Structural Characteristics and Implications of Regional Innovation Networks[1]

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1. Introduction

Since the importance of innovation as a means of industrial development and economic growth has been emphasized, the region has played a key role as an appropriate spatial unit of innovation policy and a spatial scope in which connections and exchanges between innovators are more active. However, the rapidly changing industrial environment requires to redefine the direction of regional innovation policies and rethink their design. Rapid technological change and structural stagnation in main industries due to the Fourth Industrial Revolution require improvement of innovation policies for regional industrial development. In addition, the increase in non-face-to-face activities due to the spread of COVID-19 is expected to cause many changes in the role and strategy of regional innovation activities which have been based on geographical proximity and face-to-face contact. Regional comparative advantage in innovation activities lies not in simple face-to-face contact, but in the formation of social capital shared over a long period of time and active interaction between innovation actors, which are still important factors in the interpretation and sharing of complex information. In this respect, the role of regions in the innovation process is expected to remain important. In response to changes in the new environment, however, it seems necessary to change the policy direction to strengthen networks and interaction.

The main purpose of this study is to derive implications for promoting interaction between innovators and suggest policy directions. For this, we identify innovation networks in each region, analyze the status and characteristics of interactions in the networks, and diagnose the structure of relationships among innovation actors. In particular, the role and relationship within the innovation network is examined with a focus on SMEs, which are recognized as major targets of policy amid the recent rise of small

1 This paper is based on Kim et al. (2020), "A Study on the Improvement of Innovation Policy for the Development of Regional Industry: Focusing on promoting the interaction of innovators", with revisions and supplementations.

and medium-sized innovative enterprises and small start-up enterprises.

2. Identification and Structural Characteristics of Regional Innovation Networks

(1) Definition and Identification of Regional Innovation Networks

Assuming that the interaction of innovation is a result of collective action such as joint research, this study identified regional innovation networks using jointly-applied patents. A joint patent application is an innovation product in which two or more applicants participate, and in this case, it is considered that a kind of relationship has been formed between the applicants participating in the patent. In a network structure using joint application information, each node is an application subject, and each link is a concept corresponding to a relationship formed through a joint application.

In order to identify joint application information, this study used domestic patent application data provided by the Korea Patent Information Service.[2] Patent data provides applicant and inventor information (residence, organization name, etc.) for each patent. The spatial division of patents was identified by municipal and provincial administrative district using the residence information of the applicant (s), and additional information such as company size was identified by linking with other company data[3] using corporate registration numbers.

(2) Trends and Features of Jointly Applied Patents

Quantitative and qualitative characteristics of joint-applicant patent applications were analyzed to verify their representativeness as proxy variables that reflect interactions between innovators through joint research. The number of jointly-applied patents has been rapidly increasing as of late, and their impact on other innovative activities is greater than that of single-applicant patent applications.

Table 1. Process of Identifying Innovative Networks Using Joint Application Patents

Identification of co-application patent	→	Identification of spatial units	→	Identification of innovators and matching of company information
↓		↓		↓
– Identifying co-application relationships between patents sharing the same application number		– Classification of administrative districts based on applicants' residence		– Identification of innovation subject by type – Matching corporate information based on corporate registration number

2 In this paper, we use the information on joint applications involving corporations, national institutions, universities, and public research institutes (excluding individuals).

3 Company data such as KISVALUE and CRETOP were used.

Figure 1. Recent Trend in Total Patent Applications and Jointly-applied Patents

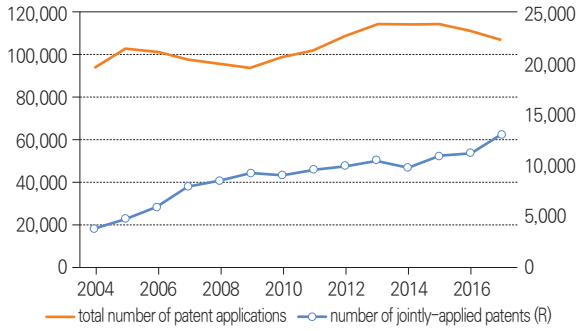
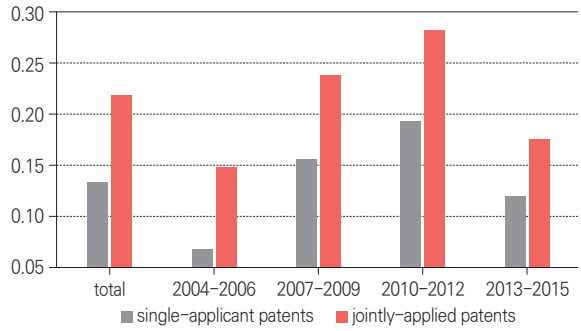


Figure 2. The Influence of a Patent Measured to the Number of Citations



Source: Author's calculation using joint patent application data of the Korea Patent Information Service.
Note: The influence of a patent is measured by the average number of citations for each type of patent.

The number of jointly-applied patents is increasing overall compared to the past, and its share in the total patent applications is also increasing gradually. The number of applications — that is, the quantitative scale — is small compared to single-applicant applications, accounting for an average of 10 percent of total patent applications. However, the average number of citations is 1.5 to 2.2 times higher than that of single-applicant applications over the entire period, meaning that joint applications have greater higher impact on other innovative activities in terms of patent quality than single-applicant applications.

(3) Status and Structural Characteristics of Regional Innovation Networks

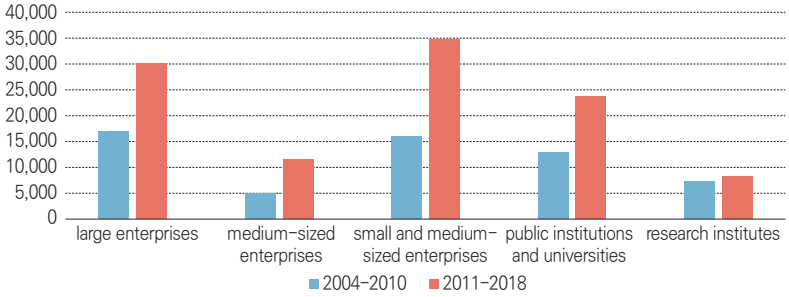
1) Status of Innovation Activities of Local Companies

Regional innovation networks examined through jointly-applied patents tend to expand quantitatively compared to the past. The number of innovators participating in the network has nearly doubled since 2010 compared to the early 2000s, when regional policies began in earnest, and the participation of local SMEs in particular increased significantly.

However, despite the active participation of SMEs in innovation networks, SMEs show the weakest trend in innovation performance. Although SMEs showed the highest number of subjects participating in joint applications across all regions, SMEs had the lowest number of joint patents compared to the number of participating entities. The number of joint applications per innovator is about two for SMEs, which is very low compared to 125 for research institutes, 19 for public institutions and universities, and 14 for large and medium-sized enterprises.

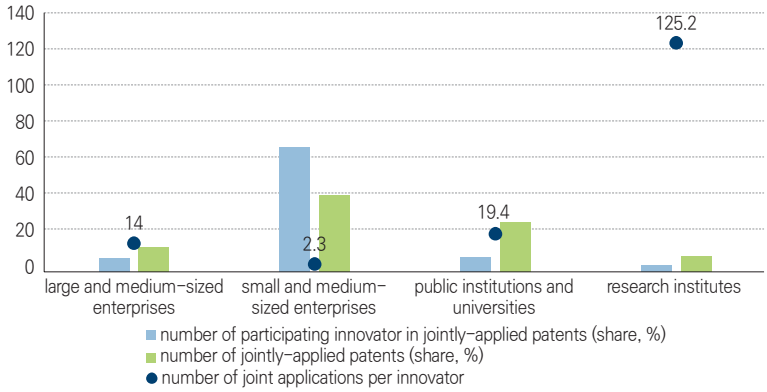
By region, SMEs tend to have the lowest number of joint applications per innovator in most regions. In Gyeongbuk province and in the city of Daejeon, the number of joint applications per innovator is overwhelmingly high for re-

Figure 3. Changes in the Number of Jointly-applied Patents by Entity Type



Source: Author's calculation using joint application patent data of Korea Patent Information Service.

Figure 4. Number of Jointly-applied Patents per Innovator



Source: Author's calculation using joint application patent data of Korea Patent Information Service.

Note: The number of participating innovators and the number of jointly-applied patents expressed by vertical bars is expressed as their share within each region, and the number of joint applications per innovator indicated by circles is calculated by dividing the number of joint applications by the number of participating subjects in networks.

search institutes, and in the provinces of Jeonbuk, Jeonnam and Gyeongnam, it is the highest for regional universities. The low innovation performance of SMEs compared to the scale of participation in the innovation network is also confirmed by the decreasing trend in the success rate of technological development. According to SME technology statistical survey data, the success rate of technological development of manufacturing SMEs exceeded 60 percent in 2005, but had since declined to 42.8 percent in 2018.

Considering that the degree of exposure and acquisition of information through the network and the resulting economic performance are affected by the structural characteristics formed differently for each network (Burt, 1992), these results of raw innovation performance of SMES suggest that it is necessary to diagnose the efficiency of the network in terms of structure.

2) Structural Characteristics of Regional Innovation Networks

Using joint patent application data, we analyzed the structural characteristics of the innovation networks, such as the composition of cooperative partners, the continuity of the relationship, and the degree to which they serve as connectivity hubs within the networks.

□ Size and Composition of Participants

The cooperative innovation relationships formed through joint applications tend to be mainly based on bilateral cooperation. The average number of innovators participating in joint applications is about 2.2, and that figure is gradually decreasing over time. This means that, on average, a cooperative relationship with two or fewer cooperative partners is formed, rather than multilateral cooperation in which a large number of innovators participate together.

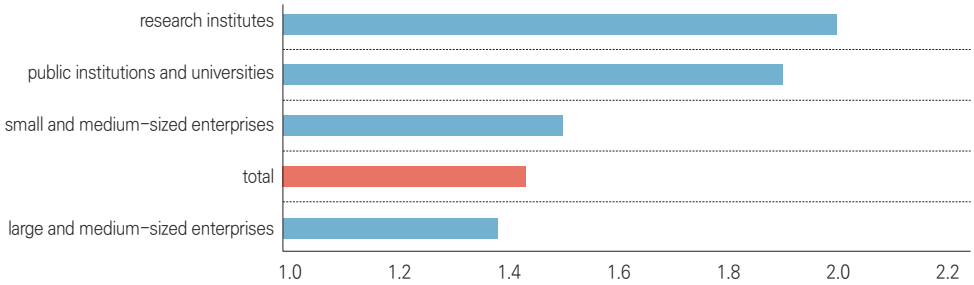
The diversity of partner composition also tends to decrease gradually. As a result of measuring how many different types of innovators and partners have been formed, including corporations, public institutions, research institutes, and universities, the average level is about 1.4, meaning that most of them tend to form partnerships with the same types of innovators. Given that the content and scope of knowledge and information of each subject type differs, this trend suggests that there may be some limitations in obtaining diverse and novel knowledge through cooperative relationships.[4]

By innovator type, corporations showed the lowest diversity of partner composition at about 1.4, and research institutes the highest at about 2, but the variation by type was not large. In the case of corporations, since R&D and commercialization are carried out together within the company, the incentive to cooperate with other types of innovators is expected to be relatively weak, particularly at large and medium-sized enterprises where innovation resources and capabilities are expected to be relatively abundant. On the other hand, research institutions and universities are relatively limited in their ability to commercialize ideas generated by research and development, which can be interpreted as highly attractive for cooperation with other entities such as companies.

In terms of the type of cooperative partners, joint applications are dichotomous: large enterprises tend to partner with other large enterprises, while SMEs tend to partner with other SMEs. Relationships between large companies and SMEs are very rare. The cooperative relationships formed among large enterprises are about 25 percent of the total, the highest level compared to other types of partnerships, and

4 In a similar vein, Kim and Yang (2017) emphasized that the more diverse the participants in joint applications the more likely they are to share various kinds of knowledge.

Figure 5. Diversity of Partner Composition by Innovator Type



Note: Diversity of partner composition refers to the number of types of innovators (corporations, public institutions and universities, research institutions, etc.) participating in one joint application.

Table 2. Number of Jointly-applied Patents by Type of Cooperation Partner

Unit: number of cases, %

	Large enterprises - SMEs	Large-Large	SMEs-SMEs	SMEs-University & research institutes	Large-University & research institutes	Large-SMEs-University & research institutes
Number of joint applications	8,106	18,967	15,293	13,711	14,744	578
Share	10.5	24.7	19.9	17.8	19.2	0.8

Source: Author's calculation using joint application patent data of Korea Patent Information Service.

the proportion of large enterprises participating in industry-academic associations with universities and research institutes is about 19.2 percent. Most of the cooperative relationships in which SMEs participated were formed with other SMEs of the same size (19.9 percent) or were industry-university-research cooperation relationships with universities and research institutes (17.8 percent).

On the other hand, cooperative relationships in which large enterprises and SMEs participated together accounted for only about 10 percent of the total, and relationships in which all types of innovators such as large-SMEs and universities and research institutes participated were also very rare at 0.8 percent. Although the number of innovation relationships in which large-SMEs participated together increased slightly from 2011 to 2018 compared to the past, the increase was not large compared to other types of relationships.

At the regional level shown in Table 2, innovative relationships centered on large corporations are prominent in some regions, such as Seoul and Gyeongbuk, and most regions outside the Seoul Capital Area tend to rely mainly on cooperative relationships formed between local SMEs. In Seoul, innovative relations involving large corporations account for about 80 percent of the total, and in Gyeongbuk, industry-academic cooperation formed between large companies, universities and research institutes

Table 3. Share of Regional Innovation Relationship by Partner Classification/Region

Unit: %

	Large enterprises – SMEs	Large–Large	SMEs–SMEs	SMEs–University & research institutes	Large–University & research institutes	Large–SMEs–University and research institutes
Seoul	5.7	70	9.1	5.8	9.1	0.3
Busan	6.8	3.1	20.1	60.1	9.5	0.4
Daegu	5.7	1.3	26.5	61.7	4.9	0
Incheon	8.3	17	51.7	21.7	1.4	0
Gwangju	2.6	0.8	36.6	58.9	0.8	0.4
Daejeon	1.4	0.1	21	60.9	16.5	0
Ulsan	26.1	4.5	30.1	36.4	2.8	0
Gyunggi	18.6	18.1	32.6	17.9	12.7	0.1
Gangwon	0.7	0	47.4	50.9	0.9	0
Chungbuk	1.5	3.9	38.7	54.5	1.2	0.2
Chungnam	9.9	2.6	37.5	46.6	3.4	0
Jeonbuk	1.2	0.6	35.5	61.2	1.4	0
Jeonnam	1.6	0.2	52.9	44.2	0.9	0.2
Gyungbuk	3.3	2.8	11.3	15.5	66.8	0.3
Gyungnam	9.4	9	37.7	40.5	3	0.4
Jeju	0	0	33.2	66.8	0	0

Source: Author's calculation using joint application patent data of Korea Patent Information Service.
Note: The results are derived based on the innovation relationship within the region for each of the 16 cities and provinces except for Sejong City, and the relationships formed with other regions are excluded from the analysis.

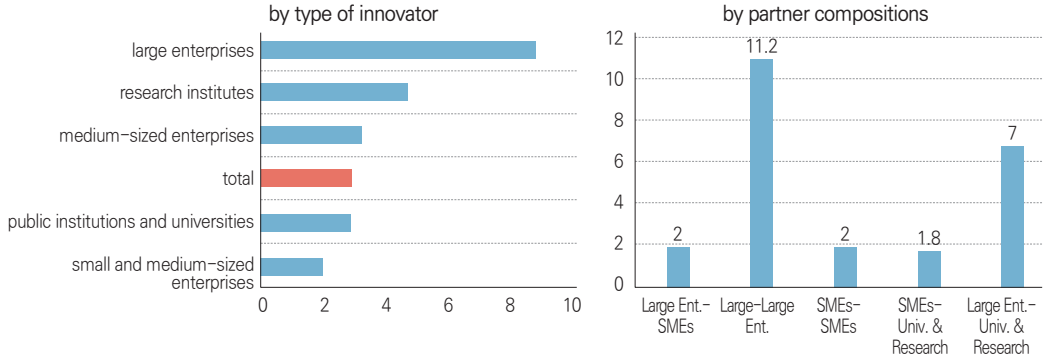
accounts for more than 60 percent, limiting the role of local SMEs.

On the other hand, in most regions outside the Seoul Capital Area, innovative relationships are formed around local SMEs, and networks in which large and SMEs participate together show a low proportion in most cities and provinces. In particular, in the province of Gangwon, Jeonbuk, Jeonnam, and the city of Gwangju, innovative relationships formed by SMEs with other SMEs, universities and research institutes account for more than 95 percent of the total, and participation of large corporations is very low.

☐ Recurrence of Innovative Relationships

In terms of the recurrence of the cooperative relationship, large companies tend to produce recurring instances of cooperation with their partners, while SMEs tend to engage in one-off relationships. The recurrence of relationships, measured by the frequency of average relationships with one partner, was the highest among large companies at 9 times on average, followed by 4.8 times for research institutes, 2.8 times for public institutions and universities, and 1.9 times for SMEs (Figure 4). This means that large companies repeatedly form cooperative

Figure 6. Recurrence of Innovative Relationships



Source: Author's calculation using joint application patent data of Korea Patent Information Service.
Note: Measured by the frequency of average relationships with one cooperative partner.

relationships with their partners over 9 times on average, while SMEs break up their relationships after two times on average. This trend is more evident depending on the type of partner, with large companies showing a high frequency of 11.2 times on average when their partner is a large company, while when the partner is an SME it tends to be only about two times.

☐ Degree Centrality

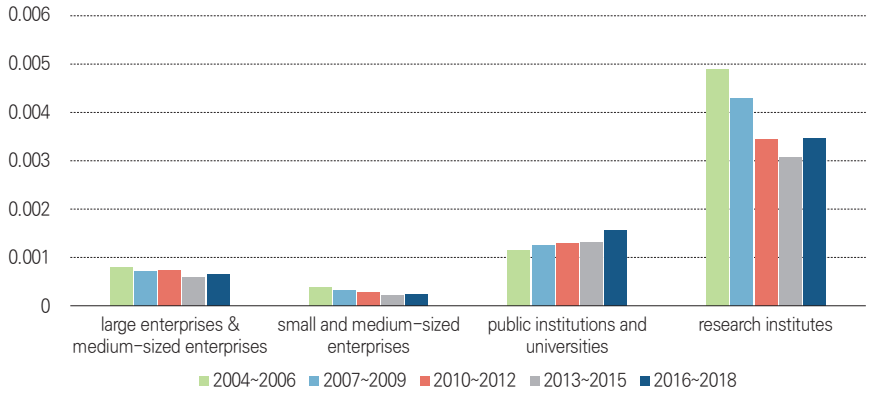
Degree centrality indicates the degree of information exchange that one entity is responsible for within the network and is measured based on the degree of connection with other nodes, i.e., other innovation entities. It can be interpreted that the greater the centrality, the stronger the influence exerted on the overall network by the establishment of relationships with a large number of cooperative partners. It also means that it is at the center of information flow within the network, that is, a network hub.[5]

According to the results of the analysis, degree centrality was highest in the research institutes and lowest in corporations. Among them, the centrality of SMEs is one fifth of that of large corporations and tends to gradually weaken compared to the past, suggesting that SMEs have limitations in playing a central role in the flow of information within networks. The low degree centrality of SMEs indicates that the information exchange channels of SMEs within the innovation network are not diverse and depend on a specific minority. This means that the scope of or opportunities with cooperative partners is limited, and as a result, there may be limitations in receiving various information or knowledge within the innovation network.

Similar results were also observed at the regional level. The degree centrality of universities and research institutes was high in metropolitan cities, while that of local SMEs is relatively low. In

5 For more details on calculating degree centrality, refer to Kim et al. (2020).

Figure 7. Degree Centrality by Innovator Type



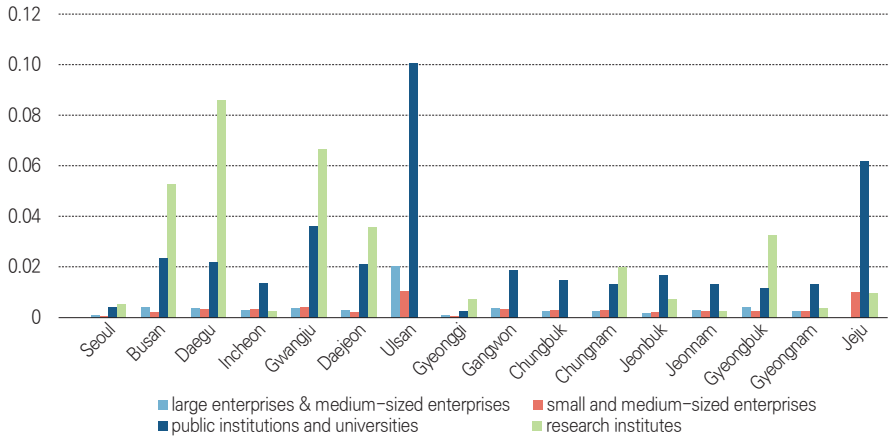
Source: Author calculation using joint application patent data of Korea Patent Information Service.

the cities of Busan, Daegu, Gwangju, and Daejeon, it is highest in research institutions. On the other hand, the degree centrality of local companies is generally low, and especially, SMEs tend to stay on the periphery rather than play key roles in the center of local networks. In the greater capital region, which includes Seoul and Gyeonggi-do, as well as in the Gyeongbuk, the degree centrality of local SMEs was particularly low.

By period, in all cities and provinces except Seoul and Gwangju, the degree centrality decreased compared to the past, and in particular, Gyeongbuk, Jeonnam, and the city of Ulsan showed a significant decrease. This means that the role of information hubs in regional innovation networks has gradually weakened.

For some noteworthy regions, the structure of the regional innovation network and the roles of

Figure 8. Degree Centrality by Innovator Type/Region



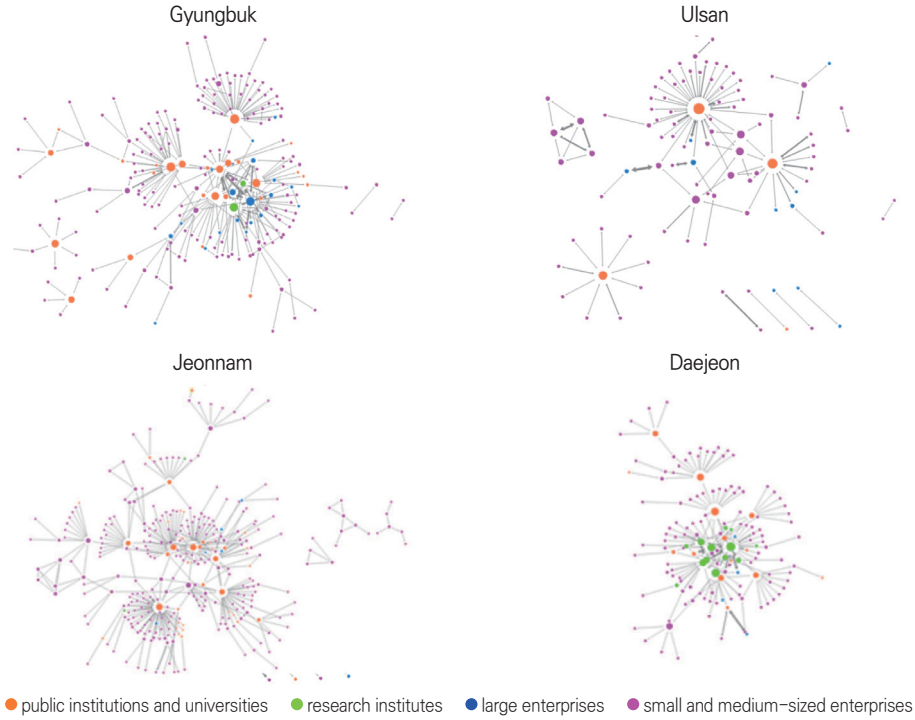
Source: Author's calculation using joint application patent data of Korea Patent Information Service.
Note: The results are derived based on the innovation relationship within the region for each of the 16 cities and provinces except for Sejong City, and the relationships formed with other regions are excluded from the analysis.

each innovation entity are diagrammed. In the case of Gyeongbuk, most of the relationships are formed with specific large corporations and universities in the region. Local SMEs, on the other hand, are located at the periphery of the sub-network which is formed and centered on major conglomerates and universities. SMEs in sub-networks are almost disconnected from each other, and most of them are in one-to-one relationships centered on hubs. It implies that there is a high risk of being isolated from the network when the relationship with a specific entity (i.e., network hubs) is broken off.

Ulsan has the highest degree centrality among regions outside the Seoul Capital Area Although the absolute number of SMEs participating in the regional innovation network is small, the connectivity within the network is relatively high. Several sub-networks are formed around the University of Ulsan and the Ulsan Institute of Science and Technology. Some SMEs are connecting two or more sub-networks, and the relationship with local large enterprises is relatively active, indicating a high level of participation and role of local SMEs.

In Jeollanam-do, some regional universities are playing the role of a hub within the network. Although the number of SMEs participat-

Figure 9. Innovation Networks in Major Regions



Source: Author's calculation using joint application patent data of Korea Patent Information Service.
Note: A node (circle) in the network represents an individual innovator within the region, and the size of the node is proportional to the degree centrality of the innovator, and the thickness of the link (line) is proportional to the number of relationships it has with other innovators.

ing in the regional innovation network is large, most are mainly connected with SMEs of similar size, and there are not many relationships directly connected with network hubs such as regional universities.

On the other hand, in the case of Daejeon, the role of research institutes is overwhelmingly high, and regional universities are also highly connected. Local enterprises remain at the periphery of the sub-networks, which are formed mainly by research institutes and local universities. The connections between the sub-networks are primarily maintained by local universities, so the role of local enterprises tends to be limited.

3. Conclusion and Implications

Regional innovation networks examined through jointly-applied patents have recently shown a trend of quantitative expansion, which contrasts with earlier observations. The number of innovators participating in networks has nearly doubled since 2010 compared to the early 2000s, when regional policies began in earnest, and the participation of local SMEs in particular increased significantly.

However, despite the quantitative expansion, the structural improvement appears to be somewhat insufficient. The number of partners participating in cooperative innovation is gradually decreasing, and the diversity of partner composition is also decreasing. Considering that the greater the number of different types of innovators that participate, the higher the likelihood that various types of knowledge and information will be shared, these results suggest that there may be limits to novelty and diversity in terms of the content of knowledge.

The role of the network hubs, which connects various innovators and plays a central role within regional innovation networks, is gradually decreasing compared to the past, and this is particularly noticeable in regions outside the Seoul Capital Area such as Gyeongbuk, Jeonnam, and Ulsan. If the role of the network hub is too high, it may lead to monopoly of information or excessive dependence on the innovator (i.e., network hub), but activation of the hub at an appropriate level contributes to the smooth flow of information in the network. In most of the regional networks, regional universities and research institutes are mainly performing the role of network hubs, but the degree of its role as a network hub tends to be low.

Innovation performance relative to the degree of participation in cooperative innovation was found to be the lowest among local SMEs. These results are interpreted to be due to local SMEs' relative inferiority in terms of structural characteristics compared to other innovation actors such as large enterprises and research institutes. Within the innovation network, local SMEs do not have diverse information sharing channels and tend to depend on a specific subject, so there is a high risk of being isolated from the network when the relationship with the subject is cut off. The sustainability of the relationship is also very low, so it is mainly a short-term,

segmented relationship. Therefore, rather than playing a leading role within the network, local SMEs have little influence within the network, and stay on the periphery.

In particular, it was found that the cooperative relationship between large enterprises and SMEs was generally low, as the relationship between SMEs and large enterprises was dichotomized. Despite the high dependence of SMEs on knowledge held by large enterprises in innovative activities, the fact that the direct relationship with large enterprises is limited can be interpreted that the formation of horizontal relationships between large enterprises and SMEs is still insufficient. Considering the technological capabilities and financial power of large enterprises, this separate cooperative relationship between large enterprises and SMEs suggests that there may be limitations in the use of external resources that can positively affect SME innovation. The reasons for the insufficient relationship with large enterprises can be considered from various aspects, such as a lack of large enterprises in a region by absolute number, access restrictions due to information asymmetry, and a lack of capacity at SMEs to form innovative relationships. Securing the critical scale of large enterprises in the region seems to be an important prerequisite, and in order to form horizontal relationships with large enterprises, it is necessary to strengthen the capabilities of SMEs first. Above all, based on the mutual needs of large enterprises and SMEs, a cooperative form is required in which participating SMEs can autonomously utilize the results of cooperative innovation.

In addition, it is necessary to gradually expand the scope of innovative relationships, and in this process, it is important to resolve the asymmetry of information by strengthening the role of intermediary functions which mediate information between various innovators.

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