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Article

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International journal of business & management

Provided in Cooperation with:
International Institute of Social and Economic Sciences, Prague

Reference: Isada, Fumihiko (2022). Alliance network structure and R&D outcomes in healthcare digital networks. In: International journal of business & management 10 (2), S. 1 - 11.
https://www.iises.net/international-journal-of-business-management/publication-detail-116986?download=1.
doi:10.20472/BM.2022.10.2.001.

DOI: 10.20472/BM.2022.10.2.001

ALLIANCE NETWORK STRUCTURE AND R&D OUTCOMES IN HEALTHCARE DIGITAL NETWORKS

FUMIHIKO ISADA

Abstract:

The aim of this study is to quantitatively analyse the impact of the inter-organisational alliance network structure on R&D outcomes in healthcare digital networks. The impact of inter-organisational alliance network structures on R&D is diverse, depending on product characteristics and other factors. In our previous study, we analysed the inter-organisational collaboration relationships between pharmaceutical manufacturers and bio-venture companies, and found that different network structures enhanced R&D outcomes, depending on the differences among conventional small molecule drugs, biopharmaceuticals and formulation development. In this study, the analysis focused on healthcare digital networks, which are expected to be useful not only in combating the recent novel coronavirus but also in improving the efficiency of healthcare resources in the long term.

As an analysis method, the method of social network analysis was used to analyse inter-organisational collaboration data and patent data of 100 major companies in the world.

The results of the analysis showed that the size and between centrality of the network may promote R&D, and the results differed depending on the area of R&D. On the other hand, cohesiveness and closeness were not significantly related to R&D outcomes. Future work should include country-specific and long-term comparisons.

Keywords:

alliance network, social network analysis, healthcare digital network

JEL Classification: M11, O32, M19

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Citation:

FUMIHIKO ISADA (2022). Alliance Network Structure and R&D Outcomes in Healthcare Digital Networks. International Journal of Business and Management, Vol. X(2), pp. 1-11., 10.20472/BM.2022.10.2.001

1 Introduction

The aim of this study is to quantitatively demonstrate the impact of inter-organisational relationships on R&D outcomes by means of social network analysis. The theoretical basis for social network analysis is embedded theory. Embedded theory was first presented in Granovetter (1985), published in the American Journal of Sociology, and has developed significantly since that article. Its basic claim is that people are embedded in a network of connections with others, doing business within the scope of that network, and are therefore influenced by their relationships.

Based on embedded theories, various theories have been proposed on the impact of network performance (Polidoro, et al., 2011).

For example, according to positional theories, those who are more connected to more people have an advantage in terms of information acquisition and dissemination. Having more connections than others is synonymous with being in a central position on the network. This is called network centrality. People with high network-centrism have access to more information and can disseminate information to a wider range of people, giving them an advantage in both receiving and disseminating information.

The impact of inter-organisational alliance network structures on R&D is diverse, depending on product characteristics and other factors. In our previous study, we analysed the inter-organisational collaboration relationships between pharmaceutical manufacturers and bio-venture companies, and found that different network structures enhanced R&D outcomes, depending on the differences among conventional small molecule drugs, biopharmaceuticals and formulation development. In this study, the analysis focused on healthcare digital networks, which are expected to be useful not only in combating the recent novel coronavirus but also in improving the efficiency of healthcare resources in the long term.

2 Previous research

We would like to provide a brief overview of our previous health-related research findings (Isada and Isada, 2018). The objective of the research was to analyse the relationship between the network structure between organizations in the development of a drug and operational efficiency. This research classified the pharmaceutical products according to the type of product based on the patent application, and performed a comparative study. The following five research hypotheses were set out.

H1. If there are many external cooperation companies, innovation results will increase.

H2. If it is a position that serves as a node of several company groups, the results of an innovation will increase.

H3. If the direct relation with several central companies is strong, the results of an innovation will increase.

H4. If the relationship with an external company is narrow and deep, the results of an innovation will increase.

H5. External cooperation does not influence the results of an innovation.

As an analytical method, patents were extracted from the open Japanese patent database. The relationships between companies regarding innovation were surveyed by analysing the joint-application status of patents. When two or more companies applied for a patent jointly, it was assumed that there was cooperation regarding R&D among these companies. To be specific, for each joint-application patent, the applicants' names and number of applications, etc. were extracted and an adjacency matrix was created. Next, the classification was tried according to the type of product with the code of the patent classification about the extracted joint-application patent. Although there were a number of types of codes of patent classification, the International Patent Classification (IPC) was used. The adjacency matrix data were analysed using social network analysis. Finally, the relationship between each network indicator and each indicator regarding the results of R&D was analysed. The R&D of pharmaceutical products is a lengthy process and there is usually a long period between a patent application and the sale of a product. Thus, in this research, data were extracted on patent applications from the year 2007 to the year 2016. In terms of firm performance, the financial data used were the business profit and R&D expenses.

As a result, the optimal interorganisational relation was different even within the pharmaceutical industry according to the type as a result of the correlation analysis. Among pharmaceuticals, in terms of biomedicine, hypothesis 1 and hypothesis 3 were supported and hypothesis 2, hypothesis 4 and hypothesis 5 were rejected. Biomedicine is a comparatively new pharmaceutical area and various new research results are produced every day. In such an environment with active innovation, it is thought to become a source of innovation to absorb as much variety of external information as possible. Also, it is thought that the strategy in which it cooperates, particularly with an important company that has taken a central position in the external network, is effective. Only hypothesis 5, which is an alternative hypothesis, was supported regarding low-molecular-weight pharmaceutical products, which are the conventional pharmaceuticals. In the research and development of conventional products, the selection and concentration capability based on experience may raise the productivity, rather than absorbing a lot of external new technology. Regarding a dosage form development, the verification results were exactly opposite, compared with the above-mentioned bio-drug development. A long and deep relationship with a customer is searched for in a dosage form development. In addition, hypothesis 2 concerned innovation related to the style of the platform network. For example, in personal computing, Microsoft's OS came together by uniting hardware and software, thereby generating profitability. The same structure may apply to dosage form development.

3 Analysis method and research hypotheses

Next, we describe the method of social network analysis, which is the method used to analyse inter-organisational relations in this study, and the hypotheses based on it. There are two main types of networks that can be analysed in social network theory: socio centric networks and ego centric networks. The former takes the whole network as the object of analysis. For example, it represents the overall character of the relationship between all organisations regarding healthcare digital networks. The ego centric network, on the other hand, is a self-centred network structure. Organisations are connected to each other in a broad network structure, but each organisation is connected to the surrounding organisations in different ways. The main interest of ego centric network research is the difference in organisational performance due to the network structure surrounding the organisation. As a result, the subject of this study is the ego centric network in individual organisations.

Using social network analysis, various indicators that show the characteristics of the network's structure can be calculated (Borgatti, Everett and Freeman, 2002). There are various ideas and calculation methods for centrality indices. First, we consider the most basic centrality, which is called degree centrality. One of the most prominent studies in social network analysis examined the weak-ties hypothesis proposed by Granovetter (1973), which empirically demonstrated the strength of weak ties. According to Granovetter (2005), interpersonal ties generally come in three varieties: strong, weak, or absent. The weak-ties hypothesis can be related to the management of innovation, in which a weak but wide network can promote innovation better than a strong but narrow network. In other words, in promoting innovation, it is necessary to search for knowledge that overcomes the limited rationality of people and organisations, and weak-but-wide networks are useful, as they allow for various forms of information to flow quickly and efficiently from a distance. However, a strong-but-narrow network tends to circulate only similar information, hindering the emergence of innovation, thereby preventing the organisation from expanding and improving its performance.

Healthcare digital networks are expanding rapidly, and various organisations are developing a wide range of technologies. Many commercialisation attempts are still in the early stages of their lifecycle, and it is not clear what healthcare digital networks will be effective. In the face of high technological uncertainty, it will be easier to realise good new healthcare digital networks by further experimentation. To this end, it may be useful to collaborate with more external organisations rather than using only the company's own internal research resources. In particular, since big data is important for healthcare digital networks, collaborating with more external organisations will facilitate the collection and use of big data and promote R&D. Furthermore, from the viewpoint of expertise, it is difficult for one company to be familiar with all the various technologies used in healthcare digital networks. Rather, it would be more efficient for the company to concentrate its research resources on the technologies in which it excels, while collaborating with organisations outside the company that have their own strengths in other technologies. In addition, such cooperation would make it easier to standardise the company's technology in the industry, since the company's technology would be used by many other organisations. For this purpose, it is also expected that patent applications will be actively pursued. The following hypotheses are derived from this discussion.

Hypothesis 1: Organisations that collaborate with more external organisations in healthcare digital networks will increase their R&D results.

Next, we consider centrality, such as that called between-centrality. In social network analysis, it has been demonstrated that a network’s performance and behaviour is affected by not only the number of connections it possesses, but also the way in which an organisation is connected to the networks around it. Burt (2004) classifies ties into Bridging Ties and Cohesive Ties, and states that Bridging Ties, which can be widely deployed even with weak connections, are effective in searching for information. Bridging Ties are defined as ties that connect separated individuals and groups; their structural features include many bridge ties and a wide range of connectivity. The strength of Bridging Ties lies in the widespread dissemination of new, formal, and heterogeneous knowledge, and it is easily linked to radical innovation.

Such a mediated network structure can be associated with a platform or platform leader (Gawer et al, 2002). Since platform leaders connect various firms, they are likely to be the nodes that mediate many other nodes in the network structure. In healthcare digital networks, we may see the emergence of platforms as being similar to those in the IT industry. For example, platform companies in the IT industry are expanding horizontally by creating new collaborative relationships with a large number of external companies beyond existing corporate affiliations and industries. In healthcare digital networks, in order to collect and use big data extensively, it is useful to collaborate beyond the traditional industry boundaries, and it is assumed that each company is working to become a platformer. The following hypothesis is derived from this discussion.

Hypothesis 2: Organisations that mediate between more external organisations in healthcare digital networks will increase their R&D results.

Next, we consider the kind of centrality that is called eigenvector centrality. The aforementioned degree centrality directly expresses the number of connections of other nodes. Eigenvector centrality is not a simple centrality, but is instead loaded based on collaborations with highly centric firms. Even if the number of direct external connections is not necessarily large, the eigenvector centrality is larger if there are many connections to the central organisation. This advantage of eigenvector centrality can be related to Complementor in previous studies on inter-organisational relations. In healthcare digital networks, in addition to the central healthcare technology, various technologies such as software, devices, and networks are integrally related, and collaboration among organisations takes place. For an organisation with a specific technology, it is expected that collaboration with a central organisation will provide opportunities to apply their technology to more businesses and to collect big data, which will promote R&D. From these assumptions, the following hypothesis is proposed:

Hypothesis 3: Organisations that collaborate with more central organisations in healthcare digital networks will see their R&D output grow.

Next, we examine the density of the network, which is one of the theories in social network analysis. These focus on the mutual cohesion of connected nodes in social network analysis. According to Krackhardt (1992), there are a number of problems in the Granovetter definition. There are subjective criteria in the definition of the strength of a tie such as emotional intensity and intimacy. Strong ties are crucial in severe changes and uncertainty. According to Coleman (1988), In a high-density, closed network, it is easier for players to develop trust in each other. Players are more likely to trust each other because they are more closely and strongly connected and interact more frequently. They are also more likely to form collective norms and to engage in mutual monitoring.

In the sparse and open network structure, it is easy to obtain various kinds of information and knowledge, but it is difficult to develop trust, and it is challenging to exchange private information and tacit knowledge. On the other hand, the structure of a dense and closed network allows for transactions that are not possible in normal business transactions. For example, in R&D, a wide open inter-organisational relationship is useful in the information collection phase, but in the research realisation phase, a dense closed inter-organisational relationship is more desirable, where especially confidential information can be shared and exchanged in a secure and close manner.

To quantify the characteristics of the network, its density is the degree to which other nodes connected to a node are also connected. If the nodes are closely connected to each other, we can determine that they are likely to form a strong and cohesive group. Additionally, in network analysis, if node A is connected to node B, and node B is connected to node C, we evaluate that A and C are connected even if not directly so. This is because node A may obtain information from node C via node B, and may be affected by it. However, in this case, the strength of the relationship between node A and node B may differ from the strength of the relationship between node A and node C. From these assumptions, the following hypotheses are proposed:

Hypothesis 4: In healthcare digital networks, organisations with a higher density of inter-organisational collaboration will achieve more R&D results.

4 Research methodology

4.1 Research data

Next, we discuss the methodology used to empirically verify each of the aforementioned research hypotheses. First, there are two types of data used in the analysis: data on inter-organisational relations and data on research results. Regarding data on inter-organisational relations, this study used data from newspaper articles and corporate press releases, through which it is possible to collect comprehensive and timely data on the relationships among many firms. Specifically, the Lexis Advance database, created by LexisNexis of the U.S., was used as the data source. The author's university has a contract with Lexis Advance, which allows for full-text searches and browsing of newspaper articles from the world's leading newspapers, including the New York Times, Los Angeles Times, Le Monde, and others. Concerning the search criteria, we selected articles on healthcare digital networks from the database and extracted information on cooperation between organisations, such as strategic alliances and joint development. Specifically, articles were selected if they contained the keywords "Digital Health" or HealthTech or MedTech or CareTech in the Headline and Lead Sections of the article. The period covered by the analysis was 2020.

Next, we used patent information for the data on research outcomes. Although there are many ways to measure research outcomes, patent information is useful for collecting objective, comprehensive, and quantitative data, and has been used in many previous studies. As with the data on inter-organisational relations, the period of analysis was set to 2020. The patent information was collected from Espacenet, which is a database of patent information operated by EU. The survey covers international patents in the majority of the world's countries, not only in Europe. In addition, the patents to be collected are registered, not patent applications. This is because, while application patents are a mixed bag, registered patents are limited to those that have been found to be novel through patent examination.

In extracting patents related to healthcare digital networks, healthcare digital networks are a vague concept that is difficult to define strictly. There is a wide range of technologies related to healthcare digital networks. Therefore, it is difficult to determine precisely whether an individual patent falls under the healthcare digital network or not. Therefore, the aim of this study was to understand the general trend in the number of patents granted in relation to the healthcare digital network for each company, while referring to previous studies. Specifically, we decided to calculate the total number of patents by company for the International Patent Classification Code (IPC), which is considered to contain a large number of patents related to healthcare DX, with reference to Astamuse (2021). In Astamuse (2021), the number of patents is aggregated by the top four digits of the IPC code, and the relevant IPC codes are A61B, G16H, G06F, G06K, G06T, B25J, G06N, G06Q, G01R, H04W, H04L, A61K, A61P, G01N, A61N, A61M, G05B, G16B and C12Q.

The top 100 companies with the highest frequency of occurrence as a result of newspaper article searches were selected as the companies to be analysed, and a database of the number of registered patents in the above patent categories was created for each of these companies.

4.2 Analytical method

After constructing the database for the analysis as described, the analysis was conducted using the following steps to verify each hypothesis. First, prior to the analysis, the database for the analysis was cleaned. Next, the structure of each organisation's inter-organisational network was analysed using the network-analysis method. For each organisation, the number of registered patents for each of the aforementioned patent categories was calculated. Finally, the relationship between the inter-organisational network's structure and number of registered patents was examined. Each procedure's details are as follows. Regarding data cleaning, the database for the social network analysis was based on newspaper articles, and the notation of organisation names is not consistent. For example, some organisation names are complete, while others include abbreviations, common names, or notation errors. The name of the organisation is the key item that links the information in each newspaper article, and the patent information in the subsequent analysis, so the same organisation must have exactly the same name. Consequently, for all information, the name of the organisation was checked individually and standardised.

Next, each organisation's inter-organisational network structure was analysed according to each hypothesis based on the database for analysis after data cleaning. For the inter-organisational network structure analysis, each organisation was viewed as a node in the network, and the social network analysis method was applied. In this study, the following network indices were used among them:

As for Hypothesis 1, degree centrality, which represents the size of the ego network comprising nodes connected to the organisation in question, was calculated as an indicator of network size.

In Hypothesis 2, EgoBetweeness was calculated as network indicators for between centrality. EgoBetweeness is an index that indicates that the firm in question connects other firms that are not directly connected to each other. The aforementioned degree centrality does not take into account whether other nodes connected to the node in question are also connected. On the other hand, EgoBetweeness measures only the connections among other nodes that are connected only through its own node. Note that network size affects this index, e.g., if the ego network's size increases, the number of intermediaries may naturally increase, so nEgoBetweeness, which is an index showing the normalised ratio, was used. Through the normalisation process, we can determine the proportion of mediating nodes to all connections of a node. This allows us to determine the degree of mediation without being affected by the size of the nodes' connections.

As for Hypothesis 3, eigenvector centrality was calculated as an indicator of the size of the connection to nodes with large mediation centrality.

As for Hypothesis 4, ego network density was calculated as indicators of interorganisational networks' cohesiveness. As mentioned previously, the ego network's density is the degree of connection between each node in the ego network, and the higher the density value, the more closely connected the nodes are. It is estimated that the value will increase as the grouping of companies progresses, such as in an affiliated group. UCINet (Version 6) was used to calculate network indices.

Next, for healthcare digital netoworks related patents, we extracted the registered patents under the extraction conditions described previously, and tabulated the number of patents by organisation. Then, by using the organisation name as a key, we correlated the data of the aforementioned network index of each organisation with the data of the number of patents, and conducted a correlation analysis. SPSS (Version 25) was used to conduct the analysis.

5 Survey results

5.1 Overview of the survey

The following is a summary of the survey carried out according to the methodology described.

The total number of newspaper articles related to healthcare digital networks was 6,282. After data cleaning of the organisations' names, we calculated the network indices of the relationships among these organisations using the social network analysis method. A search of patents with the aforementioned patent classification codes for the 100 companies with the highest frequency of occurrence in the newspaper article search results yielded a total of 18,270 registered patents. Note that when these were allocated by patent classification and by company, the number of cases did not necessarily add up to a sufficient number for analysis, depending on the company. Therefore, in the subsequent analysis, the IPC codes were aggregated to the top three digits of the IPC code. In some cases, more than one IPC code was assigned to a patent, and the number of patents was divided according to each IPC code.

The number of patents extracted for each patent category is shown in Table 2.

Table 1 Total number of patents by classification

IPC upper 3 digits	IPC upper 4 digits	Number of patents
A61		7,096
	A61B	4,095
	A61K	758
	A61M	1,295
	A61N	589
	A61P	359
B25	B25J	90
C12	C12Q	201
G01		979
	G01N	715
	G01R	263
G05	G05B	138
G06		6,977
	G06F	4,135
	G06K	393
	G06N	883
	G06Q	730
	G06T	837
G16		744
	G16B	48
	G16H	696
H04		2,045
	H04L	1,570
	H04W	475

5.2 Results from correlation analysis

We subsequently conducted a correlation analysis between each network analysis indicator and the number of patents for each of the aforementioned categories of organisations whose names were present in the databases of both inter-organisational relations and patents. However, we decided to exclude the classification with a small sample size from the analysis in order to avoid the error of judging that there is no correlation even if there is actually a correlation due to the small sample size. Five categories were therefore selected for analysis: A61, G01, G06, G16 and H04. The results of the correlation analysis are shown in Table 3.

Table 3: Correlation between network analysis indicators and the number of patents

Classification	Degree centrality (H1)	nEgoBetween (H2)	Eigenvector (H3)	ego density (H4)
A61	.417**	.157	.288**	-.044
G01	.150	.225*	-.021	-.058
G06	.208*	.181	-.039	-.035
G16	.236*	.133	.005	-.050
H04	.228*	.192	-.040	-.026

(**: 1% level of significance, *: 5% level of significance)

6 Discussion

Based on the aforementioned survey results, each hypothesis was verified.

From the results of the correlation analysis, it can be inferred that the impact of inter-organisational relations on the number of patents differs depending on the technological area of the healthcare digital network. Broadly speaking, the above five areas can be divided into G01 and other areas. In the area other than G01, the companies that applied for a large number of patents were not actually traditional healthcare-related companies, but IT giants such as Microsoft, Google and Amazon. Following these IT giants, traditional medical companies such as Roche, Johnson & Johnson and Bayer were selected. On the other hand, in the area of G01, it was the major medical device companies, such as Philips and GE healthcare, that applied for a large number of patents. As the trends of the results of the analysis are different, they will be discussed separately, and the areas other than G01 will be discussed first.

The first hypothesis concerned network size, i.e., the larger the size of the network, the greater the R&D output. In terms of network size, significant correlations with R&D performance were observed in the areas other than G01. The results of this analysis indicate that Hypothesis 1 is likely to be partly supported. In a new technological field such as healthcare digital networks, it is useful to explore and collaborate across a wide range of technologies and businesses, and the breadth of the network of collaboration among organisations is thought to contribute to the expansion of research results. In particular, companies such as Microsoft, Google and Amazon are new entrants in the healthcare domain, but are expanding rapidly based on their huge capital strength and accumulated technological capabilities in the IT domain. By collaborating with a large number of traditional healthcare-related companies and combining their own technological and service capabilities, they seem to be strongly promoting innovation in the area of new digital networks.

In addition, eigenvector centrality, which is a network indicator of Hypothesis 3, was observed to have a significant relationship with the research results in A61 classification. Eigenvector centrality is an indicator of the connection with organisations with high centrality. The A61 domain is directly related to treatment and other aspects of traditional healthcare, and many traditional healthcare companies have applied for patents in this domain. It can be inferred that these companies are fostering innovation in the digital network domain of healthcare by being complementary to emerging IT companies such as Microsoft, Google and Amazon.

Next, the G01 domain is discussed. For the network indicator of Hypothesis 2, betweenness centrality, there was a significant positive correlation in G01. H2 is a hypothesis concerning so-called platform or platform leadership. As mentioned above, in the G01 area, traditional medical device manufacturers such as Philips and GE healthcare have mainly applied for patents. Unlike pharmaceuticals, medical devices are products consisting of multiple layers, such as hardware, software and services. Such a layered structure is common in the computer industry, for example. The structure of the computer industry is increasingly separated into layers, which are linked by platforms, such as operating systems. In medical devices, it can be inferred that companies such as Philips and GE Healthcare are promoting innovation by becoming so-called platform companies and collaborating with various companies.

With regard to the density hypothesis, H4, no significant correlation was found with research results in any of the IPC areas. High density, as mentioned above, indicates, for example, a situation in which so-called enterprise groups are formed. This is the case when a limited number of manufacturing and service companies form a closed and highly interconnected network. In the area of healthcare digital networks, it has been shown that open and diverse cooperation may promote innovation rather than such closed groupings.

7 Conclusion

This study’s purpose was to empirically examine the effect of the interorganisational relationships surrounding an organisation on R&D outcome. In particular, we explored the relationship between inter-organisational relationships and research results in the development of healthcare digital networks, at a relatively early stage of its lifecycle. As a result of using the method of social network analysis concerning the inter-organisational relationship, the study demonstrated that the relationship could be explained by applying theories of social network analysis such as the weak ties hypothesis. In addition, we identified the possibility that the relationship differs depending on the area of research, such as medical devices and other. The significance of this study is that it quantitatively demonstrated the reality of research in healthcare digital networks, which is a relatively new technological field, using actual data. On the other hand, as a limitation of this study, this study only analyses a single year, and it can be inferred that the industry structure and other factors may change. Therefore, continuous research is needed as a future issue.

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