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Triple helix dynamics of South Korea's innovation system: a network analysis of inter-regional technological collaborations

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Abstract This study intends to unveil the current innovation landscape of South Korea in an attempt to examine the underlying patterns of inter-regional technology collaboration occurring at the triple helix level. Social network analysis techniques are used to quantify the structure of the four types of inter-provincial co-inventorship network between university, industry, and government (UIG). The findings confirm the declining centrality of Seoul as the primary research center with the emergence of new regional players such as Gyeonggi and Daejeon. However, they also reveal that these three main innovative regions have become strongly linked in recent years and constitute the core of the inter-regional collaboration networks. The poor linkage between the research core and the periphery, in turn, raises some concerns regarding the unfair geographical concentration of innovation resources and technology activities, hindering the synergy in the national and regional innovation systems. To create a dynamic innovative milieu for bolstering Korea's national innovation system, therefore, interactive learning between the core and the periphery, as well as between the various UIG actors, must be further facilitated.

Keywords South Korea · Triple helix · Technological collaboration · Patent · Inter-regional network · Patent

1 Introduction

The growing importance of science and technology (S&T) collaboration has been widely acknowledged by innovation scholars and policy makers. With the increasing globalization of research collaboration, considerable effort has been made to facilitate the interactions

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between the various innovation actors with the aim of enhancing R&D productivity and competitiveness at the national, regional, and organizational levels. While the interactive innovation model from a systemic perspective has long been the prevailing paradigm, the dynamics of the reciprocal university–industry–government (UIG) relationships referred to in the "triple helix model" has been highlighted as an adequate analytical framework for innovation systems. From the triple helix perspective, the extent of UIG interconnections through their technological collaboration has been extensively studied to examine the performances and capacities of national and regional innovation systems (Lei et al. 2012; Ramos-Vielba et al. 2010; Gao et al. 2011; Huang et al. 2013; Hong 2008).

Since the 1960s, Korea's national innovation system (KNIS) has progressed into a development trajectory in tandem with its rapid economic growth. This strong state-led national innovation system has, in turn, allowed Korea to successfully leapfrog over its competitors in key scientific and technological fields but, at the same time, has led to a severe disparity in the innovative capacities and resources between regions. The limited degree of regional autonomy has further aggravated this unbalanced development and led to the excessive concentration of national R&D resources in the capital regions. However, a shift away from this has been initiated thanks to the Korean government's efforts to implement a regional innovation strategy on the basis of "dynamic balanced development" coupled with the new wave of political decentralization that started in the mid-1990s (Kim 2007; Kwon et al. 2011). In the changing paradigm of national innovation policy, the region has been newly conceived as a pivotal source of innovation-driven growth and encouraged to actively foster innovative activities and interactive learning by building industrial clusters or techno-parks. Since over-centralization and increasing regional discrepancies are deemed to be major obstacles to lower national R&D efficiencies, there have been calls for constructing dynamic innovation networks among the triple helix actors within and across regional boundaries.

In this context, however, little effort has been made to empirically analyze the patterns of inter-regional collaboration networks in order to shed light on the relevant issues affecting regional innovation systems in Korea. Sohn et al. (2009) investigated the effects of government policies on university–industry linkages using social network analysis and found that local universities have emerged as an important knowledge provider for industry, especially in the noncapital regions. Shapiro et al. (2010) took a closer look at inter-regional research collaboration networks based on scientific co-authorships in an attempt to quantify the national innovation system. However, most previous studies failed to analyze the triple helix networks as a function of the type of collaboration. They also tended to neglect the technological aspect of collaboration, primarily concentrating on the co-authorship of scientific publications. While paper co-authorship relations have been a useful indicator of scientific knowledge exchanges at various levels, the co-inventorship of patents can be exploited to map the complex web of collaboration ties associated with technological innovation. The advantage of using patent collaboration relationships is that they not only take co-invention into consideration, but also reflect its commercial potential. Since little attention has been paid to cross-regional co-inventorship patterns, the present study aims to provide a more complete picture of the inter-regional networks of bilateral and trilateral relations among UIG embodied in patent collaborations. By examining the most recent status of the interaction-based knowledge infrastructure from a triple helix perspective, this study can put forward some policy suggestions to enhance the performance of Korea's national and regional innovation systems in the near future.

The following dynamic analysis of inter-regional networks of UIG relations among 16 provinces and municipalities is divided into four sections. In Sect. 2, the literature on the triple helix model of innovation in the context of technological collaboration is reviewed. Section 3 presents the research procedure and method used in this study. Section 4 provides the results of the network analyses at the regional and institutional levels. The last section concludes with policy implications for the further development of innovation dynamics in Korea.

2 The triple helix and innovation dynamics

Since the open and systematic paradigm has been widely embraced in mainstream innovation research, a network of relations cultivating synergy has been emphasized as a key strength of an innovation system. As an indicator of the synergy in the knowledge-based configuration, the Triple Helix model of UIG relations has been considered a useful lens for studying the network arrangements among these three helices at the system level (Etzkowitz 2008; Fritsch 2004; Park and Leydesdorff 2010; Powell and DiMaggio 1991; Ranga and Etzkowitz 2013; Villarreal and Calvo 2015). The triple helix indicator enables us to empirically examine the extent to which various possible interactions between the three sub-dynamics in an innovation system develop into a synergetic configuration and whether the networked systems of relations are either integrated or differentiated.

In a rapidly changing innovation landscape from the traditional mode of disciplinary knowledge production to a trans-disciplinary and cross-organizational one (Gibbons 1994), Etzkowitz and Leydesdorff (2000) elaborate the knowledge base of an innovation system in terms of a triple helix dynamics by providing a more detailed picture of the current mode of knowledge production referred to as Mode 2 (cf. for the discussion of Mode 3, see Carayannis and Campbell 2010; Park 2014). As the evolution of innovation systems is accompanied by a change in the configuration of UIG relations, the bilateral interactions among the three spheres have expanded into trilateral interactions, leading to a shift from single and double helixes to a triple helix. In this vein, the interactive triple helix model, known as Triple Helix III, has been deemed the most desirable model of innovation. This model highlights the importance of an institutional knowledge infrastructure involving overlapping institutional spheres, in which tri-lateral networks or hybrid organizations may emerge. It specifically proposes an effective mechanism for facilitating interactive learning between innovation actors that contribute to enhancing the national and regional innovation capacities.

The major merit of the triple helix model is that it provides the conceptual and empirical grounds for assessing the *systemness* of an innovation system. Although this model is primarily rooted in Western developed countries, it has been well-received as an adequate policy guide for reinforcing the quality of national systems in the context of developing and emerging economies by identifying the missing linkages and interactions between sub-dynamics, which lead to weak innovation performance (Arocena and Sutz 2005). However, most previous studies have attempted to explore the process of collective learning and interrelationships among the UIG actors involved in scientific knowledge production without considering their collaborative efforts in the field of technology (Choi et al. 2014; Glänzel and Schlemmer 2007; Kwon et al. 2011; Park and Leydesdorff 2010). Some researchers employed the triple helix model to examine co-inventorship relationships in technological collaboration, but they neither closely studied the patterns of inter-connectedness of UIG networks by type of collaboration, nor examined the collaborative relationships among the three institutional spheres at the network level (Chen and Guan 2011; Gao et al. 2011; Lei et al. 2012).

In the Korean context, very few studies have been conducted on co-inventorship relationships between UIG to grasp the system structures and interfaces. Given that a national innovation system is composed of a complex network of subsets of regional systems, the importance of inter-regional collaborative linkages is reflected in its functional dynamics. Regional decomposition can be an effective tool for policy-makers to prevent the problem of the unfair geographical concentration of technological and economic activities, which would weaken the overall national innovation performance. Using this approach, several scholars reported that there was a tendency toward the excessive concentration of innovation potentials in the Seoul capital region along with a lack of inter-regional R&D networking (Kwon et al. 2015; Sohn and Kenney 2007; Chung 2002; Shapiro et al. 2010), while others provided evidence of a major shift in the topology of innovation networks under the influence of political decentralization (Shapiro et al. 2010). Since most of these studies have tended to place more emphasis on the decentralization propensity of inter-regional collaboration networks with particular focus on the role of either specific region or institution, few attempts have been made to analyze the triple helix structure and dynamic degree of a set of networks between UIG actors in detail. In addition, more studies are needed to explore the national innovative milieu through inter-regional research collaboration among the key innovation actors using the network analysis of co-inventorship.

Given this lack of research into technological collaboration in Korea, therefore, the present study was designed to assess the quality of national and regional innovation systems by measuring the interaction and dynamic synergy between the three subsystems by means of a triple helix indicator.

3 Data and method

To analyze the pattern of inter-regional technological collaboration, this study utilizes patents as a proxy output indicator of collaborative innovation activities. Since patent data encompass valuable information on technological inventions at the national, regional, organizational and individual levels, it can be used to explore various aspects of co-inventorship by mapping technological and innovation activities. Taking patent quality into consideration, this study is based on the granted invention patent data retrieved from the Korea Intellectual Property Rights Information Service (KIPRIS) database provided by the Korean Intellectual Property Office. The KIPRIS database includes the names and addresses of applicants, the dates of applications, publication, and registration, the names of inventions, and international patent classification code.

By examining the applicant information, patents jointly applied for by multiple UIG actors are identified as co-patents, indicating the successful outcome of technological collaborations. Accordingly, this study collected 2940 co-patents of UIG in the last 5 years from 2011 to 2015 using the following search terms and search combinations: "university–industry" (*Daehak-Huisa*), "government research institute–industry" (*Yeonguwon-Huisa*), "government research institute–university" (*Yeonguwon-Daehak*) and "university–government research institute–industry" *(Daehak-Yeonguwon-Huisa*). However, it should be noted that the Government-affiliated Research Institutes (GRIs) referred to in this study represent the government sector. There have been 24 specialized R&D institutes established by the Korean government, which have played a strategic role in the NRDP. Since these Korean GRIs have vigorously engaged in technology transfer and commercialization activities, the number of patents belonging to them may indicate the extent to which the government sector has played a part in innovation efforts.

Network analysis based on patent data has often been used as a method of detecting and interpreting the patterns of knowledge networks among innovation actors in technology collaboration studies (Chen and Guan 2011; Fleming et al. 2007; Guan and Zhao 2013; Yoon 2015; Zheng et al. 2014). According to these studies, R&D collaboration efforts have leveraged industries' innovation capability, national and regional competitiveness, and academic productivity. Patent collaboration networks are very useful for policy-makers and organizational managers, especially when they need to make strategic decisions in order to select suitable R&D partners. By identifying the locations of UIG applicants in patent co-inventorships, the main innovation actors and their collaboration linkages can be deployed at both the organizational and regional levels. Therefore, in the present study, two kinds of collaboration networks among UIG are constructed employing social network techniques. The first network is built on the regional level, linking the regions based on innovation production through technology collaborations. South Korea is geographically and administratively subdivided into the seven independent municipalities of Seoul (the capital city of Korea), Busan, Daegu, Incheon, Gwangju, Daejon, and Ulsan, and the nine provinces of Gyeonggi, Gangwon, South Chungcheong, North Chungcheong, South Jeolla, North Jeolla, North Gyongsang, South Gyongsang, and Cheju, as shown in Fig. 1. Since

Fig. 1 Geographical subdivisions in South Korea

the population of each of these seven municipalities is equivalent to those of the provinces, they are all considered to be province-level regions. Accordingly, these 16 province-level regions are taken to be the units of analysis in the study. The second network is the link between the UIG institutions which contribute to knowledge production and transfer. In these two kinds of undirected network, therefore, the nodes denote the regions and organizations and the edges among them indicate that there are technology collaborations between the nodes. The width of the lines corresponds to the strength of the edges among the nodes, representing the quantity of collaboration.

The method used in this study is the social network analysis technique using the following three measures: centrality, centralization, and density. The centrality indicators, viz. the degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality, reveal the central nodes which hold the most prominent position in the inter-regional co-inventorship network. The degree centrality of each node is measured as the number of edges between that node and the other nodes. The size of the nodes within the network, therefore, depends on the degree centrality scores. The betweenness centrality (BC) is the centrality measure of a node (v), denoting the number of times it plays the role of a bridge along the shortest paths (geodesic distances) between other nodes. If g_{st} is the total number of shortest paths between nodes s and t and gst (v) is the number of these paths passing through node v, then the BC of a node v is computed as $BC\ (v) = \sum_{s<t} \frac{g_{st}(v)}{g_{st}}$; a node with a high BC score exerts considerable influence on the co-inventorship relations by means of its control over the knowledge and information passing between the other nodes. The closeness centrality (CC) of a node (v) is a measure of the average shortest path between node v and other nodes j. If d_{vj} is all the distances between two nodes, it can be defined as $CC\ (v) = \sum_j \frac{1}{d_{vj}}$; thus, the closer a node to all other nodes, the higher its centrality. The eigenvector centrality (EC) is a measure of the importance of a node (v) in the network based on the centrality of its neighbors. It can be computed as $Ax = \lambda x$, where $A = (\alpha_{v,j})$ is the adjacency matrix of the Graph $G = (v, j)$ with eigenvalue λ. Therefore, a node connecting to the most central node is likely to have a high centrality score.

In addition to the node's centrality, the network centralization measures the extent to which an entire network is centered on only a few nodes and how influential their activities are in the network. If the maximum centrality score in the network is denoted as $C\ (n^*)$ and the centrality score of each other node is denoted as C (j), the centralization measure (C) can be calculated from $C = \frac{\sum_{j=1}^{g} [C(n^*) - C(j)]}{[(N-1)(N-2)]}$; the higher the degree of network centralization, the more centralized the overall network is.

The network density refers to the total number of edges among nodes divided by the maximum number of possible edges. If the number of nodes in the network is denoted as K and the total number of edges is denoted as L, then the density (D) of the overall network would be defined as follows: $D = \frac{L}{K(K-1)/2}$; the higher the density, the more interconnected the nodes are. In general, the density measure reflects the number of ties between the nodes in the network, making it cohesive with a tight structure. However, it may not be useful for large networks, since it is highly related to the size of the overall network; that is, the larger the network, the lower the density. In this case, the mean network degree can provide a better measure of the density, in that it is less influenced by the network size and is thus comparable between networks of different sizes (Nooy et al. 2005: 64).

4 Results

4.1 University–industry collaboration network

To configure the structure of the inter-regional co-inventorship networks, the scale, density, and centralization of the relations between the actors are examined and the positions of each actor in the network are visualized as well. Figure 2 illustrates the dynamic inter-regional collaboration networks between university and industry from 2011 to 2015. The network graph also includes loops indicating intra-regional collaborations. As the capital city, Seoul lies at the core of the university–industry (U–I) collaboration, reflecting its position as the most active partner in the network. Kyonggi province, which has the closest proximity to Seoul, appears to be one of the most prominent actors, playing a considerable role in the production of technological knowledge. The edge between Seoul and Kyonggi province is the thickest, reflecting the fact that the solid connection between these two regions constitutes the focal hub of the U–I collaboration network. Daejeon and North Gyeongsang province are influential collaborators with a high degree centrality alongside Seoul and Kyonggi, as shown in Table 1. It is worth pointing out that Daejeon has a stronger tendency to rely on inter-regional technological collaborations than Seoul and Kyonggi province. By contrast, both North and South Jeolla provinces show a higher degree of dependence on intra-regional collaboration than the other regions, accounting for over 65 % of the total collaborations.

Table 1 lists the 16 provincial-level regions according to their degree centralities, closeness centralities, betweenness centralities, and eigenvector centralities. This explicitly confirms the absolute position of Gyeonggi province and Seoul in the U–I collaboration network as the major channels for the production and exchange of technological knowledge with the other regions, in that both regions obtain the highest values of all four centrality indices. Daejeon and North Gyeongsang province, which are in close proximity to the two capital regions, exhibit high centrality indices, showing relatively high capabilities to readily access other regions and obtain knowledge and information for research collaboration. Daejeon, with its higher betweenness centrality than North Gyeongsang

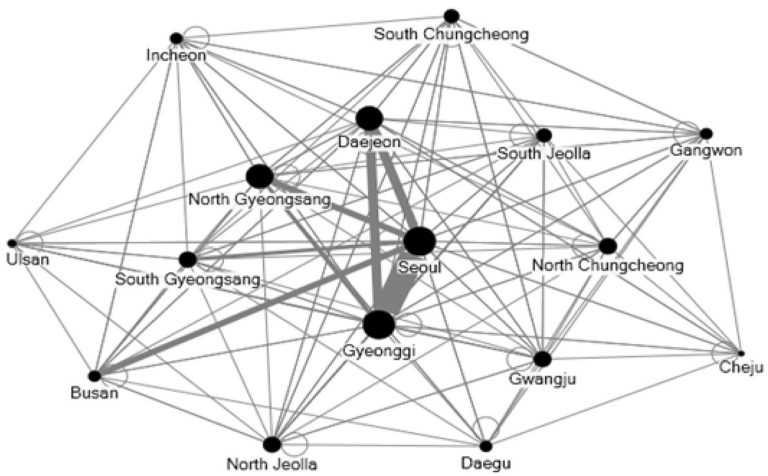

Fig. 2 Inter-regional collaboration network between university and industry

Table 1 16 Provincial-level regions with the four centrality indices

Region	Degree centrality	Betweenness centrality	Closeness centrality	Eigenvector centrality
Gyeonggi	17	3.589	0.067	0.076
Seoul	17	3.589	0.067	0.076
Daejeon	16	2.967	0.063	0.072
North Gyeongsang	16	2.386	0.063	0.073
South Gyeongsang	15	1.691	0.059	0.069
Gwangju	15	2.185	0.059	0.068
North Chungcheong	15	1.941	0.059	0.068
North Jeolla	14	1.201	0.056	0.065
South Jeolla	13	1.101	0.053	0.060
South Chungcheong	13	0.708	0.053	0.061
Gangwon	12	0.947	0.050	0.054
Daegu	12	1.236	0.050	0.054
Busan	12	0.858	0.050	0.054
Incheon	12	0.931	0.050	0.054
Ulsan	11	0.333	0.048	0.050
Cheju	10	0.336	0.045	0.044

province, has more capacity to wield influence on the collaborative relationship with other regions. However, the municipalities, Daegu, Busan, Incheon, and Ulsan, obtained the lowest values of all centrality indices, meaning that they are placed as peripheral regions a long distance from the center of the network. Compared to these four metropolises, Gwangju metropolis seems to wield more power than the others by facilitating or limiting the interactions among its neighbors and developing closer relationships with the capital region, since it has higher values of betweenness centrality and eigenvector centrality.

Consistent with previous research, the dominance of Seoul municipality in the R&D landscape is found to have been gradually weakened by the emergence of Gyeonggi, Daejeon, and North Gyeongsang as new collaborative research centers. However, the capital region, Seoul, and Gyeonggi still occupy the power positions in the network by playing the pivotal role of brokers in the management of the inter-regional collaboration relationships between university and industry. Given the fact that the leading research universities are located in Seoul, those industrial firms in the non-capital regions, where the R&D infrastructure is very weak, are expected to actively join in research collaboration with academic research institutions in the capital region. In this vein, the institutional structure of the intra-networks of Seoul and Gyeonggi may need to be closely scrutinized in order to capture the landscape of U–I collaboration between the capital and non-capital regions.

Figure 3 illustrates the entire U–I collaboration network of Seoul. The blue square denotes the academic and industry collaborators located in Seoul and all the other colored spheres represent those from the 15 non-Seoul regions. This figure demonstrates that the structure of the Seoul network revolves around several leading local universities. Namely, Seoul National University, Yonsei University, Korea University, Hanyang University, and University of Seoul are at the center of the network pursuing technological collaborations with firms inside and outside of the city. 229 academic and private institutions out of a total of 464 participants in the Seoul network are located in other regions. However, the strength of the U–I collaborative relationships between Seoul and the non-capital regions is found to be very weak, for the frequency of its technological collaboration accounts for only 30 % of the total U–I collaboration that occurred during the study period. Gyeonggi, denoted by the red square in the network graph, has been a major research partner for Seoul, in that a larger number of industrial firms in this province have been willing to collaborate with high-profile research universities located in Seoul. As revealed in Fig. 3, the majority of the U–I collaborations have taken place locally.

In the case of Kyonggi province, a few universities are similarly placed at the center of the U–I collaboration network, as displayed in Fig. 4. Such local universities as Korea Polytechnic University and Sungkyunkwan University are recognized as the most important actors in the network. In contrast to Seoul, however, some universities outside of the province, such as Seoul National University and Yeonsei University in Seoul and the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, appear as influential players in the Kyonggi network. It should be noted that the collaborative linkage between Kyonggi and Seoul is the strongest, as the occurrence of collaboration between these two regions accounts for almost 50 % of the total U–I collaboration taking place in the province. The proportion of inter-regional collaboration with Seoul is even higher than that of the local collaboration occurring within the province. Since Seoul has the most advanced R&D infrastructure in the country, Kyonggi has taken full advantage of its close proximity to the capital to promote regional innovation activities. A relatively small number of U–I actors from the non-capital regions participate in the Kyonggi network, and its linkages with local research partners in the province are also found to be weak.

As compared with the two regional network properties, the sizes of the two U–I networks are similar, but the density of the Seoul network is slightly higher than that of its Kyeonggi counterpart, as confirmed in Table 2. Seoul has a larger number of U–I actors outside the city, as well as a larger number of collaboration ties, than Kyeonggi province.

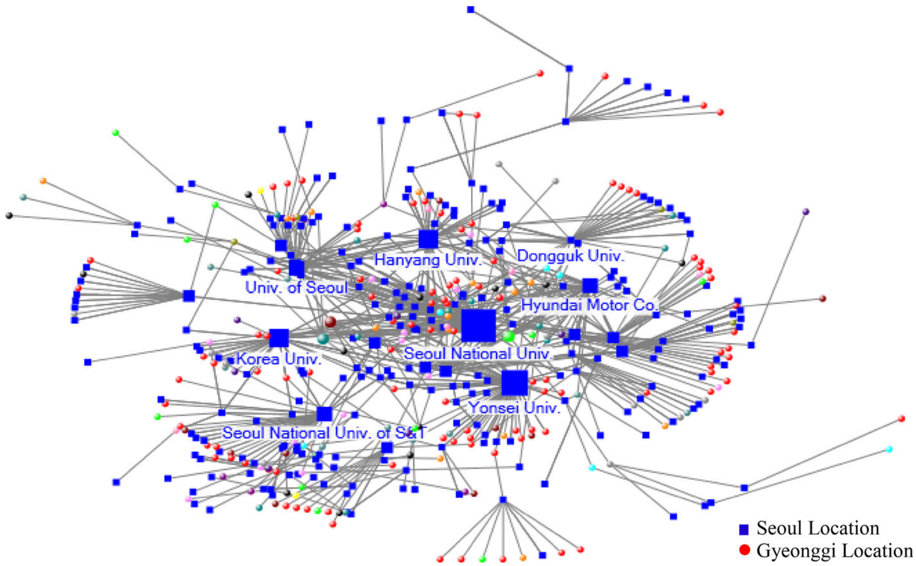

Fig. 3 University–industry collaboration network of Seoul municipality

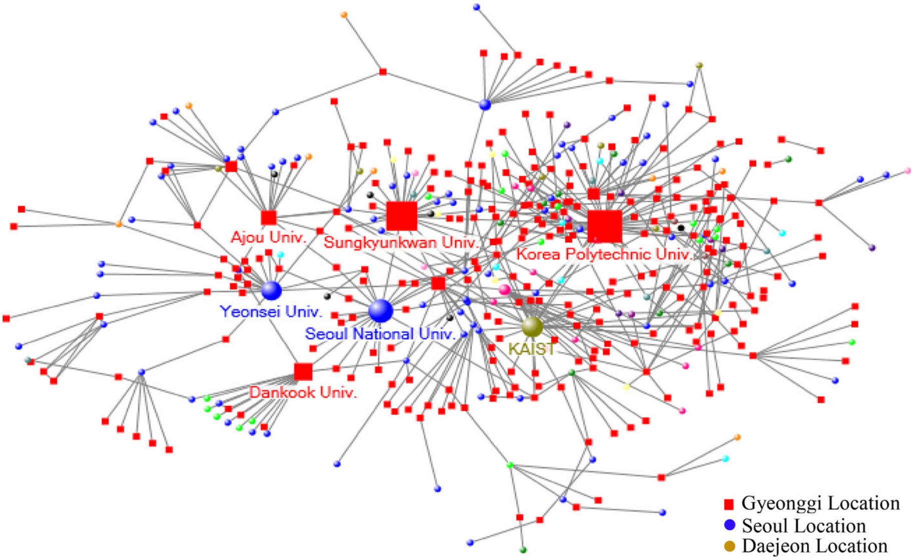

Fig. 4 University–industry collaboration network of Kyonggi province

Table 2 Descriptive statistics of the Seoul and Gyeonggi U–I networks, 2011–2015

	Seoul network	Gyeonggi network
Number of nodes	465	447
No. of local nodes	236 (51 %)	279 (62 %)
No. of non-local nodes	229 (49 %)	168 (38 %)
Number of links	854	457
Average degree centrality	2.69	2.03
Network centralization (%)	17.31	6.94

Data compiled by the author for this study

The Seoul network of U–I relations tends to be more centralized around a few local universities, whereas the Kyeonggi network is more decentralized with a variety of academic and industrial collaborators from other regions. However, neither of these regional networks has a highly centralized structure, since the overall degree of network centralization is less than 20

4.2 Government–industry collaboration network

The Korean GRIs were strategically set up as a locus of development for national R&D programmes, spurring research collaboration with the industry sector since the 1960s. Figure 5 demonstrates that the current formulation of the inter-regioal co-inventorship network between the government research sector and industry is centered around Seoul, Gyeonggi, and Daejeon. This is mainly because Korea's public research system has long been built on the basis of these three main regions. Daejeon has occupied the most powerful position as the core of the government–industry (G–I) collaboration network, whereas the link between Seoul and Gyeonggi is the strongest, followed by the Daejeon–Seoul and Daejeon–Gyeonggi ties. In brief, the collaborative linkage between these three main regions has exerted a predominant influence on the dynamic functioning of the network topology. Given their close proximity to these central regions, South Chungcheong, Daegu, and South Gyeongsang also appear as major players having the ability to facilitate and inhabit the G–I co-inventorship relations with others.

At the institutional level, several GRIs with high degree centrality are recognized as the key R&D partners for industry, as shown in Table 3. There are 17 GRIs and 257 firms involved in the inter-regional co-inventorship network and the majority of the GRIs ranked in the top 10 G–I collaborators are located in the Daejeon, Seoul, and Kyeonggi regions. Nearly half of all GRI actors are affiliated with Daejeon, since many GRIs performing R&D are situated in Daeduck Research Park in the metropolis. Four GRIs in Gyeonggi and one GRI in Seoul are also listed among the top 10 collaborators. While the Korean GRIs are heavily concentrated in these three regions, only one GRI from another region, viz. the Korea Institute of Industrial Technology in South Chungcheong, is found to be among the most active collaborators, having many co-inventorship relations with others in the network.

Daejeon has long been a public research base due to the establishment of a number of major government S&T institutions in this region and, as such, it has served as a collaborative research platform, playing a leading role in building a web of inter-regional co-inventorship relations between GRI and industry. It should be noted that Daejeon is the region with the highest degree of inter-regional technological collaborations among UIG among the 16 provincial-regions. Therefore, we made a detailed examination of the Daejeon network of G–I relations embedded in technological collaboration. As displayed in Fig. 6, 14 GRIs and 95 industry actors are involved in this G–I collaboration network. It is clear that the four main GRIs belonging to Daejeon, viz. the Korea Research Institute of Bioscience and Biotechnology (KRIBB), Korea Institute of Machinery & Materials (KIMM), Korean Research Institute of Chemical Technology (KRICT), and Korea Institute of Energy Research (KIER), play the pivotal role in the network, interconnecting with various industrial actors outside the metropolis. Each of these central nodes shows different patterns of inter-regional collaboration. For example, KRICT and KIER are more likely to collaborate with industry actors from the capital region, whereas KRIBB tends to depend more highly on local collaboration. On the other hand, KIMM shows more inclination to engage in research partnerships with industrial firms from diverse regions. However, the

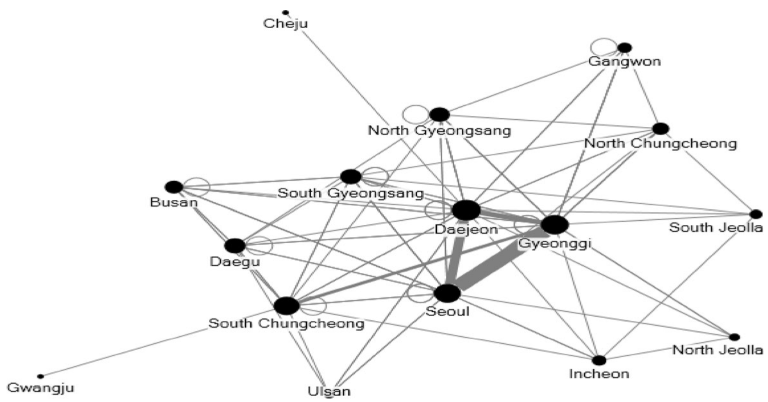

Fig. 5 Inter-regional collaboration network between government and industry

Table 3 Top 10 G–I institutions participating in collaboration, 2011–2015

Rank	Name of institutions	UIG type	Region
1	Korea Institute of Civil Engineering and Building Technology	G	Gyeonggi
2	Korea Institute of Industrial Technology	G	South Chungcheong
3	Korea Railroad Research Institute	G	Gyeonggi
4	Korea Research Institute of Chemical Technology	G	Daejeon
5	Korea Institute of Machinery & Materials	G	Daejeon
6	Korea Electronics Technology Institute	G	Gyeonggi
7	Korea Institute of Science and Technology	G	Seoul
8	Korea Food Research Institute	G	Gyeonggi
9	Korea Institute of Energy Research	G	Daejeon
10	Seoul Metro Co.	I	Seoul
	Korea Textile Development Institute	I	Daegu

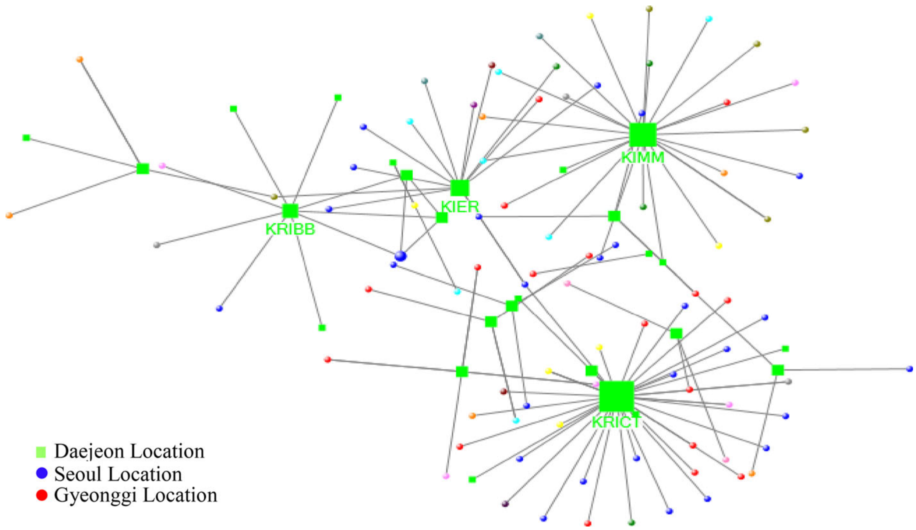

Fig. 6 Government–industry collaboration network of Daejeon municipality

strength of the overall network connectivity mainly revolves around co-inventorship relations between the three regions, Seoul, Kyeonggi, and Daejeon, wielding a significant influence on the network performance.

4.3 University–government collaboration network

In a similar manner, these same three innovative regions form the core of the university–government (U–G) collaboration network structure. Daejeon and Gyeonggi with the highest degree centrality hold the dominant positions in the network. Figure 7 also demonstrates that the link between Seoul and Daejeon is the most significant, followed by the Seoul–Gyeonggi and Daejeon–Gyeonggi links. In addition to these three central regions, South Chungcheong and North Gyeongsang, having relatively high centrality, are

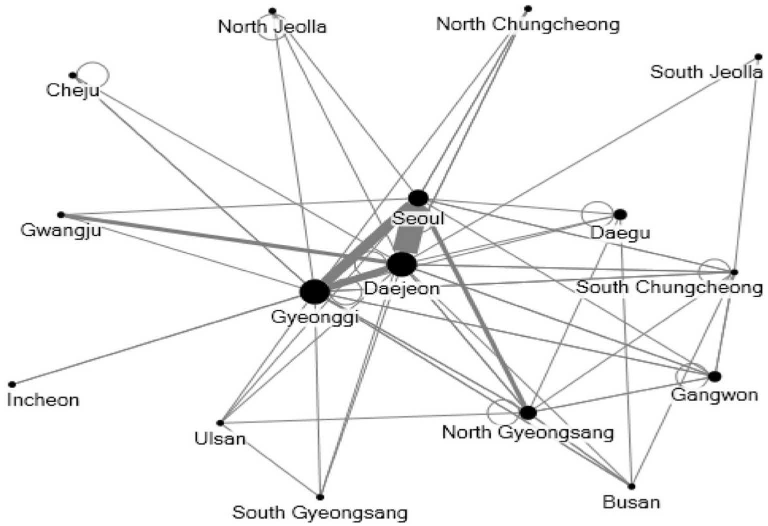

Fig. 7 Inter-regional collaboration network between university and government

active collaborators, interweaving the connection with various regional players. While South Chungcheong tends to exploit the benefits of its close geographical proximity to Daejeon, North Gyeongsang has built strong links with Daejeon and Seoul.

Since a large number of GRIs are located in Daejeon and Gyeonggi, the predominant position of these two regions in the inter-regional U–G collaboration network is confirmed by their high centrality scores. Figures 8 and 9 present the formation of the U–G collaboration networks of Daejeon and Gyeonggi, respectively. In the Daejeon network, 54 universities and 17 GRIs are interconnected for the purpose of technological collaboration. Eleven out of the 17 GRI participants are found to be located in Daejeon. As shown in Fig. 8, four GRIs, including the Electronics and Telecommunications Research Institute (ETRI) and the well-known S&T university, KAIST, have the highest degree centralities, meaning that they are the most important players in the network. Three GRIs, KIMM, KRIBB, and KRICT, are recurrently placed in the center of the inter-regional U–G collaboration network, representing the key public research institutions leading to inter-regional technological collaboration. A large number of university actors from various regions have research partnerships with GRIs in Daejeon. Nearly 40 % of the university actors from the capital region have collaborated with a few GRIs in the metropolis. KAIST has been involved in partnerships with major GRIs located in the capital region, including the Korea Institute of S&T in Seoul, and the Korea Electronics Technology Institute (KETI) and Korea Railroad Research Institute (KRRI) in Kyeonggi.

As displayed in Fig. 9, four local GRIs and one local university are placed as the central nodes of the Kyeonggi network. In particular, the Korea Food Research Institute (KFRI) and KETI obtain the highest scores of all four centrality indicators, followed by Sungkyunkwan University, KRRI, and Korea Institute of Civil Engineering and Building Technology (KICT). These leading GRIs in Kyeonggi have engaged in collaborative relationships with 36 universities from the other 12 regions. About 50 % of all university actors involved in the Kyeonggi network are situated in either Seoul or Daejeon. However, a larger number of GRIs in the network are affiliated with Daejeon, connecting to the six

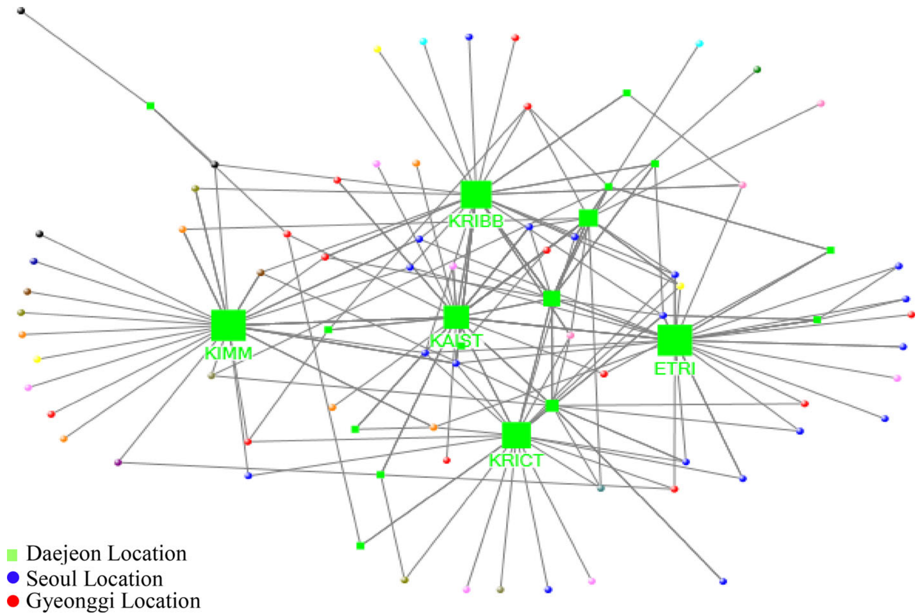

Fig. 8 University–government collaboration network of Daejeon municipality

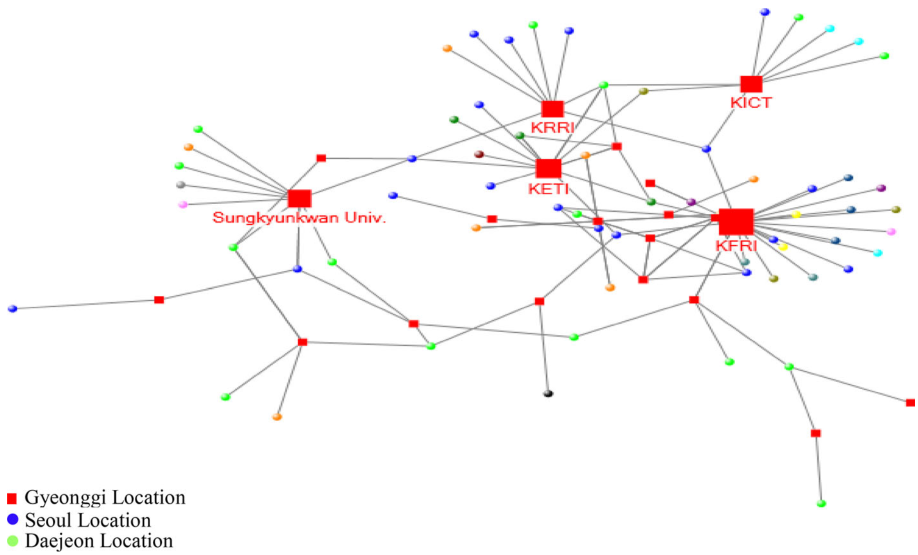

Fig. 9 University–government collaboration network of Kyeonggi province

major research universities in Kyeonggi. In fact, the strength of the Kyeonggi network seems to hinge on its solid linkages with Seoul and Daejeon.

Comparatively, the Daejeon and Gyeonggi networks are quite similar in scale, but differ in the quantity of connections between nodes, as shown in Table 4. The U–G collaboration

Table 4 Descriptive statistics of the Daejeon and Gyeonggi networks, 2011–2015

	Daejeon network	Gyeonggi network
Number of nodes	85	85
No. of local node	19 (22 %)	21 (25 %)
No. of non-local node	66 (78 %)	64 (75 %)
Number of links	220	110
Average degree centrality	3.67	2.28
Network centralization (%)	24.2	18.71

Data compiled by the author for this study

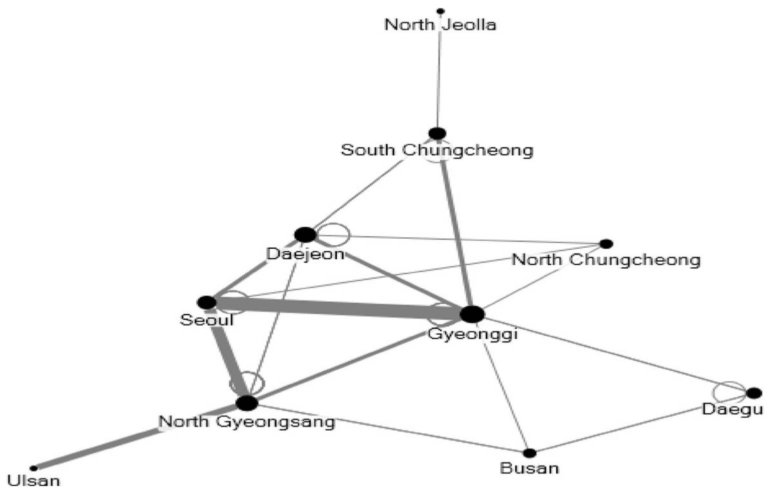

Fig. 10 Inter-regional collaboration network between university, industry, and government

network of Daejeon is more densely connected than its Gyeonggi counterpart, as confirmed by its higher average degree centrality. Given its lower degree of centralization, the Gyeonggi network is characterized by a more decentralized structure.

4.4 University–industry–government collaboration network

In contrast with the bilateral collaborations, there has been little tripartite collaboration among UIG actors in Korea, since there are only 85 patent collaborations in the study period. Notwithstanding the relatively small number of co-patents, the inter-regional network of UIG co-inventorship relations can nevertheless be drawn, as shown in Fig. 10. Gyeonggi province, which has the highest scores for all four centrality indicators, has played a substantial role as the center of the network, followed by North Gyeongsang, Daejeon, Seoul, and South Chungcheong. The strengths of the dynamic links between Gyeonggi and Seoul and between North Gyeongsang and Seoul are the strongest. Unlike the other types of collaboration networks, North Gyeongsang has especially emerged as the one of the most important actors, having strong interconnections with Ulsan, Seoul, and Kyeonggi.

There are 39 universities, 16 GRIs, and 67 enterprises constituting the structure of the tripartite co-inventorship network. Figure 11 confirms the central position of some of the UIG actors in the network, including Posco Corporation and the Research Institute of Industrial

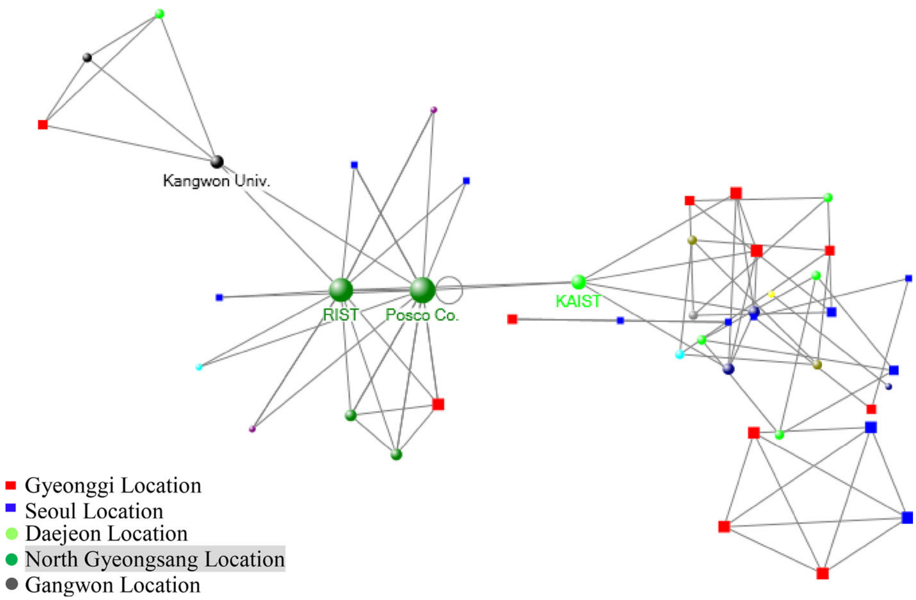

Fig. 11 Tripartite U–I–G collaboration network at the institutional level

Table 5 Descriptive statistics of the four types of UIG collaboration network, 2011–2015

	U–I	G–I	U–G	U–I–G
Number of regions	16	16	16	10
Network density	0.78	0.45	0.39	0.38
Network centralization (%)	21.67	54.17	66.67	48.89

Data compiled by the author for this study

Science and Technology (RIST) in North Gyeongsang, KAIST in Daejeon, and Kangwon University in Gangwon. Though the majority of UIG actors are situated in the three main innovative regions—Seoul, Kyeonggi, and Daejeon, the overall network of UIG relations is highly centralized around those central actors and fragmented into eight small isolated components. In addition, the networked relations are seemingly simple and sparse, which clearly signifies that the tripartite co-inventorship network has not been activated yet in Korea.

In comparison with all the networks of the bi- and trilateral UIG relations embedded in technology collaboration, all 16 provincial-level regions participated in the network of bilateral technology collaboration, whereas there are 10 regions making up the trilateral network. As denoted in Table 5, the network of U–I co-inventorship relations is more densely interconnected and decentralized than the other three types of network. The trilateral network, however, seems to have relatively weaker connectedness between regional actors, meaning that the inter-regional network of trilateral co-inventorship relations is underdeveloped. The networks of both U–G and G–I collaborative relations have the most centralized structure, with higher degrees of network centralization, indicating that the inter-regional collaboration involving the government research sector is mostly concentrated in only a few central regions. In other words, this is a reflection of the uneven distribution of public R&D resources between the research core and the periphery.

5 Discussion

This study presents a network analysis of patent collaboration in South Korea's 16 provincial-level regions, in order to ascertain the patterns of inter-regional technology collaboration on a triple helix level. Since very few studies have investigated the co-inventorship relations between key innovation actors in the Korean context, the present study attempts to explore the "systemness" of the KNIS, focusing on the triple helix structure of inter-regional co-inventorship networks. Therefore, two aspects of our findings need further discussion.

First, at the inter-regional level, the weakening position of Seoul in the R&D landscape is clearly confirmed, which is consistent with previous findings (Shapiro et al. 2010). This change in research topology is concurrent with the emergence of new research collaboration centers, such as Daejeon and Kyeonggi. Extending the findings of previous studies, the present study reveals that the three main innovative regions—Seoul, Daejeon, and Kyeonggi—are strongly interconnected with each other and constitute the core of all four types of inter-provincial co-inventorship network. Despite the trend toward decentralization with the increasing connectedness of the provinces and metropolises through collaboration, the majority of the regions are found to be poorly linked to the research core. The establishment of solid collaborative linkages between the advanced regional innovation systems would be beneficial to the overall functioning and performance of the inter-regional collaboration network. This raises the issue of the unfair geographical concentration of innovation resources and technology activities which underlies the inequalities between the research core and the periphery. The continuation of this vicious circle of concentration and increasing regional gap would hinder the synergy in the national and regional innovation system.

From a policy point of view, the Korean government needs to strengthen the quality of collaborative linkages between the advanced regions and the periphery by facilitating the establishment of a variety of inter-regional research collaborations, especially in the non-capital regions. The central government should develop various incentives to promote inter-regional R&D collaborations and implement policy programs conducive to the establishment of a collaboration platform for innovation. In addition, more policy efforts are needed to boost the capacities and performance of the regional innovation system in the periphery. Most of all, the central positions of Daejeon, Seoul, and Kyeonggi as the research brokers should be reconsidered, since the large number of public research institutes located in the three advanced regions mainly collaborate with UIG actors within the research core. In this vein, their role should be redesigned so as to revitalize the innovation activities in the peripheral regions which are lacking in local knowledge infrastructures. In order to enhance the capacities of the regional innovation system, the regional government also needs to make vigorous efforts to promote interactions with these core regions, so as to compensate for their shortage of innovation resources and capacities.

Second, at the triple helix level, the pattern of each of the four types of collaborative relations among UIG appears to vary across the regions. Compared to the networks of the bilateral UIG relations, the tripartite collaboration network between UIG is the least developed in terms of network scale, density, and centralization. Interestingly, while the web of tripartite co-inventorship relations is mainly built around the capital region, the private sector in the non-capital region has emerged as the major actor leading to the formation of the network. In the early stage of network development, the scientific and private sectors in both the research core and periphery should further participate in a broad range of tri-lateral technology collaborations. In order to create a dynamic innovative milieu for bolstering Korea's innovation systems, the interactive learning between the core and the periphery, as well as between the various UIG actors, must be facilitated by undertaking effective innovation policy initiatives at the national and regional levels.

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