of "enjoying driving" will be lost. If all cars become like buses and taxis through "sharing", the customer value of owning a car, such as the appearance, design and status of a luxury car, will become meaningless. Car sharing will drastically reduce the total number of cars sold and their value will shift from hardware to services. In addition, the adoption of "electric vehicles" will simplify the structure of the car, significantly reducing the number of components, eliminating the need for integration and coordination between components, and significantly reducing the number of component manufacturers. Existing car manufacturers and component suppliers are changing their strategies in order to survive. Many are trying to adapt to new technologies and services and to build new industry rules around themselves. Others are refining their existing technologies to differentiate themselves and survive. A number of emerging car manufacturers are also trying to gain dominance by adopting new business models.

The aim of this study is to analyse how the network structure of car manufacturers' partnerships is changing as a result of the current CASE development. As data for the analysis, real data on the partnerships of car manufacturers will be collected and a database for the analysis will be constructed. As a method of analysis, the aforementioned method of social network analysis will be used to analyse the characteristics of the network structure of each car manufacturer and its relationship with the degree of commitment to CASE based on the constructed database.

As the structure of this paper, the research question is firstly presented based on the previous studies in the automotive industry. Next, I present the research design, including analytical and data acquisition methods and the research hypotheses. After that, the research results are presented, and the research hypotheses are verified.

Research question

The research question in this study is whether the development of CASE in the automotive industry will change the inter-organizational relationship from the traditional closed vertical integration type to the open horizontal specialized type like the IT industry. In this section, previous studies on this research question are reviewed.

Relationships between organizations in the automotive industry

The relationships between completed vehicle manufacturers and parts and material manufacturers in the traditional automotive industry have traditionally been closed and cohesive. The Keiretsu system in Japanese companies is typical of this, with vertically integrated organisational relationships with the complete car manufacturer at the top of the pyramid.

There has been a great deal of debate in previous studies as to whether these traditional inter-organisational relationships will change with the development of CASE. In Japan, the automobile industry is a valuable industry with international competitiveness, the industry base is wide, and much employment depends on the automobile industry at large. Consequently, the automotive industry is particularly noteworthy in Japan. For Japanese car manufacturers, inter-organisational relationships, such as those represented by keiretsu, have been recognised as an important source of competitive advantage. Discussions on possible changes in inter-organizational relationships have been active within academic societies for many years.

For example, Murasawa (2010) positions electric vehicles as a modular development and argues that the advantage of car manufacturers is declining. Electric vehicles can be recognised as a product developed and produced by combining electric motors and on-board batteries produced by several component manufacturers. This makes it possible for small companies, such as a neighbourhood car repair shop or an electrical shop, to develop, produce and sell electric vehicles by combining interchangeable components. In the long run, vehicle manufacturers who previously had a large share in the vehicle market may decline.

On the other hand, Saeki (2011) states that the product architecture of a fully electric vehicle has characteristics of an integral type. Saeki argues that electric vehicles are products that require a combination of interchangeable components and complex software-based electronic control, and that software development requires complex coordination. Even electric vehicles require a high degree of coordination, including software development, between car manufacturers and suppliers. For this reason, it is expected that the completed car manufacturers will continue to retain their current competitiveness and that the completed car manufacturers will reign at the top of the electric vehicle market.

Horizontal specialized inter-organizational relationships

In the IT industry, the core of the horizontal specialized inter-organizational relationship is, as mentioned above, the platform leader. One of the most prominent early studies of platformers was Platformer Leadership by Gawer et al. (2002) and subsequent works analysing Intel's strategy for PCs. In this context, a platform is a product or service that serves as the basis for several complementary companies to make products or provide services. The individual components and software that make up a computer are discrete modules interconnected by an Operating System (OS) or Central Processing Unit (CPU). In such a case, the OS or CPU is the platform. The platform leader acts as an intermediary, bringing together disparate groups of companies to form a unified product or service and promote innovation. Iansiti et al. (2017) foresee a shift in the industry structure of connected cars, with Google and Apple as platformers and automakers as complements.

With regard to the relationship between platforms and innovation, Gawer et al. (2013) define an external platform or industry platform as a product, service or technology developed by one or more firms, on which more firms can build further complementary It is defined as acting as a platform on which more companies can build further complementary innovations in the form of specific products, related services or elemental technologies. Industrial platforms tend to promote and increase innovation in complementary products and services. The more such complementary innovations there are, the greater the value created for the platform and its users through network effects, creating a cumulative advantage for the platform. The increase in complementary innovations makes it easier for rivals and new entrants to be excluded and acts as a barrier to entry. For complementors, for example, as in the case of an independent software vendor partnering with SAP (Ceccagnoli et al., 2012) or a developer producing video games for a specific console (Cennamo, 2016), connecting to a platform can lead to complementary innovations, but also gain access to the platform's customers, either directly or indirectly.

Gawer et al. (2008) highlight the complex trade-off between 'open' and 'closed' innovation, pointing out that while opening up the interface increases the incentives for complementors to innovate, it is important to keep the sources of revenue and profit somewhat proprietary.

Vertically integrated inter-organizational relationships

On the other hand, a number of previous studies have explained the usefulness of integrated inter-organisational relationships, especially when industrial structures are changing in an innovative way.

Chesbrough et al. (2001) discuss a cyclical change model of the dominant product architecture in an industry. According to them, integral architectures are mainly used in the early stages of an industry. At that stage, an integral organisational strategy is crucial because of the relative complexity of problem solving for innovation. Individual modules functioning as semi-autonomous subsystems can flexibly respond to technological changes absorbed within the module. However, in the early stages of an industry, the interface rules between modules are themselves ambiguous and subject to change. Companies that adopt a modular organisational structure are more likely to be unable to lead or follow innovative technological change because of the lack of breadth of knowledge beyond the modules.

Wessel et al. (2016), citing Christensen's work, provide a case study of electric vehicles and point out that it is important to increase the Interdependence of ecosystems for innovative technological evolution. When major innovations are introduced, it is common to restructure the extended value chain. This is not only because business models are in flux, but also because innovative product designs are often yet to be created. In the early days of a new product, the inventor does not understand how to optimise the different components of the innovation relative to each other. For example, the first car manufacturers needed to tightly control research, design and manufacturing, so that changes to one part of a car often meant changes to the whole car. This is why product development requires a network of interdependent partners. The more dramatic the innovation, the more interdependence may be needed. As the transition to autonomous and electric vehicles continues, a level of interdependence close to vertical integration will again be required. Tesla's cars maintain the most interdependent architecture on the market. It controls every component of the car: the hardware, the software that manages the complex electrical system, and the algorithms and sensors that enable the automated driving functions. This tight control goes even further. Tesla also has its own sales channels, service network and charging network. This integrated model enables the company to meet all the challenges involved in producing electric vehicles capable of autonomous driving and long distances, as well as batteries for fast charging.

Research methods and hypotheses

Research framework

Next, based on the research above question, the research framework of this study on inter-organizational relations is as follows.

The research question addresses the impact of each automotive company's CASE initiatives on inter-organizational relations. However, it isn't easy to quantify how individual automotive firms are engaged in CASE externally. Therefore, I decided to use the externally measurable data as a proxy variable and analyze the relationship between the externally measurable data. In this study, I use the partner information of each firm as the data to be analyzed, which will be described in detail later. As automotive companies engage in CASE, the types of partners they associate with will change. Due to the nature of the industry, CASE is closely related to the IT industry, the information and communications industry, and the electronics industry. In addition, the proportion of software and service businesses will increase compared to hardware businesses. In the case of conventional automobile manufacturers, many of their partners were also manufacturers of automobile parts such as engines and bodies.
On the other hand, as automotive companies move forward with their CASE initiatives, the number of partners, such as IT companies, is expected to increase. As the number of partnerships with companies in the IT industry increases, the network structure of partnerships is also expected to change. Whether the network structure of the partnership is closed and vertically integrated, which has been the mainstream in the automotive industry, or open, horizontally specialized, and platform-type network structure, which is similar to the IT industry. Therefore, the framework of this study is to investigate the relationship between the type of business domain of the partnership firms and the network structure of the partnership for each firm that can be measured externally.

Social Network Theory

In this study, I adopted the social network analysis method to analyze the network structure of the partnership. Before deriving the research hypothesis on the network structure, I first review the social network theory, which is the theoretical basis of the social network analysis.

Social network theory applies various theories about the properties of complex networks in the natural sciences (e.g. small-world, scale-free, cluster properties) to social relationships. By considering people and organisations as nodes and analysing the structure of the networks in which they are connected to other nodes, it is possible to identify how the relationships embedded between people and organisations affect people's thinking and behaviour. Using the methods of social network theory, it is possible to calculate various quantitative indicators to assess the network structure.

One of the leading studies in social network analysis is Granovetter's (1973) "The Strength of Weak Ties", which has been followed by a series of studies. Granovetter (1973) argued that weak ties are most valuable for the diffusion of information across the network. According to Granovetter (2005), there are generally three types of interpersonal ties: strong, weak and no ties. Weak social ties are argued to be responsible for the degree of social embeddedness and structure of the social network, and for the majority of information transfer through the network. Specifically, more new information flows to individuals through weak ties than through strong ties. Since close friends often act in the same circles, the information they receive overlaps considerably with that which is already known to them. Acquaintances, on the other hand, know people in other circles and therefore receive more new information.

y a feature of the sociocentric network. It is an effect that can occur due to the high number of weak ties in the overall social network.

An egocentric network, on the other hand, is a network structure centred on one ego. Organisations are connected by a wide network structure, but each is connected to the surrounding organisation in a different way. The main interest of egocentric network research is the difference in organisational performance due to the network structure around the organisation. The subject of this study is egocentric networks in individual organisations. In the study of ego-centric network structure, we focus on triadic closure, i.e. whether the ego nodes are also connected to the nodes they are directly connected to. If those connected to the actor (ego) are not directly connected to each other, then there is a structural hole between them (Burt, 1992). On the other hand, if two people connected to the actor (ego) are also connected to themselves, then the triad is described as closed. The high density of the ego's network indicates the degree to which the ego's network triad is closed (Phelps et al., 2012).

Burt (2004) classifies ties into Bridging Ties and Cohesive Ties and states that Bridging Ties, which can be widely deployed even with weak connections, effectively search for information. Bridging Ties are defined as ties that connect separated individuals and groups. Its structural features include many bridge ties and a wide range of connectivity; these can be analyzed by indexes such as the number of intervening ties and structural holes. Bridging Ties' strength lies in the widespread dissemination of new, formal, and heterogeneous knowledge, and it is easily linked to radical innovation.

Among the indicators of network structure, centrality is one of the most commonly used indicators in network analysis. It is an indicator of the degree to which each node in the network is in a central position. There are various ways of thinking about what constitutes a central position, and various centrality indices have been proposed (e.g., Bonacich, 2007; Freeman et al., 1979). For example, there is degree centrality, a centrality index that defines the degree of a node as its centrality. Here, the degree is the number of ties connected to the node. In other words, the more ties a node has with other nodes, the more central a position it is considered to have. In ego networks, the size of the ego network is of equal value. Betweenness centrality is a centrality index based on how a node mediates the relationship between other nodes. It is defined as the proportion of the node's presence on a line connecting pairs of other points. The more a node mediates the relationship between other nodes, the more central it is. A node with high betweenness centrality is considered to be able to control the relationships and information between other nodes.

The following are some recent and relatively highly cited papers that analyze the automobile industry using the method of social network analysis, taking into account the recent rapid technological changes known as CASE. Li et al. (2019) provide technology forecasts for the automotive industry based on network analysis of patent data. Rashidi et al. (2020) provide a multifaceted analysis of the future impact of connected and autonomous vehicles based on a network analysis of bibliographic data. Castro et al. (2020) discuss the automotive industry's energy efficiency based on the paper's network analysis and co-authorship. All of the above are very interesting studies, but their themes and data are different from this study. Other qualitative studies existed, but this study's quantitative empirical studies are considered rare.

Research hypotheses

Next, based on the research mentioned earlier, the research hypotheses were derived as follows. The hypothesis is about the relationship between the change in the type of partnership and the change in the network structure of the partnership. The network structure characteristics were identified based on the theory mentioned earlier of social networks. This enabled us to analyze the network structure using the method of social network analysis and quantify its characteristics as network indicators.

The first simple hypothesis is that the number of partners that the firm associates with will increase as it moves from closed, integrated inter-organizational relationships to open, specialized inter-organizational relationships. As CASE develops, car manufacturers will need to tackle a range of new technological elements that they have not previously covered. For example, even if we consider only electric vehicles, it is necessary to develop various technologies related to the vehicle itself, such as batteries and motors, and to solve infrastructure issues such as charging facilities. Autonomous driving involves a huge number of issues, including the accumulation and analysis of big data, the development of road networks for location information, and the development of communication technology between vehicles. To this end, it is necessary to develop beyond the field of conventional automobile development, such as information and communication technology and artificial intelligence. Issues such as sharing and communication are also driving a change in the automotive revenue model. For car manufacturers, it is not a question of increasing car profit margins and sales volumes, but of transforming into new revenue models, including services and solutions related to mobility. This requires developers to work with a variety of companies, including railway companies and real estate companies, and to target the whole transport system and the whole city. As described previously, with the adoption of CASE, the issues needing to be addressed by automobile manufacturers and the automobile industry will be very broad, and it is expected that the partnership will be broadened.

With the shift to CASE, the issues covered by car manufacturers and the automotive industry are expected to become much broader, and the technical uncertainties will increase. According to the discussion on dynamic capabilities by Teece et al. (1997) and others, strategic decision-making capabilities become important when changes in the technological environment occur. When the technology is immature and uncertain, extending the scope of the partnership allows multiple technologies, both internal and external, to compete and to choose the better of the two. By working with a range of partners, it is also possible to penetrate their own technical specifications and aim for future standardisation.

Hypothesis 1: The higher the share of CASE-related partners in the total partnerships, the wider the network of partnerships of the automakers.

In addition to the breadth of this network, the diversity of partners is also important in terms of innovation. Innovation is necessary in order to work on unconventional technologies and new businesses. In particular, in order to achieve radical innovation, it is useful to meet with different kinds of knowledge as far as possible from the company's own knowledge domain. Therefore, it is likely that the structural hole effectively promotes innovation. The larger the structural hole, the more opportunities there are for new combinations of knowledge, and the more innovation is promoted.

Hypothesis 2: The higher the share of CASE-related partnerships in total partnerships, the larger the structural hole in the automakers' partnerships.

On the other hand, as an alternative between Hypothesis 1 and Hypothesis 2, the partner's size may not necessarily promote innovation. As for the relationship between a sparse network and superior performance, which are claimed by the theory of structural holes, previous research argues that strong cooperation is important to achieve excellent results (Gargiulo et al., 2009). This is because if the provision cost of the information provider is high, it is difficult to access the information unless the relationship between the actors is strong.

According to a series of research findings on exploration and exploitation starting with March (1991) in the study of organisational learning, if companies become too active in external collaboration, their R&D capacity may decline. A series of studies on absorptive capacity, following Cohen et al. (1990) in their study of organisational capacity, suggests that if a company's own R&D capacity is reduced, its ability to understand and use external knowledge may also ultimately be reduced. In addition, even if the partners are diverse, the probability of success tends to be lower when partnering with a partner whose R&D differs significantly from that of the company (Lane et al., 1998).

Considering CASE, for example, the structure of electric vehicles is much simpler than that of gasoline-powered vehicles, so it is conceivable that a single finished vehicle manufacturer could reduce the number of component manufacturers it deals with. In addition, as mentioned in the previous section, it is assumed that a large number of management resources will be required if one company tries to develop a wide variety of issues. Therefore, no company is likely to attempt to carry out comprehensive and integrated business activities on its own. In other words, while innovation is advancing in the mobility ecosystem as a whole, car manufacturers may be concentrating their development resources on a limited part of the ecosystem.

Hypothesis 3: The share of CASE-related partnerships in total partnerships is not related to the size of the network of partnerships of the car manufacturers, nor the size of the structural holes.

If inter-organizational relationships are moving from vertically integrated to horizontally specialized, there is a further question of whether they are becoming platform-based. This is closely related to the relationships between components or services that make up the product/value chain. By modularising computers and IT products, the division of labor can be facilitated, and individual companies can efficiently conduct R&D by concentrating management resources within their business areas. Suppose new entrants to the market are promoted. In that case, many companies will innovate in a productive and perishable manner, creating new and diverse products and services and increasing cost performance through competition. These are innovations by the ecosystem (Iansiti et al., 2004). If, as CASE progresses, the number of business areas for automakers and related companies to consider expands significantly compared to the existing automotive industry, it may be difficult for a single company to undertake comprehensive innovation. Rather, it may be advantageous for each company to share innovation autonomously.

In such a horizontally specialised industrial structure, the core company in the ecosystem is the platformer or platform leader (Gawer et al., 2002). Based on their own products and technology standards, platform leaders seek to expand the overall ecosystem by collaborating with firms that offer complementary products and services. Platform leaders therefore try to increase the number of complementary companies as much as possible by appropriately separating their own and their partners' business areas and by working together with them. Thus, making their products and technologies dominant in their industry is an important growth strategy for platform leaders. For example, platform leaders in the IT industry are building new partnerships with thousands of companies and expanding horizontally across existing business lines and industry boundaries. with the development of CASE, the automotive industry could also be reshaped, with companies aiming to become platform leaders.

Such platform leadership is considered a good fit for betweenness centrality among the measures of network structure characteristics. The measure of betweenness centrality allows us to measure how other firms are connected through the firm. If a car manufacturer has a platform leader position in the network of partnerships, the value of the betweenness centrality indicator will be higher.

Hypothesis 4: The higher the proportion of CASE-related partners in the total partnership, the higher the betweenness centrality in the network of automakers' partnerships.

On the other hand, as an alternative to hypothesis 4, even if CASE progresses, the industrial structure may not be modularised and the inter-organisational relationships may not become platform-based. This could be due, for example, to causes related to the stages of the product lifecycle, or to industry-specific characteristics. Technological developments related to CASE are still ongoing, and many products will be put to practical use in the future. In addition, the scope of technological development is not limited to automotive products. Nevertheless, they cover a wide range of fields, including transport infrastructure, residential and commercial facilities in towns and cities, and energy issues. These interact with each other and are likely to require complex coordination. In the initial stages of technological development on such a large scale, it would be appropriate to develop the technology in an integrated manner, working closely with specific companies, rather than through an autonomous division of labour. Later, as the overall composition and the interrelationships of the components become clearer, the phase may shift to one in which standardisation and division of labour are promoted.

It also needs to consider the unique characteristics of the automotive industry. Today's passenger cars are integrated products because they are designed with numerous components coordinated to optimize individual consumers' diverse and ambiguous quality requirements. As CASE progresses, the complexity and individuality of the car itself may decrease. Still, the car will respond to each city's complex and individual demands as part of all means of transportation in the city right. Transportation issues differed from region to region, such as congested urban areas and depopulated rural areas, advanced and aging countries, and countries with immature infrastructure. Suppose individual and optimal solutions are needed to solve each regional issue. In that case, it may be desirable in the future for the industry to be integrated and for companies to cooperate and coordinate closely.

This inter-organizational partnership situation is considered a characteristic of a network structure with high density. The high density of the network means that all the nodes that make up the ego network are interconnected. The inter-organizational network was dense in the conventional automobile industry because of the close interconnection among a limited group of companies. If integrated inter-organizational relationships are maintained, the density of the network structure of partnerships is likely to remain high even with the development of CASE.

Hypothesis 5: The ratio of CASE-related partners to total partnerships is not related to the density of automakers' partnership networks.

Data

As mentioned earlier, the analysis in this study is based on data on partnerships of car manufacturers. The data on partners comes from FactSet's Supply Chain Relationships database, which collects information on the suppliers and partners of companies around the world, based on public information such as company press releases and information from surveys conducted by FactSet. FactSet Supply Chain Relationships is an additional service of Nikkei Telecom. The data in FactSet Supply Chain Relationships is categorised into suppliers, customers and partners. The data on partners in this study were obtained from the partners.

As candidates for the companies to be extracted, we consulted the industrial yearbooks published by Fourin (2019a, b), a research company specialising in the automotive industry, to compile a list of global car manufacturers. We then searched the FactSet Supply Chain Relationships database to obtain data on all companies included. The total number of companies we were able to obtain was 106 car manufacturers and 901 partners in total.

From the FactSet Supply Chain Relationships database, we obtained the names of car manufacturers and partners, as well as information on partnership type and industry category. The industry category was used to measure how automakers collaborate with their partners on CASE. We then calculated the percentage of CASE-related partners in each automaker's total partnerships. This value will henceforth be referred to as the "CASE ratio".

Network indicators

Network indicators were selected according to each hypothesis, as described below. We then statistically analysed the relationship between the proportion of CASE-related partners in the total number of partners of each automaker. In addition to the statistical analysis of overall trends, case study analysis was carried out for companies with particularly large and small CASE ratios.

The network indicators used to test each hypothesis are as follows. In hypothesis 1, the size of the network is based on the size of the ego network of each car manufacturer. The size is the number of actors (alters) to which the ego is directly connected.

Constraint was used for the structural holes in Hypothesis 2. Constraint is Burt's index (Burt, 1992). It is a measure of the degree of Constraint in a network; the smaller the value of Constraint, the larger the structural hole, indicating that firms are effectively coordinating with various firms. The Constraint of node I to node j is calculated as a weighted sum of the number of paths that directly or indirectly connect the two nodes i and j in the network. The weight is calculated as the ratio of the strength of node i's connection to each node until it reaches j to the strength of node i's connection to the whole network. One of the nodes is fixed, and the Constraint between it and all other nodes is added together to obtain the Constraint per node. Regarding Burt (1992), this indicator is used as a measure of the structural hole because of the social and economic costs of creating and maintaining strong connections between nodes and the interpretation that the more paths there are to reach other nodes. The more connected these paths are, the less freedom to act.

Hypothesis 3 corresponds to the null hypothesis of Hypotheses 1 and 2.

In the platform of hypothesis 4, we used broker and ego betweenness. These are measures of the brokering of a node, indicating the percentage of connections it brokers between other nodes in the network. Broker provides the number of times and services on the shortest path between two alter egos (i.e. the number of pairs of alter egos that are not directly connected). The nBroker is a normalised measure, a function independent of the size of the ego network. EgoBetweenness is the sum of the proportion of times the ego is on the shortest path between each part of the alternatives. The contribution of an ego to the alter connected via one or more other egos is 1/k, where k is the number of nodes connecting that pair of alters. nEgoBetweenness is Ego Betweenness normalized by the number of nodes in the ego network.

For Hypothesis 5, density was used. Density is the number of connections between nodes in the ego network divided by the maximum number of possible connections between all the nodes in the ego network. (Wasserman et al., 1994).

The network analysis is based on UCInet ver. 6.6. Borgatti et al. (2002) was referred to the calculation method.

Result of analysis

Data

The number of companies available from FactSet Supply Chain Data, mentioned above, was 106 for car manufacturers and 901 for partners in total.

The main types of partnership were Research Collaboration, Manufacturing collaboration, Joint Venture, In-licensing, Out-licensing, equity Investment, and investors. There was also at least one company in the distribution, marketing, and integrated product offering categorizations.

As it is difficult to categorise each partnership strictly as CASE or not, the ratio of partners in the following industry categories to all partners was used in this study as a proxy variable for the degree of cooperation with partners on CASE. The industry categories are Packaged Software, Electrical Products, Internet Software/Services, Telecommunications Equipment, Electric Utilities, Broadcasting, Information Technology Services, Semiconductors, Electronics/Appliances, Electronic Equipment/Instruments, Electronic Production Equipment, Major Telecommunications, Electronic Components, Internet Retail, Alternative Power Generation, Wireless Telecommunications, Computer Processing Hardware, Data Processing Services, Computer Communications, Electronics Distributors, Specialty Telecommunications, Cable/Satellite TV, and Computer Peripherals.

As a basic statistic, the average CASE ratio for each car manufacturer was 0.18 with a standard deviation of 0.21. For example, a CASE ratio of 0.18 means that 18% of the total number of partner companies belong to the above-mentioned industries. Car manufacturers are working on their own CASE initiatives and many electrical components are already in use. However, if the CASE ratio is low, it can be assumed that automakers are not doing much joint research with partner companies on electrical components, etc., and are simply using them as purchased items.

Network analysis

Next, I calculated the network indicators for the extracted partnership data of each car manufacturer.

First, as a preliminary preparation for calculating the network index, I reconstructed the original database into a combination of two companies each. For example, if company A's partners are company B and company C, I extracted two combinations, company A and company B, and company A and company C. Next, the names of the firms were collated. The unit of analysis in this study is the firm, and the firm name appears many times in the database as a partner of another firm. The same firm name was sometimes spelled differently in the FactSet Supply Chain Relationships database. Therefore, I checked the original data one by one and corrected the names of the same firms to be the same.

The data on the firms' partnerships were then replaced by an adjacency matrix and entered into the UCINet software. As mentioned earlier, each of the network indices was calculated for the Ego network by UCINet. For the betweenness centrality, I used nBroker and nBetweeness to use the normalized values. This is because the original Broker or Betweenness is affected by the size of the ego-network, since the larger the size of the ego-network, the more paths are simply mediated by the nodes under analysis. By normalizing, the degree of betweenness centrality can be compared with other nodes without being affected by size.

Regression analysis

A regression analysis was conducted for each automaker using the percentage of partnerships related to CASE as the objective variable and each network indicator as the explanatory variable. Before the regression analysis, I calculated multi-collinearity indicators such as the variance inflation factor for each network indicator.

As a result, various possibilities of multi-collinearity were suspected. Therefore, a single regression analysis was conducted for each network indicator. The regression coefficients and the significance probabilities of the results of the single regression analysis with each network indicator as an independent variable are shown in Table 1.

Table 1
Results of Regression Analysis of Network Indicators and CASE Ratio

Network index	Regression coefficient	p-value
Size	0.348*	0.038
Constraint	-0.390*	0.019
nBroker	0.241	0.157
nEgoBetween	0.075	0.666
Density	-0.241	0.157

Note: *: 5% significance level
Source: Authors' work

As shown in Table 1, the size of the ego network and the size of the structural hole were significantly related to the proportion of partners associated with the CASE. Note that the magnitude of the Constraint represents the smallness of the structural hole. Since the regression coefficient is negative, the higher the proportion of partners associated with CASE, the larger the structural hole.

On the other hand, betweenness centrality and density were not related to the proportion of partners associated with the CASE.

Case analysis results

Out of all the car manufacturers, two companies with high and two companies with low CASE ratio were selected and the network index of each company was extracted. As a result, NIO and BYD, both Chinese automakers, were identified as automakers with high CASE ratios. On the other hand, Daihatsu and Subaru in Japan were identified as automakers with low CASE ratios. Each network indicator has been standardised (mean value subtracted and divided by standard deviation) for ease of comparison (Table 2).

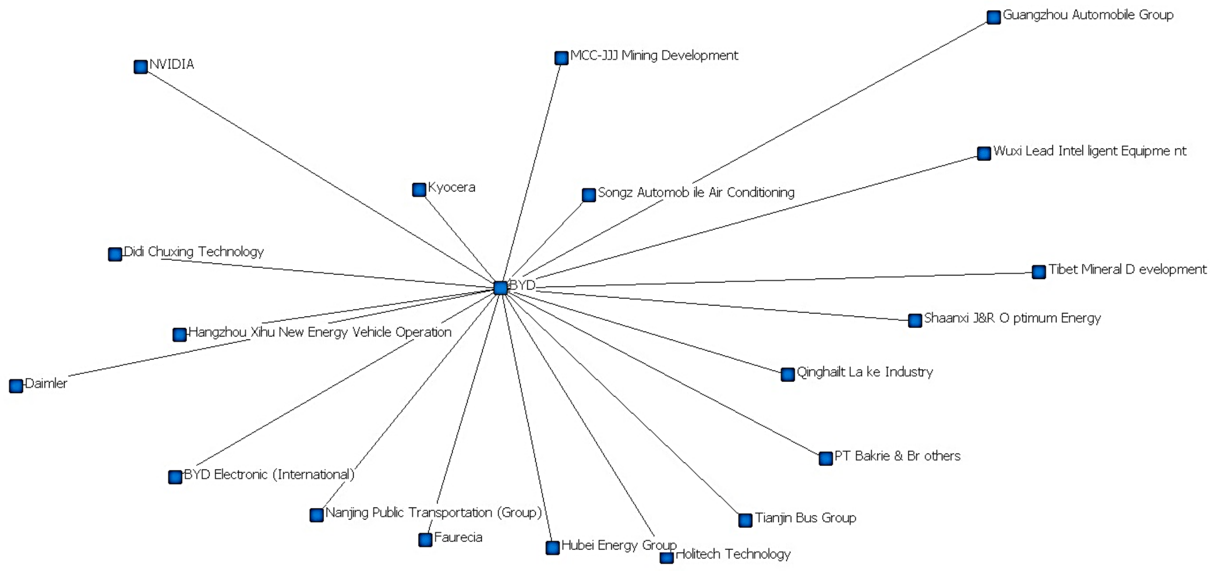
Table 2
Network Indices of Companies with High/Low CASE Ratios (After Standardisation)

Company	NIO (China)	BYD	Subaru	Daihatsu Motor
CASE ratio	High	High	Low	Low
Size	-1.0	-0.6	-0.7	-0.9
Constraint	-0.6	-0.6	1.2	2.0
nBroker	0.7	0.8	-1.7	-1.5
nEgoBetween	0.9	1.0	-1.2	-1.2
Density	-0.7	-0.8	1.7	1.5

Source: Authors' work

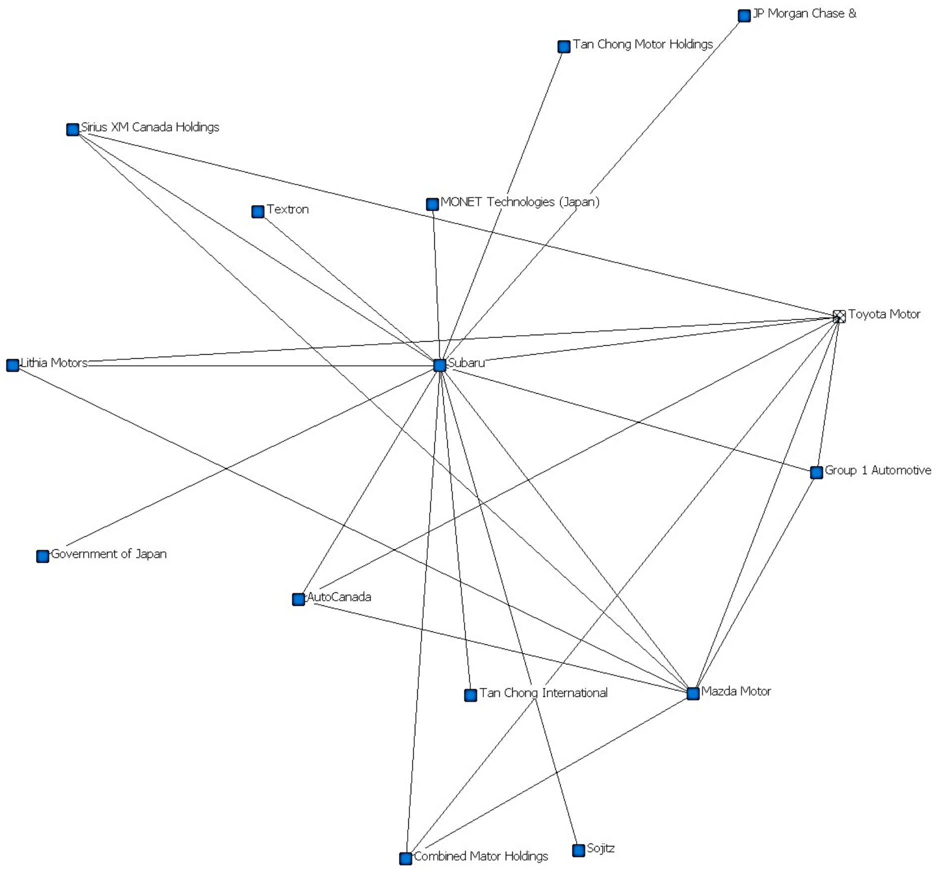
The case study results show that while there is no difference in the network index representing size between the automakers with high and low CASE ratios, there are contrasting results for each of the other indices, with different positive and negative values after standardization. Figure 1 shows the ego-network diagram of BYD described above, and figure 2 shows the ego-network diagram of Subaru.

Figure 1
Ego-network diagram of BYD



Source: Authors' work

Figure 2
Ego-network diagram of Subaru



Source: Authors' work

An intuitive comparison of the two diagrams shows that BYD is the medium through which the other firms are connected in the BYD diagram. On the other hand, the Subaru diagram shows that the partners of Subaru are also closely interconnected.

In contrast to the aforementioned statistical analysis of manufacturers as a whole, the results of the statistical analysis of manufacturers as a whole showed that betweenness centrality and density were unrelated to the CASE ratio, but in the case study, some trends were observed that differed from the results of the overall statistical analysis. The reasons for this are estimated in the following discussion.

Discussion

Next, we have verified each hypothesis based on the results of the previous analysis. Firstly, the results of the correlation analysis on the trends of all car manufacturers show that the companies that are promoting CASE have a wider and more diversified range of partnerships. This result supports hypotheses 1 and 2 and rejects the opposing hypothesis, hypothesis 3. A number of car manufacturers are currently expanding their R&D activities by investing aggressively in new CASE areas while maintaining their existing gasoline engine-based vehicles and vertically integrated supply chains. To this end, it is presumed that the network of new partners is being expanded. The expansion of partnerships and the diversification of R&D themes require a large number of resources. The results of our analysis are consistent with these phenomena, as global automakers are currently aggressively pursuing M&A and scaling up their operations in preparation for CASE. Passenger car manufacturers' profitability is expected to decline, and they may be forced to scale up to cover the huge upfront investment in CASE.

On the other hand, the results of the correlation analysis show that horizontal specialisation and platformisation are not correlated with the development of CASE. These facts seem to indicate that the existing vertically integrated organisational relationships have not changed with the development of CASE, as is the trend in the automotive industry as a whole. This trend was the same for both finished vehicle manufacturers and component manufacturers. Therefore, the results of the correlation analysis seem to reject hypothesis 4 and support the alternative hypothesis, hypothesis 5.

For example, the current overall trend seems to indicate a situation that is different from the past experience of the computer industry. In the computer industry, since the 1990s, digitalisation and networking, exemplified by the spread of the internet, has changed the relationship between organisations throughout the industry. The vertically integrated companies that had previously dominated the industry were dismantled and replaced by a horizontal division of labour between specialist companies. The computer industry became an ecosystem industry, sharing a variety of interface standards.

This raises the question of whether inter-organisational relationships in the automotive industry will remain unchanged as CASE progresses. It can be presumed that existing car manufacturers and parts suppliers are trying to extend the life of their current business models as much as possible and maintain their current profitability. In addition, the realisation of autonomous driving and car-sharing in CASE involves companies from many industries, each with different interests. In order to overcome the various difficulties, it is possible to maintain vertically integrated organisational relationships and to continue joint prior investments. Alternatively, another possibility is that the technology development for CASE is vertically integrated because it is at an early stage in its lifecycle. In other words, a possible scenario is that as development progresses, many of the technologies mature, and various technology standards are established, the relationships between organisations will specialise horizontally.

This is difficult to discern from the results of the current correlation analysis alone, but can be suggested by the results of the case studies. Of the automakers selected as case studies, the two with the highest CASE ratios were both electric vehicle manufacturers from China: NIO (China), a venture company established in 2011, is a promising manufacturer of electric vehicles. BYD was established in 2003 as an affiliate of an automotive battery company and is one of the world's largest producers and sellers of electric vehicles. As a partner, the company has established electric vehicle joint ventures with major companies such as Toyota Motor Corporation.

On the other hand, two Japanese car manufacturers were considered to have low CASE ratios. Both of these companies are small complete vehicle manufacturers and are mainly existing petrol car manufacturers. They also sell some hybrid vehicles, but both companies are part of Toyota Motor Corporation and are presumably receiving technical assistance from Toyota.

Interestingly, when we compared the network indicators for each of them, the results were opposite except for size. Individually, the results show that all four companies have a small network size. This is presumably due to the fact that each company is relatively specialised in new technology electric vehicles and existing petrol vehicles. For Constraint, the same trend as in the overall correlation analysis described above was observed: the smaller the value of Constraint, the larger the structural hole and the more efficient the collaboration with the various companies in the network.

On the other hand, for the Broker, EgoBetween and density indicators, there is no clear trend in the overall statistical analysis, but there is a relatively clear trend in the comparison between the companies analysed in the case study. Each of the selected companies is relatively small and deals almost exclusively with either new or old technologies. It can therefore be inferred that the organisational characteristics of each company are more clearly represented than those of companies engaged in a variety of R&D and business activities.

The results of the case studies suggest that emerging electric vehicle manufacturers with high CASE ratios are building partnership networks using themselves as platforms. This means that they may be in a position to be the platform leader in their network. Since the partners of each company include existing companies as well as new entrants that have become more cooperative as CASE has progressed, we can infer that a relatively loose ecosystem has been formed. In other words, the inter-organisational relationships may be similar to those in the IT industry. On the other hand, traditional car manufacturers with a low CASE ratio form a closed network with a relatively limited number of companies. This may well be a feature of inter-organisational relations in the traditional automotive industry. These two companies are not located at the centre of the network. They are presumably located on the periphery of a network of large partner companies that are expanding and diversifying their business. Let's say that, due to national legislation, internal combustion engine-based vehicles disappear in the future. In that case, the narrow and closed network structure of the past may not be adopted.

The results of this analysis suggest that there are two main types of inter-organisational relationships that the automotive industry could adopt in the future as a result of the development of CASE. The first is a large, comprehensive and relatively closed network centred on existing large companies. The other is a relatively open network in which new technology-based start-ups are the platform leaders. According to the framework of competition between ecosystems presented by Adner et al. (2016), the former network structure is more suitable when the pace of future technological innovation is relatively slow or when there are large differences in the characteristics of transport demand between regions. This is the inter-organisational relationship which is more suited to a business model in which a group of companies with integrated technology are familiar with each country and region and offer individual solutions.

The latter network structure, on the other hand, would be effective if innovative technologies related to CASE are realised and provided as platform technologies that allow various companies to work together efficiently. It can be assumed that cost performance will rapidly improve for users of transport and that companies based on existing products and technologies will be forced to change. However, these assumptions are only speculative based on the results of the current analysis, and continued research is needed to determine which network structures will become the norm.

Conclusion

In this study, we have created a database on the network structure of partnerships by car manufacturers worldwide and analysed it using network analysis methods, which has led to some useful insights. In response to technological changes in CASE, car manufacturers are increasing the size and diversity of their networks. The case studies also show that inter-organisational relationships in the automotive industry may be shifting from a closed, integrated to a platform-based network structure.

There has been a lot of discussion in newspapers, magazines, blogs and research papers about the impact of the technological innovation known as CASE on inter-organisational relations in the automotive industry. However, their conclusions are not always the same. Moreover, most of them are qualitative case studies and their generalisation is problematic. The contribution of this study is that all the major car manufacturers in the world were included in the analysis and the results of the quantitative study are presented.

One limitation of this study is that CASE is still in progress and the structure of inter-organisational networks in companies may change further in response to future technological changes. As a future task, it is desirable to continuously investigate the changes in the technological environment and their impact. In addition, although CASE was analysed collectively in this study, the impact of the four elements of CASE on inter-organisational relationships may differ (Fujimoto, 2020). Therefore, we would like to consider a method to analyse these elements separately.

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