2E07 R&D Networks in the U.S.: Emerging Concentration?

○岡村浩一郎, Nicholas S. Vonortas (The George Washington University)

This paper empirically studies two types networks, one formed through U.S. patent citations (Patent network) and another formed through the participation in research joint ventures (RJV network) in the U.S. context. We examine the longitudinal development of the network structure of four industries (automobiles, pharmaceuticals, computer hardware, computer software) as well as the whole industry. We focus on the network core, *i.e.* the concentration of certain organizations occupying the central position in the networks. The core reflects the individual industries' 'sectoral innovation systems' that are influenced by their underlying technologies.

1. Introduction

Organizations are embedded in the layers of various networks through a wide range of social, industrial, or economic relations. Patent citations and the participation in Research Joint Ventures (RJVs) are examples of such relations. In the recent years, researchers have become more interested in these networks and have studied them extensively. It is now widely agreed that network is an important organizational form for R&D activity. They also found that the technologies used in an industry influenced the network structure (*e.g.* Orsenigo et al., 2001). The concept that technological factors influence the industry and the pattern of innovations itself isn't new although it might not have gone far enough to the relation between technology and the network structure. It is often described as the 'sectoral innovation system.' Several researchers have proposed the frameworks capturing the relation between technological factors and the industries (*e.g.* Pavitt, 1994; Malerba and Orsenigo, 1996).

Kash and Rycroft (1993) focused on the characteristics of technologies and made a distinction between simple and complex technologies. They claim that a simple technology is one which can be understood in detail by an expert while a complex technology cannot. Pharmaceuticals, for example, belongs to the simple technology. Patent is an effective tool to protect the technology and to communicate it to other experts in the industries characterized by the simple technology. Automobiles and computer software are labeled as complex technologies. In these industries, technologies and knowledge are accumulated and transmitted by organizational learning. When we consider the implication of their categorization for the network structure, it is expected that different industries' networks, which may be viewed as the aggregation of the behaviors of individual organizations influenced by the characteristics of technologies they use, follow the distinct developing patterns.

we describe the data briefly in Section2. We examine the network structure of the Patent and RJV networks across the industries in Section 3. Finally in Section 4, we discuss how individual industries' 'sectoral innovation systems' have influenced the network structure.

2. The data

2.1. Data sources

The data comes from two sources: The NBER Patent Citations Data File prepared by the National Bureau of Economic Research (NBER) and the NCRA-RJV database, which is maintained by the George Washington University's Center for International Science and Technology Policy.

The NBER Patent Citations Data File compiles detailed information on almost 3 million U.S. patents granted from January 1, 1963 and December 31, 1999, including all citation made to these patents from 1975 and 1999 (over 16 million). Patent information includes application year, granted year, inventor(s), country, assignees, citations, and so on. For more detailed description of the database, see Hall et al. (2001).

The NCRA-RJV database is a database of Research Joint Ventures (RJVs) that have been reported on the U.S. Federal Register. Currently, it covers the information regarding 796 RJVs published in the Federal Register from January 1, 1985 to December 31, 1999. The information is made available by the enactment of the National Cooperative Research Act in 1984 and its amendment, the National Cooperative Research and Production Act in 1993. The participants of an RJV seeking for the exemption from the anti-trust accusation are required to file notifications with the U.S. Department of Justice disclosing the composition and principal research content of the RJV. Vonortas (1997) provided the extensive description of the database.

We obtained a group of 2,435 organizations after merging the two databases by identifying the ultimate parental organizations in the NCRA-RJV database, which also appear as assignees in the NBER Patent Citations Data File. They constitute the basis of our analysis. We confirmed that the merged database inherited the characteristics of the two parental databases very well. The merged database thus enables us to examine organizations' networking activities in patenting and RJV activities simultaneously.

3. The analysis

3.1. Patent network and RJV network

We studied the structure of the Patent network formed through patent citations and the RJV network formed through their participation in RJVs, using the tools of social network analysis. In social network analysis, organizations are represented by 'nodes,' and a connection between two nodes are represented by a 'link'[1]. The Patent network is constructed using the information on patent citations between the patents granted to the organizations in the merged database. 'Self-loops' *i.e.* links to oneself, may happen in the Patent network if a firm cites its past patents. We eliminate the 'self-loops' because our main interest is the connections between organizations rather than the connections within organization. The RJV network is constructed by creating a link between two organizations when they participate in the same RJV(s). We eliminate the 'self-loops' that may happen when, for example, a firm participates in an RJV multiple times through its divisions or subsidiaries.

The Patent network has a 'direction.' There exist the information flows from cited patents to citing patents. We didn't take the direction into consideration in the analysis. A link is created if there is a patent citation in either direction between two organizations. In contrast, the RJV network doesn't have a direction since the only available information in the merged database is whether the organizations participate in RJVs or not.

The observation period is fifteen years between 1985 and 1999. It is same as the NCRA-RJV database. We chose the five-year period in creating the networks based on a finding that alliances' life span is five years in average (Kogut, 1988).

3.2. Industry selection

Each industry has the unique sectoral innovation system and may have followed its own evolutionary path. As a result, each industry may develop the unique network structure in the network among the organizations in the industry. We examined the network structure of the following four industries: automobiles (SIC 371), pharmaceuticals (SIC 283), computer hardware (SIC 357), and computer software (SIC 737) as well as the whole industry. They are defined based on the three-digit level SIC codes shown in parentheses after the industry names.

We took the following two-step approach when identifying the organizations belonging to each industry. Firstly, we identified a group of firms, in the merged database, which share the same three-digit SIC code (industry firms). We used the firms' SIC code assigned in the Compustat in the process. Then we selected the organizations that have a link(s) with the industry firm(s) through patent citation for the Patent network or RJV participation for the RJV network (industry partners). Industry partners is a larger set of organizations that include the industry firms. The Patent and RJV networks share the industry firms in each industry. However, the industry partners consisting of the Patent and RJV networks aren't same between the two.

The motivations driving the organizations to participate in the Patent and RJV networks might be different from one another. The two-step approach enables us to capture the nature and the outcome of organizations' 'networking activities' in the Patent and RJV networks.

3.3. Results

We first studied the longitudinal change in the number of nodes (organizations) in the Patent and RJV networks. The number of nodes have been monotonously increasing for all industries in the Patent network. The numbers of nodes in the RJV network, in contrast, have either remained constant or decreased gradually. Literatures have reported the recent increase in the formation of strategic alliances including RJVs. The observation of the RJV networks suggests that the recent increase in the RJV formation doesn't necessarily mean that more organizations have participated in the RJVs, however. Rather it implies that certain organizations might have repeatedly participated in the RJVs.

Fig.1 and Fig.2 show the graph density of the Patent and RJV networks, respectively. Graph density is the total number of existing links in a network divided by the number of all possible links among the nodes in the network. The measure tells us how dense the connections among organizations are. A smaller graph density, for example, means that there are fewer links between nodes in the network.

All the graph density in the Patent network have monotonously decreased. The observation agrees with the previous observation of the number of nodes; more organizations have obtained the patents and have joined in the Patent network. As for the RJV network, the graph density has declined except the pharmaceuticals. Together with the previous finding, it indicates that smaller number of the organizations have participated in the RJVs than they had done so before. The

[1] For the detailed explanation of the social network analysis, see the literatures in social network analysis (*e.g.* Wasserman and Faust (1994)).

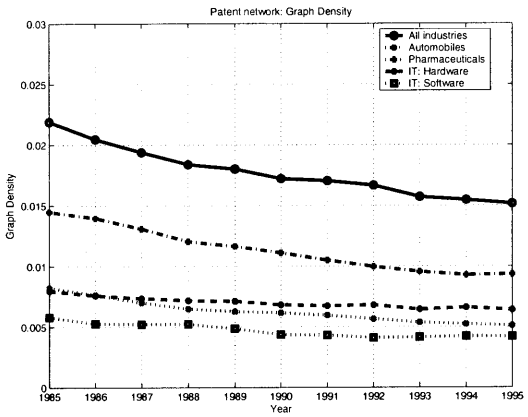

Figure 1. Patent network: Graph Density

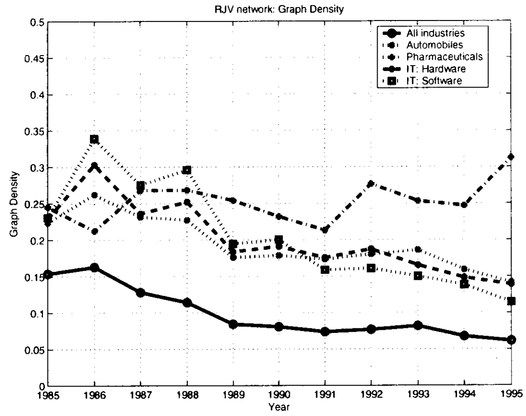

Figure 2. RJV network: Graph Density

pharmaceuticals is the only industry showing the increase in the graph density in the RJV network. Their RJV network has become more consolidated in both number of participants and the connections.

In sum, the Patent network has become flourished in the recent years. Then, other things being equal, it would be more important for the organizations to position themselves in more favorable location in the network. If certain organizations indeed move toward such favorable position in the Patent network, we will observe a network core, *i.e.* the concentration of certain organizations occupying the central in the network, emerges. The observation of the RJV network, on the other hand, indicates a possibility of the concentration. If the RJV network is, in fact, formed around the certain organizations, we will observe a network core in the RJV network, too. Seeking for the answer for the question, we study the graph betweenness of the Patent and RJV networks next.

Graph betweenness captures the overall degree of concentration of the network. The more organizations have direct connections with one another, the smaller is the graph betweenness. A large graph betweenness means that there exist a network core, the concentration of certain organizations playing the role of 'hub' or 'gatekeeper,' which may control the connections between the organizations.

Fig. 3 and Fig. 4 show the longitudinal change in the graph betweenness in the Patent and RJV networks, respectively. The graph betweenness of the whole industry's Patent network shows the monotonous increase while its graph betweenness in the RJV network remains roughly constant. In contrast, the graph betweenness of the automobiles' Patent network has declined; but its graph betweenness of the RJV network shows an increase. The graph betweenness of the computer hardware moves in the similar manner as the automobiles. The graph betweenness of the pharmaceuticals' Patent network has increased while the graph betweenness in the RJV network has decreased significantly. Finally, the computer software's betweenness in the Patent network has remain flat while its graph betweenness in the RJV network has slowly increased after the initial dip.

The network core has emerged in the pharmaceuticals' Patent network while its RJV network has become less concentrated. The network core, on the other hand, has emerged in the automobiles' and the computer hardware's RJV networks while their Patent networks have become less concentrated. The network core has emerged in the computer software's RJV network; but its Patent network hasn't become either concentrated or less concentrated. Finally, The whole industry's Patent network has formed the network core; the core hasn't either formed or dissolved in the RJV network, however.

4. Conclusions

We observed that the network core has emerged in either the Patent or RJV network but not in both networks in each industry. It suggests that the dynamics underlying the Patent and RJV network are different from one another. We found the formation of the network core in the pharmaceuticals' Patent network. The pharmaceuticals' sectoral innovation system is characterized by the simple technology where patenting is an effective tool in protecting and exchanging the tech-

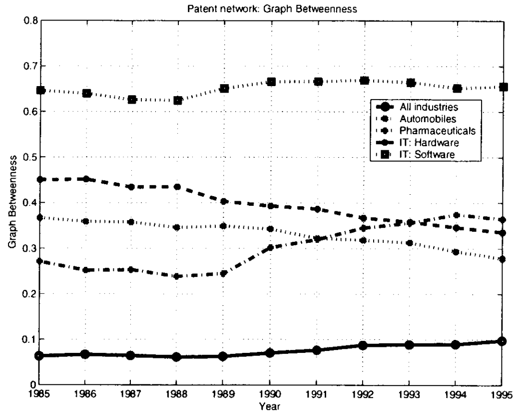

Figure 3. Patent network: Graph Betweenness

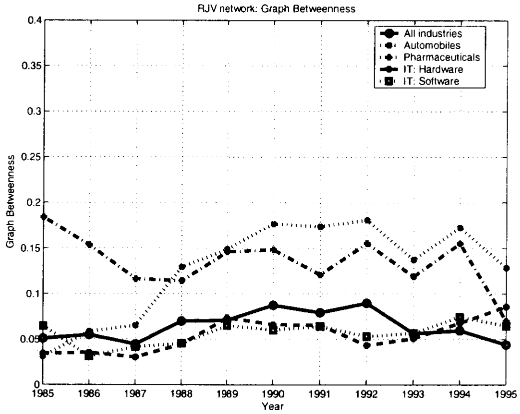

Figure 4. RJV network: Graph Betweenness

nologies. The aggregation of the behaviors of the pharmaceuticals that are directed by the characteristics of simple technology have resulted in the formation of the network core in the Patent network.

The automobiles, which is characterized by the complex technology, has formed the network core in the RJV network. The network core has emerged in the computer software's RJV network, too, which is also characterized by complex technology. Organizational learning is effective to accumulate and exchange the technologies in these industries, The computer hardware that is closely linked with the computer software, has formed the network core in the RJV network. The whole industry, which we might view as the U.S. quasi-national innovation system, has formed a network core in the Patent network. In the U.S. national innovation system, clearly-defined and thus easily transmittable knowledge such as patents is favored over the knowledge that needs to be cumulatively learned through long-time collaboration. Such characteristics have influenced the network structure of the whole industry.

Acknowledgment

Koichiro Okamura and Nicholas Vonortas acknowledge the support from the U.S. National Science Foundation (grant# SRS-0097948) and the George Washington University's Center for the Study of Globalization.

References

Hall, B. H., Jaffe, A. B., Trajtenberg, M., Oct. 2001. The NBER patent citations data file: lessons, insights and methodologial tools. NBER Working Paper 8498, National Bureau of Economic Research, retrieved from http://www.nber.org/papers/w8498.pdf.

Kash, D. E., Rycroft, R., Feb. 1993. Two streams of technological innovation: Implications for public policy. Science and Public Policy 20 (1), 27–36.

Kogut, B., 1988. A study of the life cycle of joint ventures. In: Contractor, F. J., Lorange, P. (Eds.), Cooperative Strategies in International Business. Lexington Books, Lexington, MA, pp. 169–185.

Malerba, F., Orsenigo, L., May 1996. Schumpeterian patterns of innovation are technology-specific. Research Policy 25 (3), 451–478.

Orsenigo, L., Pammolli, F., Riccaboni, M., Mar. 2001. Technological change and network dynamics: Lessons from the pharmaceutical industry. Research Policy 30 (3), 485–508.

Pavitt, K., 1994. Key characteristics of large innovating firms. In: Dodgson, M., Rothwell, R. (Eds.), The handbook of industrial innovation. Elgar, Aldershot, U.K., pp. 357–366.

Vonortas, N. S., Dec. 1997. Research joint ventures in the US. Research Policy 26 (4-5), 577–598.

Wasserman, S., Faust, K., 1994. Social Network Analysis. Cambrdige University Press.