A Network Analysis of Japanese Innovation Clusters

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***Abstract*— Regional clusters can offer more opportunities for innovation than scattered locations and understanding the network structure in the focused region is an inevitable step to grasping the current status of regional industrial structure and effective policy development. We examine the interfirm networks of two famous regional clusters in Japan, Kyoto and Nagano and discuss the route to enhance regional networking for innovation. Both regions have established innovative interfirm networks which are highly clustered and had small path length in average. Firms trade not only within modules but also among ones. These structures have contributed to innovate radically in these regions. However, the hub firms are old and the phenomenon of network aging might prevent further innovations. In order to accelerate innovations, interfirm networks have to be more open by reducing the barriers of "Keiretsu", strengthening trade and economic linkages to other accumulations nearby, and taking in young start-ups into the regional ecosystem.**

***Index Terms*—regional clusters, innovation, network, headquarter, entrepreneur, start-up**

I. Introduction

In the last decades, there has been a widespread resurgence of interest in the economics of industrial locations, particularly in the issue of regional clusters [1]. Innovative milieu [2], technology districts [3], and regional innovation systems [4] are also used as regional innovation models although they tend to be used for different focuses, contexts, and applications. In these models, innovation is associated with places where relevant resources are easily accessed by firms in close proximity. Some regions have superior innovative capabilities, as evidenced by the localized production of patents [5, 6].

Porter argued that enduring competitive advantages in the current global economy lie increasingly in local things - knowledge, relationships, motivation - that distant rivals cannot match, while companies in a global economy can source capital, goods, information and technology from around the world [7]. Silicon Valley and the Route 128 zone of Boston [8, 9], Cambridge [10], Baden-Württemberg [4] and “Third Italy” [11, 12] are typical example of such distinguished regions.

Regional clusters can offer more opportunities for innovation than scattered locations, which is typically driven by reduced transaction cost [13], access to venture capitalists [14, 15], local labor market pooling [16], entrepreneurial activity within the region [17, 18], enhancement of knowledge diffusion [19,20], and localized learning [19, 21]. Regional clusters are distinguished from pure agglomerations by their interconnected nature, i.e. clusters are characterized as collaborative networks and concentrations of collaboration and competition, which offer significant opportunities and stimulate economic development [7]. Another characteristic of regional clusters is the diversity of actors contained within. According to Porter [1, 7, 22], an industrial cluster includes suppliers, consumers, peripheral industries, governments, and supporting institutions such as universities. In sum, the network among actors is the key to understanding the performance of regional clusters [23].

Networks are especially important for small and medium-sized firms, since they lack their own resources to compete effectively with other firms [24, 25]. To overcome these deficiencies they must either depend on resource transfers from large enterprises or be linked to a community of small firms in which productive resources are jointly procured, developed, and utilized. Stinchcombe used the term, ‘liability of newness,’ to explain the higher rate of failure among young firms, which he attributed to the difficulties new firms have in securing the resources they need for survival [26]. This liability arises at least in part because young firms have less of the legitimacy needed to gain trust and support from other actors [27]. Dense networks can reinforce trust building. Trusting behavior affects the persistence of interfirm networks and improves the quality of information flows critical to innovation [26]. The connection to market leaders or highly regarded firms that can give a reputation or legitimacy to the young firm [28]. In this way small firms can become parts of a 'set of organization' [29], enjoy many of the advantages possessed by large firms, and consequently offer jobs of comparable quality. Especially for regional clusters consisting of medium and small firms, networking activity and the resulting network structure should play an important role.

Therefore, understanding the network structure in the focused region is an inevitable step to grasping the current status of regional industrial structure and effective policy development. Owen-Smith et al. [30] and Owen-Smith and Powell [31] investigated network structures consisting of biotechnology firms, pharmaceutical corporations, venture capitals, and public research organizations in the United States. They analyzed intra- and inter-cluster linkages, and showed that the Boston cluster occupied a central position in the network by using social network analysis and network visualization. However, except for a few works, literature is not yet rich enough to facilitate understanding and evaluation of the network structure of regional clusters. Given the ongoing lack of a comparative study on inter-firm networks among regional clusters, we have little empirical evidence with which to discuss and understand the similarities and differences among network structures of regional clusters. The aim of this work is to investigate network structures in two regional clusters and to discuss the route to enhance regional networking for innovation. We examine the interfirm networks of two regional clusters in Japan, Kyoto and Nagano. Next, we illustrate our research methodology.

II. METHODOLOGY

A. Interfirm network

The term "network" refers to a set of nodes and the relationships that connect them (see Fig. 1.). A social network can be defined as 'a set of nodes (e.g. persons, organizations) linked by a set of social relationships (e.g. friendship, transfer of funds, overlapping membership).

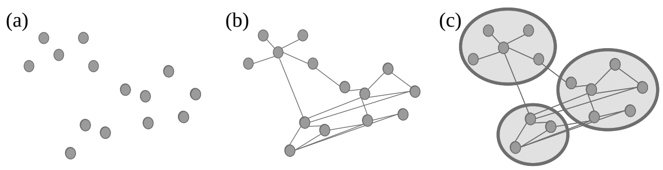

Fig. 1. Levels of analysis. (a) aggregates of firms. (b) interfirm network. (c) firm modules.

Because regional clusters are distinguished from pure agglomerations by their interconnected nature, the level of our analysis is interfirm network and firm modules. In this paper, we regard customer-supplier relationships as links in the network among various relationships between multiple firms, because these relationships are known as the best source of information for Japanese firms. A white paper on small and medium enterprises in Japan reports that the top priority information channel for Japanese firms is the contact with customers and outsourcing contractors [34]. Although there is a variance of emphasis between firms that have entered new fields and those that have not entered, customer-supplier relationships is cited as the remarkable information channel. Researchers also increasingly regard interaction within customer-supplier relationships as key to the successful management of innovation, as customer and supplier relationships play a critical role in knowledge development, resource mobilization and co-ordination [35]. The key characteristic of customer-supplier relationships in Japan is the fact that the relationships with customers are more dedicated and long-term than in other countries [36, 37]. In the following, we explained our data and analyzing schema.

B. Data

We select two clusters, Nagano and Kyoto in order to compare. We listed firms corresponding with the industrial categories located in each region, using a database provided by NTT. This NTT compiled database includes the addresses and industrial category of the firms registered by themselves. We define business transactions between firms as links. The data by the Teikoku Data Bank (TDB) has up to five suppliers and customers for each firm, meaning each firm can link up to a maximum of ten other firms. Because business transactions include a range of traded volume, this restriction on the number of links enables us to extract not the entire business network in the region but just its essential features. One study reports that firms have an average of 10 important business relationships [38]. These datasets were collected in the year 2007 for Kyoto and 2005 for Nagano. The analysis was performed at the geographic scale of prefecture. We integrated these two databases by NTT and TDB into a single dataset on networks consisting of nodes and links. The networks are non-weighted and non-directed. Subsequently, we extract the maximum connected component of each network. We analyzed the network structure of firms that locate in the region.

C. Analyzing Procedures

In order to investigate network structures in two regional clusters, we investigated the structure of interfirm network by three levels; macro, semi-macro and micro. As the macro level analysis, the two properties well know as “small-world” were calculated. The first one, the clustering coefficient quantifies how well connected the neighborhood of the node are. The clustering coefficient C_i for a vertex i is then given by the proportion of links between the vertices within its neighborhood divided by the number of links that could possibly exist between them. For a directed graph, e_{ij} is distinct from e_{ji}, and therefore for each neighborhood N there are $k(k-1)$ links that could exist among the vertices within the neighborhood. Therefore, C_i

reflects the extent to which friends of i are also friends of each other. The nodes with high Ci occupy a central position in the locally clustered neighboring nodes. The clustering coefficient (C) of entire graph is the average of all Ci.

The second one, the average path length (L) is frequently used to express the relative accessibility of an average node to the other nodes in a network, is defined as the number of links in the shortest path between two nodes, averaged over all pairs of nodes [40]. Evaluation of the average path length is essential to evaluate network performance. Networks can act as pipes of information about resource opportunities and potential partners. In particular, the individual small firm lacks sufficient resources to compete effectively with large firms. To overcome these deficiencies it must either depend on resource transfers from large enterprises, i.e. on a foster relationship, or be linked to a community of small firms in which productive resources are jointly procured, developed, and utilized. In this way small firms can become parts of "big" organizations, enjoy many of the advantages possessed by large firms, and consequently offer jobs of comparable quality [24]. A small value of L indicates a small diameter of the network and that firms in the network can pool resources over networks via fewer paths, and in a network with small L structural holes are buried.

In order to comparatively evaluate network performance, we normalized C and L by C_{rand} and L_{rand}, as adopted by Watts and Strogatz [40], i.e. we use clustering coefficient and average path length ratio defined by C/C_{rand} and L_{rand}/L as a measure of the small world property of the network. Because small world property improves as both L_{rand}/L and C/C_{rand} increases, it is desirable for a network to have higher L_{rand}/L and C/C_{rand}.

Then, we focus on 'a set of organizations' [29]. In the following, we name tightly knit groups as modules, where dense intra-group links exist. As noted by Staudenmayer *et al.* [42], industries are characterized by interfirm modularity. In order to detect modules, we perform a topological clustering of networks. Although such a methodology had been difficult to achieve due to the difficulty in performing cluster analysis of non-weighted graphs consisting of many nodes, recently proposed algorithms [43, 44] facilitate fast clustering with calculation time in the order of $O((l+n)n)$, or $O(n^2)$ on a sparse network with l links; hence this could be applied to large-scale networks. The algorithm proposed was based on the idea of modularity. Modularity Q was defined as follows [43-45]:

$$Q = \sum_{s=1}^{N_m} \left[\frac{l_s}{l} - \left(\frac{d_s}{2l} \right)^2 \right]$$

where N_m is the number of modules, l_s is the number of links between nodes in module s, and d_s is the sum of the degrees of the nodes in module s. In other words, Q is the fraction of links that fall within modules, minus the expected value of the same quantity if the links fall at random without regard for the modular structure. A good partition of a network into modules must comprise many within-module links and as few as possible between-module links. The objective of a module identification algorithm is to find the partition with the largest modularity. The algorithm to optimize Q over all possible divisions is as follows. Starting with a state in which each node is the only member of one of n modules, we repeatedly join modules together in pairs, choosing the join that results in the greatest increase in Q at each step. Since a high value of Q represents a good modular division, we stopped joining when ΔQ became minus. At the maximal value of Q, Q_{max}, we obtain a modular structure of a network with effective partition. Modularity Q_{max}, means the connectedness among modules. A network with larger Q_{max} means that there are more independent modules in the network, while one with smaller Q_{max} means that modules are intermixed and the network is more uniform. We can expect that there are a number of structural holes between modules in the network with larger Q_{max}. On the other hand, structural holes are buried in the network with smaller Q_{max}. In other words, in the network with larger Q_{max} there is ample room to build bridges between separated modules.

As the semi-macro analysis, we analyzed each module in detail. Firms are divided into modules at the maximal value of Q. A module is a set of densely-connected firms and whole networks are connected by the links among modules. In this process, characteristics of each module could be revealed from the viewpoint of industry and geography.

In the final step, as the micro analysis, the characteristics of hub firms are investigated. For each hub firms, two variables z and P are calculated and the roles of each firm in the topology are analyzed. After dividing the papers into optimized clusters using Newman's method, the role of each paper is determined by its within-cluster degree and its participation coefficient, which define how the node is positioned in its own cluster and between clusters [45]. This method is based on the idea that nodes with the same role should be at similar topological positions. These two properties can be easily calculated after clustering the network. Within-cluster degree z_i measures how "well connected" node i is to other nodes in the cluster, and is defined as

$$z_i = \frac{\kappa_i - \bar{\kappa}_{s_i}}{\sigma_{\kappa_{s_i}}}$$

where k_i is the number of edges of node i to other nodes in its cluster s_i, k_{si} is the average of k over all nodes in s_i, and σ_{ksi} is the standard deviation of k in s_i. z_i is high if the within-cluster degree is high and vice versa. Participation coefficient P_i measures how "well distributed" the edges of node i are among different clusters and is de fined as

$$P_i = 1 - \sum_{s=1}^{N_M} \left(\frac{\kappa_{is}}{k_i} \right)^2$$

where k_{is} is the number of edges of node i to nodes in cluster s, and k_i is the total degree of node i (the number of edges of node *i*). Participation coefficient P_i is close to 1 if its edges are uniformly distributed among all the clusters and 0 if all its edges are within its own cluster. Nodes with large *z* are strongly connected within the module. On the contrary, ones with large *P* are global hubs and connected among modules. This analysis enables us to extract not only the hub firms but also the roles of them in the network.

III. Results

Network variables for macro analysis are shown in Table 1. For instance, the clustering coefficient of Nagano was 0.07 and this meant that every two firms, which trade with a certain company, trade at 7% of the time. Compared to the one of random network, it was more than twelve times. The average path length was 4.04. Nagano could be said a city of “four degrees of separation.” This path length value is only 25% longer than the one of random network. Therefore, Nagano has “small-world” properties where clustering coefficients are much larger than the ones of random network ($C >> Crand$) and the path length is close to the one of random network ($L\sim Lrand$).

The regional network of Kyoto has also “small-world” properties. However, *K/n* is smaller than the one at Nagano. The reason is that firms in Kyoto tend to trade with the firms outside Kyoto. Connection to significant market and industrial complexes of manufacturing enhance both the quantity and the quality of incoming information to the region. Therefore this did not mean that the interfirm network of Kyoto was inferior to the one of Nagano.

TABLE 1
NETWORK VARIABLES OF TWO REGIONAL CLUSTERS

Region	***n***	***K***	***K/n***	***C***	***C/Cr***	***L***	***Lr/L***	Q_{max}
Nagano	1,930	9,862	5.11	0.07	12.4	4.05	0.81	0.51
Kyoto	1,063	4,134	3.89	0.06	8.10	4.42	0.77	0.59

n: number of nodes, *K*: number of links

Then let us discuss about the semi-macro structure. The values of Q_{max} were relatively small compared to the other clusters we examined. In both regions, modules are not highly independent and the links among modules are relatively dense. This means that firms interact among modules so that both regions have appropriate interfirm network structure to for innovations.

The module structure at Nagano was shown in Fig. 2 coordinated by spring layout algorithm. We use graph drawing tool, Pajek, to visualize them. The size of node is proportional to the number of firms in each module obtained by topological clustering. The width of lines is proportional to the number of links between two modules. In those figures, hub firms of each module is also shown. When the firm name is surrounded by a rectangle, it means that the headquarter of the firm locate in the region. When the firm name is not surrounded, the headquarter is outside the region. The largest module #1 contains the local firms of materials for electronics, metals, and mechanics. Module #2 is consisted of the local firms of local precision equipment manufacturers, its component makers, and its materials makers. In module #3, there were large optical equipment manufacturers as Seiko-Epson and in #4 large electronic and IT firms as Fujitu and NEC were. The characteristics of the interfirm network at Nagano were 1) there were electronic and precision equipment manufacturers in many modules, 2) local firms are independent from large makers as #3 or #4, and 3) although electronic and precision equipment manufacturers, which require various materials as metal, plastic, and ceramic, the only module of materials was #1. This meant that firms tended to buy the materials from outside of this region.

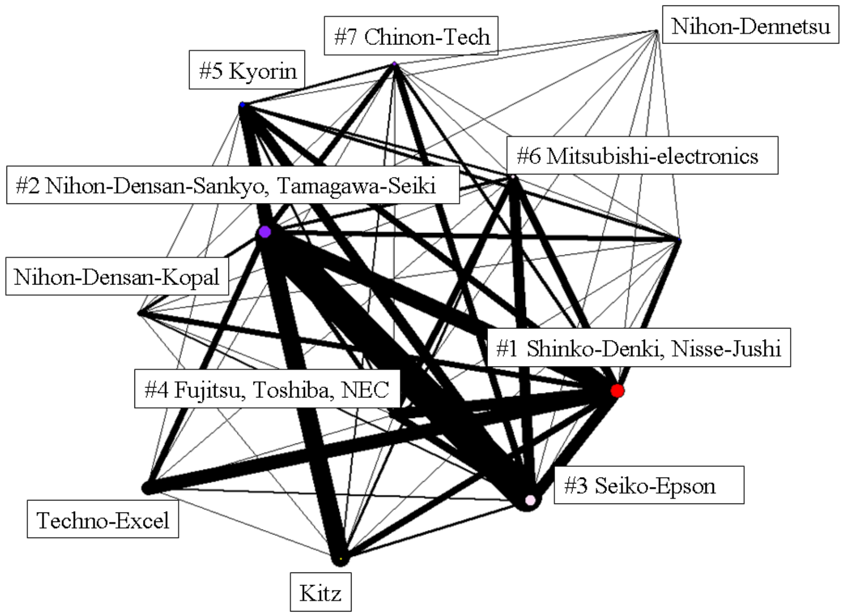

Fig. 2. Modular network structures at Nagano.

The module structure at Kyoto was shown in Fig. 3. Same industry was colored by same color in this figure. There were modules of electronics, mechanics, and precision equipment manufacturers and hub firms were Shimazu Corporation, Horiba Ltd., Murata Manufacturing Company, Ltd., Omron, and Nihon-Densan, whose headquarters were at Kyoto. The characteristic of Kyoto was that each large module, except the medical one, was in the central in the network and strongly connected to each other.

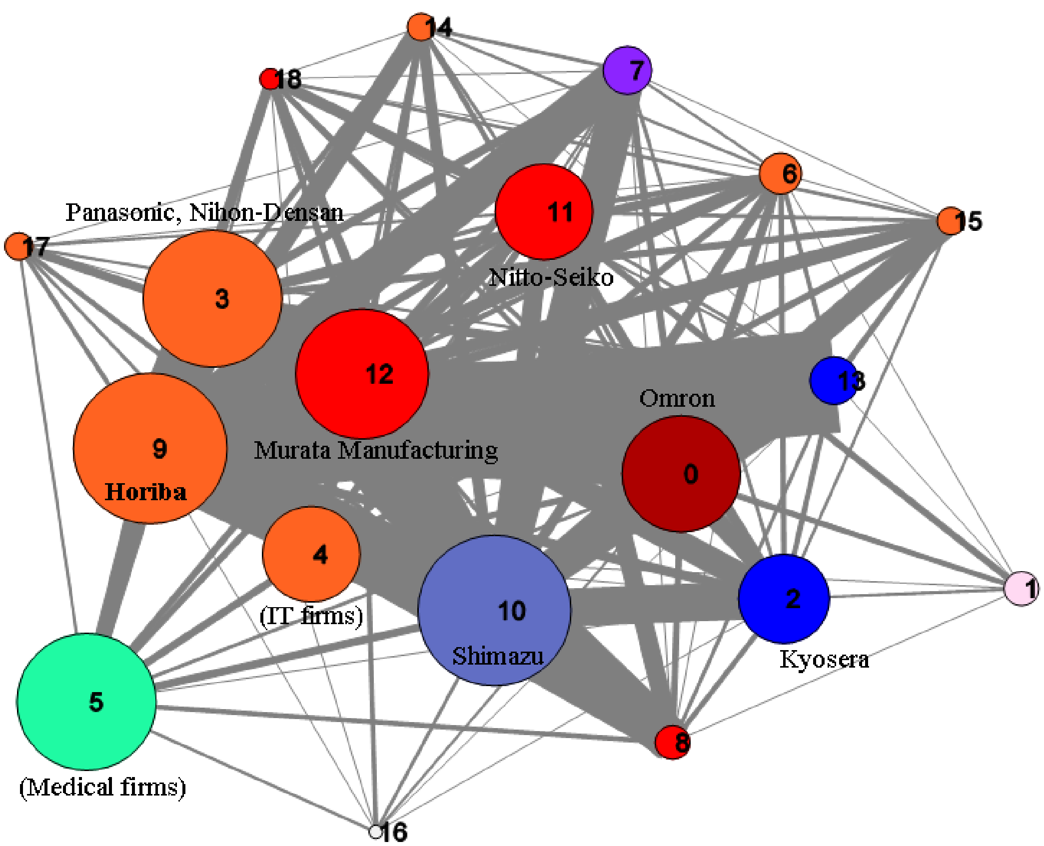

Fig. 3. Modular network structures at Kyoto.

The last analysis was about the role of each hub firms. Fig. 4 represented the *z* and *P* plots of firms in both regions. At Nagano, firms with large *z* were the hubs in large modules as Seiko-Epson (#3), Toshin-Kotetsu (#2), Fujitsu (#4), Kokko (#2), Toshiba (#6). On the contrary, firms with large *P* were national manufacturing companies whose headquarters were not at Nagano as Seiko-Epsion (#3), Mitsubishi-Denki (#6), Omron (#3), Kyocera (#3), Hitachi Electronics (#4), NEC (#4) and Toshiba (#6). Connector hubs with large *z* and large *P* as Seiko-Epsion, Fujitsu, Toshin-Kotetsu, Kokko, and Toshiba were not only the hubs in their modules but also connected to other modules so that played significant role in this region. At Kyoto, strong connector hubs with large *z* and *P* were Panasonic, Omron, Shimazu Corporation, and Kyocera. Firms which connected to other modules with large P were local firms as Murata Manufacturing Company Ltd.

These hub firms are typically aged firms in both regions. In Fig. 4, each firm was categorized by the age with the mark. This figure represented that most of young firms were not hub firms. Some of them had large *P* and connected among clusters. However most of young firms could not have large *z*. They were not hub firms not only in whole region but also in their own modules.

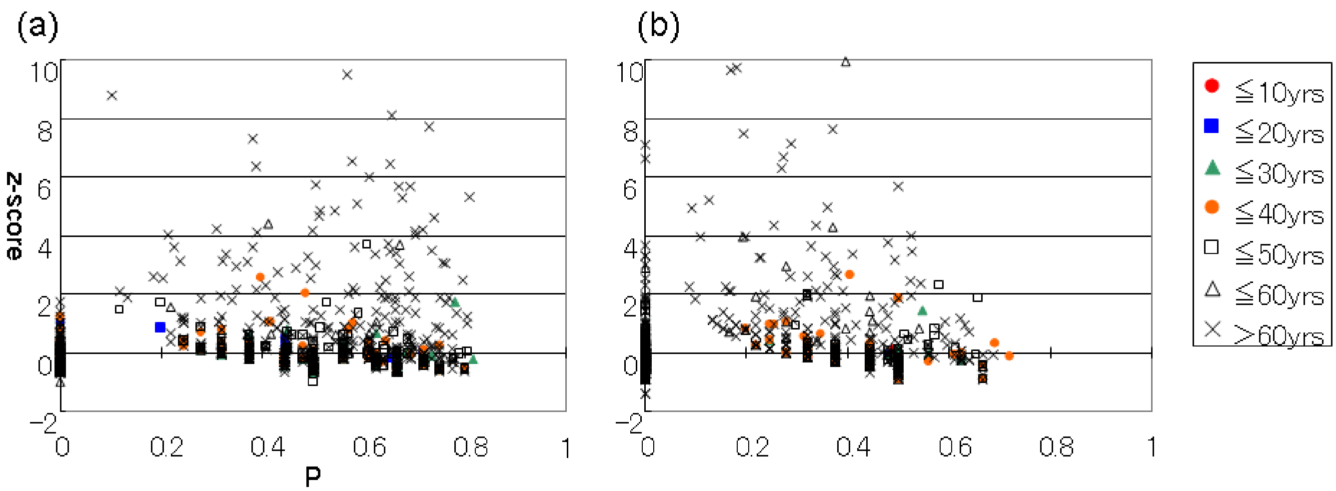

Fig. 4. Roles of hub firms in (a)Nagano and (b)Kyoto.

IV. Discussions

Both regions have established innovative interfirm network with the characteristics of “small-world” network for now with high clustering effect and small path length in average. Modularity is relatively so small that firms trade not only within modules but also among ones. These structures have contributed to innovate radically in these regions. However, the hub firms are old and the phenomenon of network aging might prevent innovations.

At Nagano, firms are almost fixed within small ecosystem. The branches of national firms are hubs within modules and play significant roles to bridge among modules. This structure has been the strength of this region but it may prevent further innovations. At Kyoto, there had been a huge number of well-grown start-ups. The headquarters of these firms are located at Kyoto and established ecosystems of “Keiretsu.” Local government has been also supportive to incubate start-ups. However, grown start-ups formed “Keiretsu”, which are the restrictions for newly established start-ups.

Even famous accumulations of Japanese manufacturing companies could not be the optimal structure as an innovation ecosystem for entrepreneurs. Basically, interfirm networks have to be more open. In concrete terms, it is necessary to reduce the barriers of "Keiretsu", to strengthen trade and economic linkages to other accumulations nearby, and to take in young start-ups into the regional ecosystem.

V. Conclusion

Regional clusters can offer more opportunities for innovation than scattered locations and understanding the network structure in the focused region is an inevitable step to grasping the current status of regional industrial structure and effective policy development. We examined the interfirm networks of two medium scale regional clusters in Japan, Kyoto and Nagano and discussed the route to enhance regional networking for innovation. Both regions have established innovative interfirm networks which were highly clustered and had small path length in average. Firms trade not only within modules but also among ones. These structures had contributed to innovate radically in these regions. However, the hub firms were old and the phenomenon of network aging might prevent innovations. In order to accelerate innovations, interfirm networks have to be more open by reducing the barriers of "Keiretsu", strengthening trade and economic linkages to other accumulations nearby, and taking in young start-ups into the regional ecosystem.

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