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NETWORK ANALYSIS OF INNOVATION IN THE INTERNET OF THINGS

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ABSTRACT

Background: In the Internet of Things (IoT) firms, innovation beyond the border of a company is important. Furthermore, advantageous positioning in the innovation network is thought to enhance the result of innovation and ultimately contribute to profit. **Objectives:** The objective of this research is to clarify empirically the influence of the network structure among companies on innovation in the IoT field. **Method:** In this research, the relationship between the network structure and the result of innovation was analysed through social network analysis. Joint application patents related to the IoT companies were extracted from the intellectual property database. **Results:** As a result, the difference in the network structure of a company was related to the result of research and profitability. In particular, a company with a platform type of business model is considered highly profitable in the IoT business field. **Conclusion:** Drawing on an intellectual property database and employing social network analysis, this research quantifies the structure of innovation networks in terms of the results and operational efficiency of R&D.

KEY WORDS

social network analysis, innovation, Internet of Things (IoT), joint application patent

CLASSIFICATION

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INTRODUCTION

The objective of this research is to clarify empirically the influence of the network structure among organizations on innovation in the Internet of Things (IoT) business field.

At present, IoT businesses are attracting considerable attention and are rapidly advancing. In Europe, Industry 4.0 and other trends in automation are mentioned as similar notions. Transformations in information and communication technologies before the IoT included advances in computing, the spread of the Internet and so on. The IoT directly concerns autonomy and the advanced features of all devices in a process termed ‘smartization’. The impact of the IoT on changes in industrial structure is important. Various myriad devices collect big data autonomously. Big data are shared by the Internet as a database and are analysed through artificial intelligence, etc. Moreover, various devices are controlled automatically and in an integrative fashion. Porter and Heppelmann [1] compared the IoT using several examples. For instance, a farm tractor evolves from a stand-alone farming implement into a complex system of agricultural automation. It is thought that the impact of the IoT on industrial structure is considerable and its coverage is wide. The IoT constitutes a significant business opportunity. Moreover, many companies are beginning to enter into the area of IoT business all at once and all around the world and competition in terms of technological development is extremely high. For a company to produce excellent results from research in the context of such competitive environment, with rapid technological development, it is necessary to increase both the speed and efficiency of research and development (R&D).

Recently, open innovation [2] has attracted attention as a means of enhancing the efficiency and speed of R&D. That is, it is a strategy which promotes innovation through cooperation with an external organization, leveraging the specific technical resources of the company. It is thought that speeding up development and its correspondence with various areas can be attained through open innovation, using the technology of an external organization. In carrying out business in the IoT field, there are various related technical factors, for example ensuring cooperation among various systems in terms of hardware, software, network communications, database applications, etc. To enable such cooperation, there is a need for technology, such as information and telecommunications, analysis and security. It is difficult for a single company alone to bring these various technical developments to bear simultaneously. It is thought that by cooperating with many companies, excellent research results can be produced.

However, if a company depends too greatly on external technology, there is a risk that the company-specific capability to create technology may decline. If the technological capabilities of the company decline, there is also a risk that the capability to understand external technology and to utilize it may decline. Therefore, the need to increasing the level of cooperation and extending the research area is not necessarily linked to the results of research.

This is a point also made concerning the relationship between the results of R&D and profitability. That is, the results of R&D are not necessarily related to revenue due to various problems. In the area of technology management research, the problems of the Death Valley Curve and digital Darwinism are widely acknowledged. Regardless of the results of research, they do not necessarily expand the revenues of a company. IoT businesses are still on the path to development and a number of businesses have begun this process in various industries. Moreover, while there are some IoT businesses which have large revenues, many do not. One of the aspects addressed in this study is raising awareness of the problem of the difference between businesses in which the results of R&D are readily connected with revenues and those in which this is not the case. For example, in the computer industry, there are plentiful examples to date in which a restrictive and strong connection in R&D with a specific external company has increased the potential for the growth and profitability of a company, as in the case of Intel and Microsoft. Furthermore, in the motor vehicle industry, in-depth and narrow cooperation with a specific company with strength in R&D has induced strong competitiveness and has realized high profitability. Thus, it can be argued that R&D partnerships differ in terms of increasing profitability depending on the traits of the product or the industry.

Thus, this research analysed the actual effect of the R&D relationship empirically in IoT firms. The research employed social network analysis, which has attracted attention as an analytic tool for examining inter-organizational relationships. The object of the analysis comprised the application patents among the major companies related to the IoT business field, extracted from the patent information database.

LITERATURE REVIEW

INTERPERSONAL TIES

Granovetter's article [3] on the strength of weak ties was a seminal work in the study of social networks and is an extremely famous publication in sociology more generally. According to [4], interpersonal ties generally come in three varieties: strong, weak or absent. Weak social ties, it is argued, are responsible for the majority of the embeddedness and structure of social networks in society, as well as the transmission of information through these networks. Specifically, more information that is novel flows to individuals through weak rather than strong ties. As close friends tend to move in the same circles, the information they receive overlaps considerably with what is already known. Acquaintances, in contrast, know people in other circles and thus receive more information that is novel. Granovetter [3] argues that for diffusion across a network, weak ties are most valuable.

However, according to [5], there are some problems with Granovetter's definition. Krackhardt [5] contends that there are subjective criteria in the definition of the strength of a tie, such as emotional intensity and intimacy. He considers that strong ties are very important in cases of severe change and uncertainty.

The notion of structural holes theory [6] is related to some extent to the strength of weak ties theory. This theory draws on the fundamental idea that the homogeneity of information, new ideas and behaviour is generally higher within any group of people compared to that between two groups of people [7]. An individual who acts as a mediator between two or more closely connected groups of people could gain important comparative advantage. In particular, the position of acting as a bridge between distinct groups allows a person to transfer or gatekeep valuable information from one group to another. In addition, the individual can combine all the ideas received from different sources and come up with the most innovative idea based on all the information. At the same time, a broker also occupies a precarious position, as ties with disparate groups can be fragile and time consuming to maintain.

OPEN INNOVATION

According to [2], conventional innovation has been performed primarily through vertical integration model in one industrial group. However, in terms of the speed of the transmutation of management environments, for example resulting from the development of a technique or the diversification of a market, innovations will support these developments in a network of various companies. Innovation involves a high level of uncertainty and entails a necessary process of trial and error. The greater the divergence that a player brings to the process of innovation, the more instances of trial and error will be generated by the various players. There are many ways for innovation to be achieved. The greater the diversity of different kinds of attempts at innovation, approaching problems from different perspectives, such as the external viewpoint, the user's viewpoint, the viewpoint of a different society, or the viewpoint of a different culture, the more it is thought that innovation can be facilitated.

Dittrich et al [8] describe the different approaches in a joint research network as comprising an exploitation strategy and a pursuit strategy. In an exploitation strategy, an alliance partner has a funding relationship, generally related to the same technological or business field. It is rare for a new alliance partner to participate in a collaborative network and the speed with which an alliance partner changes is slow. An exploitation strategy is similar to a closed innovation, in which a development is made in an originally outstanding field mostly with a specific partner. In a pursuit strategy, an alliance partner does not have a funding relationship and is in many cases in a different technological or business field. In the pursuit strategy, many new alliance partners participate in a collaborative network and alliance partners change rapidly.

Christensen [9] defines organizational capability as comprising special technical and integration capabilities. The special technical capability is the team's basic capacity to mobilize resources for a specific production activity. Integration capability is a high-level administrative ability, which mobilizes, cooperates in and develops exchangeable resources or capabilities, yielding value and competitive advantage at the system level. Thus, special technical capability is promoted through the resources inside an organization, whereas integration capability serves as the central resource of open innovation and organizational boundaries may differ according to managerial resources.

PLATFORM LEADERSHIP

Gawer and Cusumano [10] define external or industry platforms as products, services or technologies developed by one or more firms, which serve as foundations upon which a larger number of firms can build further complementary innovations in the form of specific products, related services or component technologies. Iansiti and Levin [11] note the role of the 'keystone firm', i.e. one that drives industrywide innovation for an evolving system of separately developed components. Industry platforms tend to facilitate and increase the degree of innovation in complementary products and services. The greater the innovation in such complementary aspects, the more value is created for the platform and its users via network effects, creating a cumulative advantage for existing platforms. As these grow, they become harder for rivals or new entrants to dislodge; the growing number of complements acts as a barrier to entry. Highlighting the complex trade-offs between 'open' and 'closed' innovations, Gawer and Cusumano [12] suggest that while opening up interfaces will increase complementors' incentives to innovate, it is important to preserve some source of revenue and profit as proprietary.

According to [13], switching costs and network effects bind customers to vendors if products are incompatible, locking customers or even markets into early choices. Lock-in hinders customers from changing suppliers in response to (predictable or unpredictable) changes in efficiency and gives vendors lucrative ex-post market power over the same buyer in the case of switching costs (or brand loyalty), or over others with network effects.

RESEARCH HYPOTHESES

According to existing studies, the network structure regarding innovation with an external organization affects the results of innovation and the financial impact. However, there is no consensus in terms of what kind of network structure is effective.

The first issue is the comparison between a broad network and a narrow network. IoT companies consider to be involved in more technological areas than conventional businesses.

In terms of deriving results from research in an unknown area, it is assumed that technological results that are more radical can be achieved by cooperating with a wide range of companies. Therefore, it is assumed that a broader network confers an advantage.

To obtain innovative technological results, homogeneous relationships in the same industry may not be appropriate. Connecting with companies in different industries, locations, etc., is thought to be helpful in achieving wide-ranging technological results.

However, to convert a technological result into a profit-making business, considerable resource inputs and long-term effort are necessary. The various technical factors necessary for a business must be integrated and a revenue-sourcing scheme must be accomplished. In a partnership with an external company, business success may be derived from building strong fiduciary relations. For this purpose, it may be more effective to build a strong partnership with a specific external company than associating with many, unspecified companies more broadly.

In addition, the opportunities to earn profits can be expanded by developing the spread of the technical standard of the company from the viewpoint of a technological strategy. In particular, in the dawn or the growth phase of a new industry, as in the IoT, the competition for a standard with an exclusive competing product is important to the business. With this in mind, it is important to segment the companies concerning complementary technology and domain identity and to form a group. Good cases of precedence, for example, are Intel and Microsoft in the personal computing industry and Apple in the Smartphone industry. If the technology of a company is transformed into an industry aggregate platform technology, it may also be possible to promote the product of the company through the evolution of the industry aggregate. The spread of technical standards and the increase in revenue are thought to result in a virtuous cycle.

Based on the above, the following hypotheses are developed:

H1. A broad network between organizations regarding innovation enhances the results of innovation.

H2. Networking with a distant organization enhances the results of innovation.

H3. A narrow (strong) network between organizations regarding innovation enhances the results of such innovation.

H4. A platform style network between organizations enhances the results of innovation.

VERIFICATION METHOD

OBJECT OF ANALYSIS

As an analytic method, IoT-related 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.

In detail, concerning each joint application patent, the applicants’ names and number of applications, etc., were extracted and an adjacency matrix was created. 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 were analysed. The methods and indicators of social network analysis employed are addressed later.

IoT-related technology is an emerging and evolving field. In extracting the patents related to IoT technology from the [14], various search terms related to engineering were employed as keywords, namely the following: information network, big data analysis, artificial intelligence, cyber security, software-based technology, etc. In all, 921 open patents (2005 or later) entailing joint applications by two or more legal persons regarding IoT-related technology were extracted.

To investigate R&D networking with external organizations, patent applicants in the same industrial group were excluded; for example, joint applications for patents by Toshiba Corp. and the Toshiba Solutions Corporation were excluded. In addition, we accounted for the name of an old company transposed to a new company or a merged company.

Moreover, to address the importance of the patent, we not only considered the number of patents but also the number of references. An indicator often used as a means of the objective evaluation of patent value is reference information. Although there are critiques of this method, the number of references is understandable as a patent value indicator. For example, according to [15], the number of patent citations can be correlated with the evaluation of the significance of the patent by an expert. In addition, Schoenmakers and Duysters [16] value innovations by the number of references during observed period, and value patent importance with the number of patent citations.

In terms of financial data, the average of the operating profit for sales in the latest three years was computed from the financial statements of each company. It should be noted that in cases in which the company was involved in two or more businesses, the information on the segment thought to be the IoT-associated business was extracted.

NETWORK ANALYSIS INDICATORS

This section addresses the method and indicators of social network analysis used for verification in the study. Social network analysis is the process of investigating social structures using network and graph theories [17]. It characterizes networked structures in terms of nodes (individual actors, people, or things within the network) and the ties, edges, or links (relationships or interactions) that connect them. Examples of social structures commonly visualized through social network analysis include social media networks [18], message propagation in a social network service [19], friendship and acquaintance networks, collaboration graphs, kinship, disease transmission and sexual relationships [20, 21]. These networks are often visualized through socio-grams, in which nodes are represented as points and ties are represented as lines. Network features can be at the level of individual nodes, dyads, triads, ties and/or edges, or the entire network. For example, node-level features can include network phenomena such as betweenness and centrality, or individual attributes such as age, sex, or income [22].

Social network analysis software generates these features from raw network data formatted as an edge list, adjacency list, or adjacency matrix (also called a socio-matrix), often-combined with (individual/node-level) attribute data [22]. Although the majority of network analysis software uses a plain text ASCII data format, some software packages contain the capability to use relational databases to import and/or store network features. Either network analysis software generally consists of packages based on graphical user interfaces (GUIs), or packages built ztools are more powerful and capable of extension. Widely used and well-documented GUI packages include NetMiner, UCINet, Pajek (freeware), GUESS, ORA, Cytoscape, Gephi, SocNetV (free software) and muxViz (open source). In this research, UCINet 6 for Windows was used.

With regard to the aforementioned hypotheses, of the various indicators employed in social network analysis, ‘degree centrality’ was used as an indicator of network breadth. In graph theory and network analysis, indicators of centrality identify the most important vertices within a graph. Applications include identifying the most influential person(s) in a social network, key infrastructure nodes in the Internet or urban networks and super-spreaders (of disease). Centrality concepts were first developed in social network analysis and many of the terms used to measure centrality reflect their sociological origin [23]. Degree centrality is defined as the number of ties related to a node. UCINet (https://sites.google.com/site/ucinetsoftware/home) calculates the degree, and normalized degree centrality of each vertex and provides the overall network degree centralization. The number of vertices adjacent to a given vertex in a symmetric graph is the degree of that vertex. For non-symmetric data, the in-degree of a vertex u is the number of ties received by u and the out-degree is the number of ties initiated by u. In addition, if the data are valued, the degrees (in and out) will consist of the sums of the values of the ties. The normalized degree centrality is the degree divided by the maximum possible degree expressed as a percentage.

Next, 'constraint' was used as an indicator of the relationship with a distant organization. A structural hole is a relationship with no redundancy between two contacts. Constraint is essentially a measure of the extent to which ego is invested in people who are invested in other alters of the ego [7]. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes several measures of structural holes, including all of the measures developed by Burt. The measures are computed for all nodes in the network, treating each one in turn as the ego. Constraint is a measure of the extent to which ego is invested in people who are invested in other alters of the ego [24].

Next, 'ego density' was used as an indicator of a strong narrow network. Density refers to the 'connections' between participants. Density is defined as the number of connections a participant has, divided by the total possible connections a participant could have. For example, if there are 20 people participating, each person could potentially connect to 19 other people. A density of 100 % (19/19) is the greatest density in the system. A density of 5 % indicates there is only 1 of 19 possible connections [25]. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes standard ego network measures for every actor in a network. This routine systematically constructs the ego network for every actor within the network and computes a collection of ego network measures. Both in and out networks can be considered separately or together.

In addition, 'brokerage' and 'betweenness' were used as indicators of the style of network platform. Brokerage is the number of pairs not directly connected. The idea of brokerage is that the ego is the 'go-between' for pairs of other actors. In an ego network, the ego is connected to every other actor. If these others are not connected directly to one another, the ego may be a 'broker' ego, intervening in the paths between others. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes the number of times the ego lies on the shortest path between two alters, i.e. the number of pairs of alters that are not directly connected. Normalized brokerage is the brokerage divided by the number of pairs. This assesses the extent to which the ego's role is that of broker. One can be in a brokering position a number of times, but this is a small percentage of the total possible connections in a network. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes brokerage normalized by the number of brokerage opportunities, which is a function of ego network size.

Betweenness is an aspect of the larger concept of 'centrality'. Ego is 'between' two other actors if it lies on the shortest direct path from one to another. The ego betweenness measure indexes the percentage of all geodesic paths from neighbour to neighbour that pass through the ego. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes the sum of the proportion of times the ego lies on the shortest path between each pair of alters. For alters connected to each other, the contribution between the pair is zero. For alters connected to each other only through the ego, the contribution is 1. For alters connected through the ego and one or more other alters, the contribution is $1/k$, where k is the number of nodes connecting that pair of alters. Normalized betweenness compares the actual betweenness of the ego and the maximum possible betweenness in the neighbourhood of the size and connectivity of the ego. The 'maximum' value for betweenness would be achieved in the case that the ego is at the centre of a 'star' network; that is, no neighbours communicate directly with one another and all communications between pairs of neighbours go through the ego. UCINet (https://sites.google.com/site/ucinetsoftware/home) computes Ego Betweenness normalized by a function of the number of nodes in the ego network. The notions of 'brokerage' and 'betweenness' are differing ways of indexing just how 'central' or 'powerful' the ego is within its own neighbourhood. This aspect of how an actor's embedding may provide strategic advantage has received a great deal of attention.

RESULTS AND DISCUSSION

RESULTS

Correlation analysis was conducted between the network analysis indicator computed using the aforementioned analytic method and the total number of registered patents and an operating profit ratio. The number of patents registered is a proxy variable for the results of R&D. The number of patents registered is not the number of applications, but the number of patents approved. SPSS Version 23 was used for the correlation analysis. The results of the correlation analysis are shown in Table 1.

Table 1. Coefficient of correlation between the network indicator, registered patents and profit ratio.

Network indicator	Total number of registered patents	Operating profit ratio
Degree Centrality	0,487**	–0,006
Constraint	–0,427*	–0,297
Density	0,164	0,383*
nBroker	0,164	0,383*
Normalized Ego Betweenness	0,138	0,394*

*statistically significant at 5 %
** statistically significant at 1 %

DISCUSSION

Each hypothesis is considered based on the results of the aforementioned correlation analysis. First, H1 concerns the breadth of the innovation network. 'Degree centrality' was used as the network analysis indicator. The analysis shows a significant correlation between network breadth and the number of registrations of patents. In the IoT field, R&D results can be generated through wide-ranging cooperation with many companies. This shows that open innovation is effective in R&D within the IoT field. This may be because IoT is realized through cooperation among wide-ranging technologies and industries.

However, there was no significant correlation between network breadth and the profitability ratio. The breadth of the innovation network is not necessarily linked to the profitability of the IoT business. To advance a joint research project with many companies, it is assumed that considerable investment in R&D is necessary. If investment in R&D increases, the volume of its results may also increase. However, if the results of such research are not connected with the business, cost effectiveness may be lower.

H2 concerned innovation networks involving companies with a distant relationship. 'Constraint' was used as a network analysis indicator, with the analysis showing a negative correlation between constraint and the number of registered patents. Moreover, there was no correlation with profitability. That the value of constraint is low shows that the degree of freedom of an entity is high. When the constraint is small, it may be easy to reproduce the results of research. Granovetter's hypothesis that 'weak ties are strong' is posited to be applicable to IoT-related R&D. However, the volume of research results is not necessarily connected to profitability as in the aforementioned centrality. To increase profitability, it is argued that it is not only the novelty and number of R&D results that matter, but also the existence of a business strategy or scheme.

H3 concerned the narrowness (depth) of an innovation network. 'Ego density' was used as the network analysis indicator analysing the correlation with the reciprocal number. The results of the analysis were the opposite of those for degree centrality and constraint: that is, although the narrowness (depth) of the innovation network was not significantly correlated with the number of patents registered, there was a significant correlation with the profitability ratio. Thus, the optimal strategy may not necessarily be to undertake R&D with a wide range of external companies; rather, IoT companies may seek to narrow the scope of R&D and build a close relationship with a specific collaborator. In terms of specialization, the capability to understand and utilize the external results of research may also increase. As a result, the ratio of operational efficiency over R&D investment may increase.

H4 concerned innovation related to the style of the platform network. As network analysis indicators 'nBroker' and 'Normalized Ego Betweenness' were employed, considering intervention tendency. The results of the correlation analysis were the same as for the narrowness (depth) of an innovation network. As mentioned above, the network platform style is not simply related to network size or breadth. It is assumed that different industrial or technological groups are connected through a certain company. For example, in personal computing, Microsoft's OS came together by uniting hardware and software, thus generating profitability. The same structure may apply to the dawn of an IoT business. However, the formation of the platform style of an innovation network does not necessarily correlate with the volume of research results. This may show the advantage of a technological strategy that focuses on the company at the centre of the network, rather than distributing R&D resources widely.

At present, in the dawn and the growth phase of IoT businesses, various large-scale corporations, start-up companies, research institutions, etc. globally are investing many research resources and are performing a wide range of R&D activities in such firms. To succeed in the face of extreme innovation competition, it is important to have an excellent technological strategy. It is considered desirable to strengthen strategic cooperation, makes the company the platform of an innovation network and selecting an external company or companies with which to cooperate carefully rather than distributing R&D resources widely, thus increasing the efficiency of R&D.

CONCLUSIONS

The objective of this research was to analyse quantitatively the relationship between innovation network structure and the results of innovation in relation to the dawn and growth phase of IoT firms. Using intellectual property database and employing social network analysis, this research investigates quantitatively the structure of innovation networks in terms of the results and operational efficiency of R&D.

As an implication of this research, it is expected that the results of this quantitative analysis will serve as criteria for evaluation by managers of companies considering R&D strategy in the IoT field, which is in line with numerous previous research [26-28]. In terms of the limitations of this research, there is no telling whether the traits of the birth and growth phases of such firms will be appropriate in later phases. In addition, the object of analysis concerned only Japanese firms and thus the results of the analysis may not be generalizable to other contexts. Therefore, further research, particularly undertaking international comparisons, is needed.

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