

The evolution of South Korea's innovation system: moving towards the triple helix model?

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Abstract The South Korea's innovation system has been transformed in tandem with rapid economic growth over the last three decades. In order to explore the evolution process of the innovation system in Korea, this study examines the trends and patterns in collaboration activities among the triple helix actors, such as university, industry, and government (UIG), using co-patent data. The triple helix framework is employed to analyze innovation dynamics within the networks of the bi- and trilateral relations embedded in patent collaborations. The analyses focus on how the triple helix dynamics have been shaped and transformed in the course of development of the innovation system. The results reveal that collaboration activities among UIG largely increased across three developmental phases from 1980 to 2012. In the early periods, strategic R&D alliances between industry and government sector were set up to strengthen enterprises' innovation capabilities. When the Korean large conglomerates, *Chaebols*, became a dominant driver of domestic innovation activities, the primary agents of the collaborations shifted from industry-government to industry-university. The network analysis shows that university-industry collaboration is the strongest within the triple helix in recent years, followed by industry-government relations and then UIG relations. The tripartite collaboration has emerged with the rise of entrepreneur universities, but its network has rather been weak and inactive. While Korea has experienced a transition from statist model to a triple helix, the full-fledged triple helix model has not been established yet.

Keywords Co-patent · Innovation systems · Triple helix · University-industry-government relations · Collaboration network · South Korea

Introduction

South Korea has been well-known as one of the late-industrializing countries achieving remarkably rapid industrial and technological catch-up. The unprecedented economic

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growth has been accompanied by the evolution of Korea's national innovation system (KNIS). The government's vigorous efforts to construct a competitive innovation system have transformed the country from imitator to innovator (Kim and Nelson 2000). In recent years, the Korean government has announced new ambitious national science and technology (S&T) plans for the next few years to realize Korea's aspirations to become a global innovation leader. The main S&T strategies are to raise national innovation capacities to world-class levels through the expansion of national R&D investment in key technology fields and to make the building blocks of an innovation-driven economy by boosting technology-based industries.

While the KNIS has undergone dynamic transformations for the last three decades, the shift from a "catch-up" to a more "creative" mode of development has brought the changes in its structure that reshape the actions and interactions of key innovation actors (Keenan 2012). The emergence of university, industry, and government (UIG) as the main innovation actors in the development of the innovation system has cultivated the linkages between science and industry, generating various forms of collaborations among UIG. The reciprocal relationships between three institutional spheres have been co-evolved gradually with growth of each independent UIG entity, which in turn shape the dynamics of the KNIS over time.

The importance of UIG collaborations for innovation has been widely acknowledged, not only by innovation scholars but also by policy makers. The triple helix thesis emphasizes the relationships and interplay of UIG as the core of knowledge production and innovation (Etzkowitz and Leydesdorff 2000; Etzkowitz 2003). The triple helix model of UIG relations has been considered as a guider of national innovation policy and practice that led to institutional transformations and development paths of the national innovation system (NIS). It has the capability to provide a snapshot of the evolution of innovation systems in terms of the dynamics within the UIG relations and new development at both institutional and network levels. The triple helix model, therefore, is not only enable us to study the dynamic underpinnings of innovation focusing on interacting institutional spheres in the innovation process, but also suggest a policy direction in creating environments for further technological innovation and sustainable development in a NIS (Park and Leydesdorff 2010).

Since the Korean S&T policy concern has lain in the establishment of a more globally open, creative, and diffusion-oriented NIS, it has shed light on the importance of building strong linkages and networks between main innovation actors. Despite an increasing trend of innovation activities among UIG, only a few studies are empirically carried out to examine the evolution process of the KNIS from the triple helix perspective. In this vein, this study aims to analyze the collaboration patterns and networks of UIG relations in Korea based on patent network analysis in order to historically assess the transformation of the NIS. It particularly focuses on patenting activities and patent collaborations among UIG to illustrate the Korean model of innovation in transition. The findings from analytical results will enrich our understanding of the evolutionary dynamics of innovation systems.

Literature review

System of innovation approach

The system of innovation approach has been widely accepted as an analytical tool to better understand innovation process as well as a guide for S&T policy-making to effectively

strengthen the national innovation capacity. The underlying concept of innovation systems derives from the NIS approach (Nelson 1993; Patel and Pavitt 1994; Edquist 1997). The NIS is originally defined as “the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies” (Freeman 1987: 1). The NIS literature shows the diversity in national approaches to innovation, addressing that the pace and pattern of technological progress and accumulation vary across countries according to the dynamic nature of the national system of innovation.

The system of innovation approach deviates from the simplistic accounts of the linear model of innovation, conceptualizing innovation and technical progress as a complex set of relationships among actors producing, applying, and distributing various kinds of knowledge (OECD 1997). It places an emphasis on the interactive and collective learning process within a web of personal and institutional connections which evolve over time. The system approach illuminates the interactivity of the innovation process, regarded as feedback loops within the system composed of networks of the actors and institutions. Therefore, innovation is embedded in social relationships, largely depending on how a community of actors and institutions function and interact together to create, diffuse, and appropriate new knowledge.

In the national context, the innovation system is mainly structured by components, relationships, and attributes that interplay in the production of knowledge and technological innovation (Carlsson et al. 2002). The feedback mechanism built in a national system coordinates all components as well as forges the linkages between them in the innovation process, constituting the system dynamics. The major components of the NIS are actual knowledge producers, i.e. firms, university, and research institutes, as well as coordinators, such as government agencies, which set the goals and visions for innovation policies and implement policy programs to activate interactive learning among knowledge producers. Those components systematically interact not only with each other, but also with institutional components, including the set of practices, norms, regulatory laws, and policies that manage and control the behaviors of innovation actors and their relationships. The interrelationships between all the system components serve the functions of the innovation system, contributing to the building up of national innovation capacities. In this manner, the main concern of the NIS is how to effectively configure the national setting of innovation actors and how to well-construct the feedback mechanism in a national system, which serves as a facilitator of interactive learning between major actors within the setting (Chung 2002).

However, the NIS approach has faced the criticisms with regard to the absence of theoretical formalization and measurement issues (Carlsson et al. 2002; Hekkert et al. 2007). It is generally considered as an analytical tool and a guide for policy-making rather than formal theory (Edquist 2005). Because of its vague concepts and measurement difficulties, the lack of coherence between theoretical constructs and empirical applications has stood out as problematic. Despite some analytical and methodological issues, the NIS approach has been embraced by many scholars due to a flexible and useful framework for analyzing technological innovations (Cassiolato et al. 2003). Given that the process of technological change is relational, interactive, and cumulative in nature, the NIS approach is well-suited to capture the complexity and dynamics of innovation processes, providing a snapshot of the transformation of innovation systems in which the co-evolution of technology, institutions, and organizations takes place.

While the NIS framework was constructed based on experiences of developed economies, there has been some skepticism about its applicability to emerging countries. Viotti (2002) specifically points out that the processes of technical change in late industrializing

countries differ from those of industrialized countries, because it often occurs outside the innovation realm, such as industry sector, which is at the core of innovation system in most cases. By contrast, Arocena and Sutz (2005: 1) propose the concept of the NIS as a useful tool “for studying the concrete aspects of innovation activities in underdeveloped countries, thus contributing to a revitalization of development thinking.” The NIS approach can be taken from the perspective of underdevelopment as an “ex-ante” concept for the cases of developing countries, suggesting the development strategy by identifying the missing linkages and interactions within a national system of innovation, which do not occur for different reasons thereby reducing the national innovation performance.

Triple helix model of innovation systems

The innovation literature has emphasized the systemic characteristics of innovation and knowledge production with focus on vertical interaction and collective learning process. Some crucial ideas derived from the innovation system approach have created a wide variety of the nonlinear models of innovation (Cooke 1996; Breschi and Malerba 1997; Porter 1990; Carlsson and Stankiewicz 1991). Gibbons’s (1994) new production of knowledge as one of those models has illustrated the transformation of system dynamics from the disciplinary knowledge production referred to as Mode 1 to the Mode 2 knowledge production occurring in a trans-disciplinary and cross-organizational context. The rapidly growing Mode 2 scientific knowledge is highly interactive and socially distributed, which characterizes the mode of innovation today. Given the situation, the triple helix model provides a more detailed picture of Mode 2 by specifying the social structure of a dynamic system of innovation with the institutional relations among universities, industry, and government (Etzkowitz and Leydesdorff 2000).

The triple helix model underpins the study of innovation systems at various levels, fortifying the conceptual and empirical grounds for exploring the “systemness” of innovations (Leydesdorff and Zawdie 2010). The triple helix denoted as the networks of relations among academia, business, and government builds a knowledge infrastructure that generates knowledge-based innovation. According to the triple helix framework, the innovation system is conceptualized by the three major institutional spheres as well as their activities and interactions. The triple helix provides an analytical model at the level of social structure and dynamics, taking the arrangements and networks among UIG into account. The triple helix model of innovation system has three basic propositions (Etzkowitz 2003; Etzkowitz et al. 2007). First, unlike the NIS tradition which considers the firms as the center of innovation systems, the triple helix thesis postulates that the university plays a more prominent role in innovation as an entrepreneur in knowledge-based societies. Second, university, industry, and government are co-evolving components consisting of innovation systems and the interactions between them are essential to enhance conditions for innovation. Third, the evolution of innovation systems is accompanied by transformations in the UIG relationships as well as each institutional sphere.

The triple helix network of UIG relations enables us to trace the development paths of innovation systems in varying institutional arrangements. The interactions among UIG are considered as the triple helix network overlay of communication that historically evolves and reshapes the structure and dynamics of innovation systems. Bilateral interactions among UIG have expanded into trilateral interactions, shifting from single and double helixes to a triple helix regime through enhancing the traditional roles of each institutional sphere. Etzkowitz and Leydesdorff (2000) classify the triple helix of UIG relations into three configurations: (1) statist model (Triple-helix I), (2) laissez-faire model (Triple-Helix

II), and (3) triple-helix model (Triple-Helix III; see Fig. 1) They show the development pathways from two different starting points—the statist and laissez-faire models—to the triple helix model of innovation, which reflect changes in the arrangements of UIG relations in innovation systems.

In the statist model labeled as Triple-Helix I, government plays a leading role as the innovation organizer, encompassing university and industry and coordinating the relations between them. The statist triple-helix is viewed as the top-down model of development with government controlling academia and industry. As the subordinate parts of the government, both university and industry have weak research capabilities and lack of resources that require strong guidance from government. In this triple helix configuration, government takes the lead in coordinating the other institutional spheres to promote the creation of new S&T based industries. Universities play a more traditional role as teaching-oriented institutions, providing well-trained research personnel to work in other spheres. Large-scale government projects raise the level of public research to create new enterprises and support the growth of strategic industries. Given that there is not much room for “bottom up” innovation, the Triple-Helix I is largely seen as a failed development model in which innovation is discouraged rather than encouraged.

Triple Helix II is a laissez-faire model of separate institutional spheres with strong boundaries and highly limited interaction among the spheres. Three institutional spheres act independently without close linkages between them. The model is substantially reflected in the laissez-faire policy, which places an emphasis on the loosening of government control. The role of government is expected to be limited to regulation or only larger in the case of so-called ‘market failure’ where the market is unable to provide an activity. In the Triple Helix II model, industry is a driving force for innovation with other two spheres serving as ancillary structure supporting firms. The university is indirectly connected to industry through production of useful knowledge in the form of scientific publications and trained personnel. Enterprises set apart from each other in the intense competition environment, but interact modestly in the market relationships of buying and selling. The roles of government and industry in Triple Helix I are indeed reversed in a laissez-faire regime.

The shift to Triple Helix III from either the statist or laissez-faire models takes place with the global tendency toward convergence of three institutional spheres. The Triple Helix III model is an interactive model consisting of overlapping institutional spheres, where institutional spheres of UIG actively interact with each other by performing its traditional functions and taking the role of the other. It is the most desirable model of the

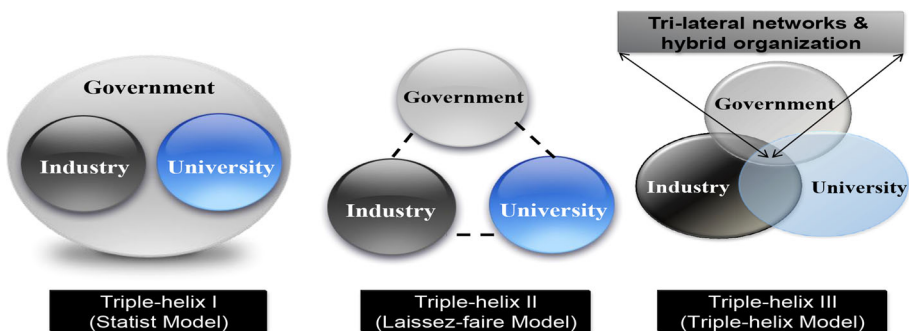


Fig. 1 Three models of UIG relations. *Source:* Etzkowitz and Leydesdorff (2000, p. 111)

triple helix that most countries and regions attempt to achieve in order to promote innovation. In this model, the university assumes the entrepreneurial functions as a source of firm-formation in addition to its traditional role as a provider of human resource and basic research. Industry is also taking up the new role of the university by delivering training and its own research at higher levels, while government helps to support development of a triple helix regime through the new rule of games by changing the regulatory environment and direct or indirect financial assistance, such as the provision of venture capital to help start new enterprises. The Triple Helix III becomes the innovation platform for the new institution creation in that hybrid organizations emerge from interactions among UIG as the forms of the incubators, university spin-off firms, venture capital firms, tri-lateral initiatives for knowledge-based development, and strategic R&D alliances.

In sum, the triple helix configurations give a snapshot of the innovation system with particular focus on the formation of the triple helix of UIG relations at each moment in time. As the NISs vary considerably in their pace and pattern of innovation production, the triple helix dynamics may also be diverse across countries, set in motion from various starting points with different triple helix configurations. For example, the Triple Helix I model is mostly found in the former Soviet Union and some of European and Latin American Countries, while the Triple Helix II model is exemplified in Sweden and the United States (US).¹ Despite its usefulness for the analysis of innovation systems, the triple helix model has encountered criticism with regard to its validity and applicability in different national and cultural contexts. Although there has been no one-size-fits-all approach, some scholars have a skeptical view that the triple helix model initially grounded in Western developed countries is not applicable to developing and emerging economies due to different national and local contexts (Eun et al. 2006; Williams and Woodson 2012). However, the triple helix model has been frequently used in innovation studies in non-western countries as the adequate analytical framework of innovation dynamics and policy guide for developing NISs (Saad et al. 2008; Lei et al. 2012; Park and Leydesdorff 2010; Shapiro 2007). The model has been proposed as an effective mechanism for innovation policy planning and development, providing an institutional platform for interactive learning for knowledge-based innovation between the three UIG actors and enhancing endogenous S&T capacities of national or regional innovation systems.

In this study, therefore, the triple helix model of UIG relations is adopted to examine the transformation of the KNIS, since the triple helix paradigm has not been extensively applied to the Korean context. The bi- and trilateral relations among UIG evince not only the extent to which networks of UIG relations have developed into a synergetic

¹ The triple helix thesis focuses on the path to the triple helix from two different standpoints, such as a statist model and a *laissez-faire* model. The former Soviet Union, France, and many Latin American countries exemplify the statist model of government coordinating industry and academia to promote technology development. The loosening of top-down control and devolving powers of the central government often precede changes in the classic statist regime and lead to the statist transition process. However, Sweden and the US exemplify the *laissez-faire* model, where a strong ideology of individualism and limited state intervention operates in practice. For example, the anti-trust regulations and strong individual entrepreneurship in the US and the tradition of academic freedom and institutional autonomy with strict separation between public and private spheres in Sweden formed a *laissez-faire* triple helix, consisting of separate institutional spheres, distinct institutional roles, and indirect relations among spheres. When there was an economic crisis, however, government came to play a more interventionist role through providing the rule of the game (e.g., the US Bayh-Dole Act) as well as tri-lateral initiatives (e.g., Vinnova in Sweden). Government's changing roles were observed in the US from economic recession of the 1970s and Sweden in the 1990s made the transition to an interactive triple helix. Recently, the model of government seems to be placed at the midpoint between the interventionist model (direct innovation policies) and the *laissez-faire* model (indirect innovation policies) in both countries.

configuration, but also how the network dynamics have been constituted and transformed that is underlying the evolution of the innovation system.

Korea's national innovation system in transition

The KNIS has been transformed in accordance with the development of system elements (Yim and Kim 2005; Hemmert 2007; Kim 2008). The evolution of the KNIS throughout the last 40 years can be divided into three phases: (1) the period of imitation of foreign technology in the 1970s and 1980s; (2) the period of technological catch-up during the 1990s; and (3) the period of creative innovation since 2000s. The shifts from the imitative and catch-up to the creative mode of development are made under the influences of the Korean government's strategic policies and initiative programmes (see Table 1).

In the first period 1970s–1980s, Korea initiated the building of the NIS by establishing the government research institutes (GRIs) to engage in first modern R&D activities. Because industry and university had weak technological capabilities, the Korean government had to take an active role in constructing S&T infrastructure that could absorb imported technologies from advanced countries through duplicative imitation and reverse engineering. The Ministry of Science and Technology (MOST) was founded to formulate and implement S&T policies and strategic programs, coordinating and guiding overall S&T activities in the country. The first GRI—the Korea Institute of Science and Technology (KIST)—was set up by the Korean government as the strategic locus of national R&D. While university and industry completely lacked in technology capabilities, the KIST played a pivotal role of the integrated research center, not only training research personnel but also transferring industrial technology to firms by executing reverse engineering and providing high-quality researchers. Subsequently, a number of GRIs were created in order to meet the increasing demands from strategic industries in the areas of machinery, chemicals, shipbuilding, and electronics, designated by the government. While universities predominately remained educational institutions with the lack of research activities, they were encouraged to focus on vocational training in science and engineering in order to supply a skilled manpower, especially technicians and engineers to industry.

During the catch-up phase, the private sector was an important vehicle for large-scale strategic technology development, marking a shift from an early GRI-centered NIS to an industry-led NIS. Industrial firms began enhancing technological capabilities by building their internal research centers in response to severe international competitions and government policy supports for industrial R&D. The share of the private sector in the national R&D expenditure rose from 38 % in 1980 to 73 % in 1995. In fact, the launch of the National R&D Programmes (NRDP) under the supervision of MOST in the early 1980s had ignited firms' innovation activities and revitalized government-sponsored research projects, in which GRIs, industry, and university could engage in R&D cooperation. Firms were especially encouraged to set up in-house R&D laboratories and global research centers by various policy measures, such as tax incentives, financial supports, and exemption from compulsory military service for key researchers (Yim and Kim 2005). As innovation capabilities of the private sector were strengthened and reached technological frontiers, the GRIs had played a supplementary role for the technological upgrading of industrial firms. The dramatic growth of private R&D activities, in turn, weakened the exclusive position of the GRIs that consequently led to the reform of its structure and funding system. Meanwhile, universities gradually turned into more research oriented institutions, not only rearing high-quality R&D manpower but also undertaking innovation

Table 1 The evolution of the system elements in the KNIS

	1970s–1980s	1990s	2000s–Present
Mode	Imitative	Catch-up	Creative
Key actor	GRI	Industry	University
UIG status	University: Primarily teaching-oriented institution with weak R&D capabilities Industry: Minor role in the national R&D with the lack of R&D activities	University: Transition to research-oriented institutions Industry: Major performer in the national R&D with enhancement of indigenous R&D capabilities	University: Strengthening of R&D capabilities with a special focus on basic research Industry: Dominant position in the national R&D
	GRI: Major performer in national R&D with absorptive and technology transfer capacities	GRI: Strategic partner of industry with a leading role in the NRDP	GRI: More emphasis on experimental development to produce large complex advanced technology
Policy strategies	Imitation and reverse engineering of imported technologies Building up basic S&T infrastructure for industrialization	Promotion of indigenous technology in the private sector to produce high-tech products Development of highly skilled S&T manpower and university R&D Enhancement of national R&D efficiency	Fostering innovation in industrial clusters Development of high-tech and high value-added industries Expansion of basic research capabilities Promotion of exploitation of academic research
Major policy initiatives and programmes	Establishment of the MOST to coordinate overall S&T policies and Laws Foundation of the KIST and 20 other GRIs Encouragement of vocational training in science and engineering in universities	Launch and implementation of national R&D Programme Implementation of government programmes for promoting academic research (e.g., science and engineering research center, regional research center, etc.) Reform of GRIs	Implementation of various R&D programmes for University (e.g., Brain Korea 21, creative research initiatives, connect Korea, etc.) Execution of the R&D programmes for the creation of core technology (e.g., 21st century frontier R&D)

Source: Compiled from various documents

activities. This reflects the Korean government's efforts to establish the academic research base by implementing several policy programmes.

In the third period, the university emerged as one of major innovation performers with an increase in research capabilities. Around 2000, the Korean government induced the expansion of academic research, stimulating the university R&D activities and emphasizing its contribution to the economy. Academic research was invigorated by the government policy strategies conducive to promoting basic research and its commercial exploitation (see Table 1). Government investment in academic research largely increased, tripling in 10 years from \$894 million in 2002 to \$3.4 billion in 2012. While the university became an important partner for enterprises, industry reinforced their own indigenous innovation capabilities by intensifying their R&D investment and globalizing their R&D

activities. As a result, a group of the Korean enterprises reached the global technological frontier in certain high-tech areas. When innovation capabilities of both industry and university were more strengthened, the role of the GRIs becomes less clear-cut. After the reforms of GRIs in the late 1990s, new evaluation and management systems skew R&D activities of GRIs toward more performance-based. This brought the change in their research foci from basic research to short-term experimental development and applied research. Recently, the roles of GRIs are redefined in terms of the development of basic core technology and R&D commercialization.

Data and methodology

Data collection

In order to trace the development of innovation activities of UIG and networks of interactions among them, this study analyzes the trends in domestic patent applications filed by university, firms, and GRIs between 1980 and 2012. The patent data is retrieved from the Korea Intellectual Property Rights Information Service (KIPRIS) database provided by the Korean Intellectual Property Office (KIPO).² The KIPRIS, as an online patent search service for Korean patent documents, has provided a dataset with complete patent information. Domestic patent statistics have been systematically collected and published by the KIPO for over the past 20 years. The patent database of the KIPO contains rich and reliable information on Korean domestic patent applications and grants. According to the Korean patent system, there are three types of patents—invention, utility models, and design. Of the three types of patents, invention patents represent the most important and technologically sophisticated inventions like a significant technological improvement in products or processes. Utility model and design patents are less technologically innovative than invention patents. Taking the quality of inventions into consideration, therefore, only invention patent information is collected and employed in the analysis. Compiled patent database includes the names of inventions and its abstract, the dates of applications, publication, and registration, the names and addresses of inventors and assignees, and the international patent classification (IPC) code.

Examining the assignee information, patents jointly applied for by UIG are identified as co-applications, representing the results of successful collaborations among UIG. In this study, bibliographic information of 18,097 invention patent applications jointly filed by UIG is obtained and exploited to map the dynamic networks of UIG for collaborations. By setting appropriate search conditions, co-patents applied for by UIG actors are accessed as follows: for industry sector, the search term of assignee name is a “company (*Huisa*)”; for academic sector, the assignee name is a “university (*Daehak*)”; and for government sector, the assignee name is a “research institute (*Yeonguwon*).”³ The combinations of search

² This study utilizes patent data from the KIPO over those from the United States Patent and Trademark Office (USPTO), because domestic patent data from the KIPRIS are easily accessible and contain abundant information of co-inventorship, compared to those from the USPTO. It is more suitable to analyze collaborative networks among UIG, covering a range of domestic patent applications jointly filed by various UIG actors.

³ The Korean search terms are in parentheses and the search was made by the author in November 2013. Previous studies used various search terms for UIG in the Korean context. For example, Choi et al. (2014) and Park and Leydesdorff (2010) classified universities, colleges, and their affiliated institutions as the university sector; those including the terms “incorporated,” “corporation,” and “hospital” were labeled as

terms, such as “university-company (*Daehak-Huisa*),” “research institute-company (*Yeonguwon-Huisa*),” “research institute-university (*Yeonguwon-Daehak*)” and “university-research institute-company (*Daehak-Yeonguwon-Huisa*)” are used to obtain a co-invention dataset.⁴

It is noteworthy that GRIs could be a measure of government’s innovation activities in the particular context of Korea. There have been 24 specialized R&D institutes established by the Korean government on the legal basis for the foundation, management, and promotion of the publicly funded research institutes. At present, the Korean GRIs can be viewed as quasi-government organizations in that they are funded by government to pursue R&D activities as well as directly guided by the government initiatives, but the relative autonomy is given to the GRIs in its operation. However, the Korean GRIs have long been the strategic locus of government S&T policies as played the leading role in the NRDP. The main tasks of the Korean GRIs have been not only performing public R&D, but also undertaking commercial activities through technology transfer and creation of research-based spin-off firms. Given that GRIs are founded and directed by government to pursuit public interests, patents belong to GRIs, to some extent, indicate the outcomes of innovation efforts made by the government sector.

Co-patent analysis

Co-patent analysis has been a useful method to measure technological collaborations (Chen et al. 2013; Zheng et al. 2012; Petruzzelli 2011; Lei et al. 2012, 2013; Ma and Lee 2008), to analyze knowledge networks among innovation actors (Ortega 2011; Guan and Chen 2012), and to examine the performance of innovation systems (Ma et al. 2009; Gao et al. 2014). Patent statistics have long been considered as a well-grounded proxy for innovation activities and collaboration efforts. As computerized and publicly available data, patent records are not only easy to access, but also include detailed information on the inventions, technological fields, inventors, assignees, and so on. They are also able to indicate inventions or innovation outputs of the public sector, such as universities, GRIs, and other non-profit organizations. Since patent data contain the temporal, geographical, sectoral, and organizational dimensions of innovation, it enables us to analyze collaborative relationships for innovation activities at both macro (e.g., national and regional) and micro (e.g., firm and individual) levels in a certain time period. Given that technological collaboration is a crucial element forming the dynamics of a NIS, co-patent analysis offers valuable sources of information and insights about collaborative efforts and interactive relationships between innovation actors in assessing the performance of innovation systems.

Footnote 3 continued

the industry sector; and national agencies and non-profit organizations were considered as the government sector. In this study, however, universities and their affiliated organizations, such as the technology licensing office, are identified as the university sector. The “company” (*Huisa*) is used as the search term for industry, because it is a more suitable term to search for industry patents at the KIPRIS. In this study, all patents where co-assignees names include at least one of 24 Korean GRIs are considered as those that are relevant for the government sector and then they are filtered out in all the patents found with the search term “research institute (*Yeonguwon*).”

⁴ The total number of joint patent applications filed by university, industry, and GRI is 18,097. The actual cases for industry-GRIs are 8151, those for industry-university are 8193, those for university-GRIs are 1675, and those for university-industry-GRI are 78.

In this study, the UIG collaboration trends and patterns are examined, using co-patent analysis. Previous studies often use co-authorship relations in the scientific publications (Park and Leydesdorff 2010; Choi et al. 2014; Kwon et al. 2012), institutional relationships on the Web (Khan and Park 2011), or both (Park et al. 2005) to measure collaboration patterns in networks of UIG relations. Comparably, co-inventorship relations in patents can be a more appropriate indicator of innovation activities and technology collaboration patterns, because it measures the outcome of invention process that is closer to commercial application than other indicators. In this study, therefore, the bi- and trilateral relations among UIG for technology collaborations are observed in the case of co-assigned patents. Those collaborative relationships for technological innovation are measured by the count of patents jointly assigned by UIG. In general, patent applications can tell the name of assignees and the assignees' stated address, identifying the intended agent and the location for deployment and commercialization of intellectual property rights attached to patents after the filing of a patent application (Ma et al. 2009). The information of patent assignees, therefore, can be used as an indicator of inventive activities and collaboration relationships. A patent can be assigned to single or multiple assignees, including the inventors for commercial exploitations of intellectual property. Multiple assignees mean that several innovation entities may collectively involve in invention activities and share the ownership of a patent. Thus, patent collaboration represents the dimension of innovation, concerning not only the generation of new knowledge and technological inventions but also its potential implementation into economic value.

Patent collaboration network

Patent collaboration network is one of the frequently used methods to provide a vivid picture of collaborative patterns and knowledge networks at individual, organizational, regional, and national levels. It is based on a social network technique using patent data to detect and interpret the patterns of collaboration ties among innovative actors. The network approach enables us to explore social structure, denoting structural components—people, organization, regions, and countries—and mapping the complex web of interactions between them. It has been applied to examine knowledge infrastructure of innovation systems in terms of networks through the use of patent statistics and visualization. For example, Hong (2008) investigates the geographic variations in university–industry collaborations captured by joint patent applications, deploying knowledge transfer networks. Using patent network analysis, his study found a decentralizing and localizing trend in university–industry collaborations in China along with the growing importance of university in the NIS. Chen and Guan (2011) employ bibliometrics and social network analysis to examine the performance of innovation actors at both organizational and regional levels in the field of biotechnology. Two kinds of knowledge networks are constructed and analyzed to measure knowledge transfer through patent collaborations. In order to explore the patterns of knowledge exchanges across regions, Gao et al.'s (2011) study examines patent collaboration networks that contribute to policy-making when designing national and regional innovation systems. Zheng et al. (2014) construct the collaboration networks of the top 20 countries and regions using nanotechnology patents and discover an upward trend of international collaborations in nanotechnology.

The empirical investigation of this study is based on the collaboration networks of UIG, linking UIG actors and their connections by four different types of patent collaborations in a given period of time. It is worthwhile to build collaboration networks of UIG with this method, for it indicates the knowledge infrastructure of innovation systems that operate to

produce technological innovations. The network analysis exhibits the changes in the dynamics of innovation systems at each moment in time by visualizing the evolving knowledge base of the systems. In patent collaboration networks, each node represents the actors and the edges among them indicate the collaboration relationships that are embedded in co-patents. The collaboration networks between UIG in both double and triple helix forms are constructed at different times. Descriptive statistics of each network in different time periods are provided to analyze the development patterns in collaboration networks among UIG.

Results

Overview of patenting activities in Korea

The overall growth trend of innovation activities and development patterns of UIG collaborations in Korea are traced and scrutinized. Figure 2 shows an increasing trend of patenting activities in Korea from 1980 to 2012. Domestic technology capabilities have been enhanced over time in that the number of domestic Korean patent applications has gradually increased since the mid-1990s, surpassing that of foreign ones. During the period 1980–1990, domestic Korean patent applications accounted for only 20 % of total Korean patent applications, indicating that Korea had depended heavily on imported technologies. The top three foreign assignees were Japan, the US and Germany, accounting for the lion's share of foreign patent applications in Korea. With a rapid increase in patenting activities, however, domestic assignees firstly took over half share of total Korean patent applications in 1997 that almost tripled the foreign share at the same time.

A sharp upward trend of domestic Korean patents results primarily from a substantial increase in patenting activities of industrial firms. The number of patents applications by firms escalated from 6634 in 1990 to 58,244 in 1997 with an average annual growth rate of 46 %. The predominance of the private sector in domestic patenting activities might result from the so-called 'patent bubble' during the 1990s, when the fastest growing patent

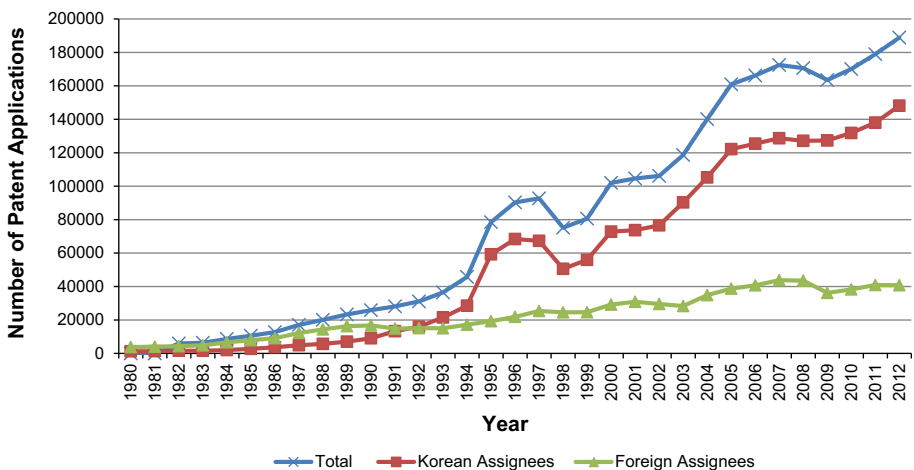


Fig. 2 Historical trends in patenting in Korea, 1980–2012

activities of large Korean enterprises occurred due to the fierce competitions in both domestic and international markets. As a global competition accelerated in tandem with the information technology (IT) boom, industry faced a new situation where strengthening technological capacity was essential to introduce new innovative products to the market. Consequently, this led to a lot of Korean enterprises to file large numbers of patent applications in order to protect their intellectual property rights for technological inventions with commercial potentials and to gain competitive advantage over their rivals. The Asian financial crisis of 1997, however, had a critical impact on an abrupt drop in Korean domestic patenting with a decline in the industry’s patenting activities.

From 2000 to 2012, the number of domestic patent applications increased by 85 %. A surge of domestic patenting since 2000 is characterized by the rapid expansion of innovation activities in both private and public spheres. This notable growth occurred at the institutional levels especially within and between UIG that constitute a structure of the KNIS. The number of patent applications filed by UIG rose from 52,114 in 2000 to 117,895 in 2012, almost three times higher than the number held by individual inventors during the period. It is sure that large investments in the NRDP targeted to foster R&D activities in private and public sectors have brought about a shift of main innovation entities in the KNIS from individuals to institutions since the early 1990s. Given that the probability that individual patents are commercialized is generally uncertain (Trajtenberg 2001), the fast-growing number of institutional patents marked by UIG can be viewed as a result of the Korean government’s efforts to realize key technological innovations in certain industry sectors as for the new engine of economic development in the country.

Patenting activities of UIG in Korea

A substantial increase in the industry’s patenting activities has played an important role in enhancing domestic innovation capabilities in Korea. As illustrated in Fig. 3, industry has been a predominant player in patenting among UIG, indicating that they are the primary locus of the KNIS over time. Compared to industry, GRI and university account for only 20 % of total UIG patent applications, but have gradually increased its share from 4 % in

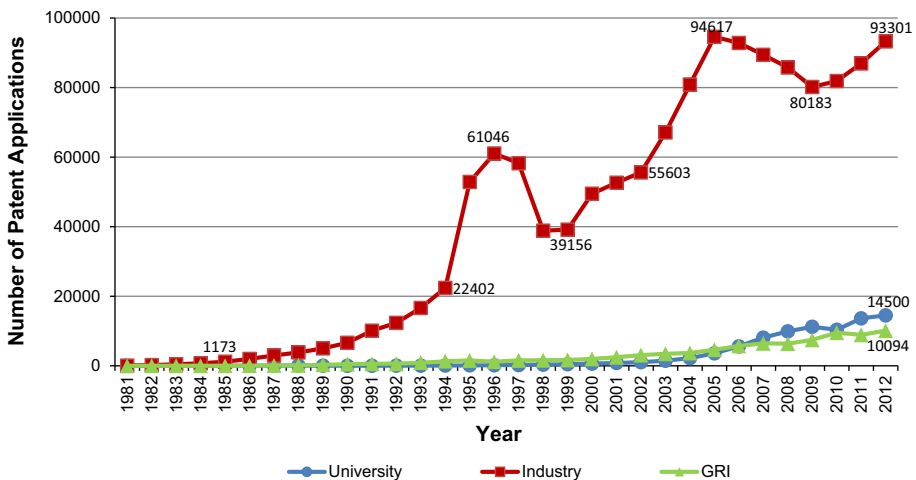


Fig. 3 Number of UIG patent applications in Korea, 1980–2012

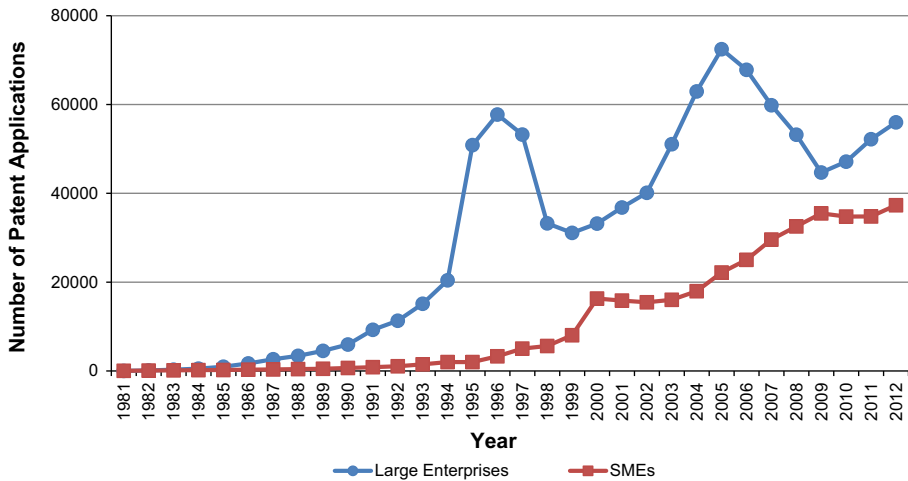


Fig. 4 Number of patents applied by large enterprises and SMEs in Korea, 1980–2012

2000 to 21 % in 2012. The increasing trend in patent activities of university and GRIs denotes that they have emerged as national R&D performers supporting industrial innovations.

The patent applications of industry can be divided by large enterprises and small-medium sized enterprises (SMEs). Large Korean enterprises, known as *Chaebols* (e.g., family-owned large conglomerates), account for a preponderant proportion of Korean domestic patents, representing itself as a leading innovation actor in the KNIS. Major Korean *Chaebols*, such as Samsung, Hyundai, and LG, emerged as top Korean patent assignees, actively performing R&D in their in-house research laboratories and internationalizing their R&D activities (Kim and Yi 1997). The number of patent applications filed by large enterprises plummeted right after the global financial crisis of 2007. At that time, *Chaebols* changed their intellectual property strategy with a shift of their focus from the quantity to the quality of patents, concerning their competitiveness in international markets.

The SMEs have steadily increased its share of domestic patents after the mid-1990s, as shown in Fig. 4. The remarkable increase in patenting activities of SMEs took place particularly in the fields of automobile and IT. In contrast to large enterprises which had a significant fall in patenting activities due to the Asian financial crisis of 1997, the patent applications of SMEs kept increasing at an annual growth rate of 55 % through the implementation of an “Act of Special Measure for Promotion of Venture Business” and a rapidly growing high-tech sector by the dot-com boom.⁵ The Korean government exerted various policy efforts to enhance technology capabilities of SMEs and to stimulate innovative entrepreneurship, expanding government R&D supports and revising the patent law, such as reducing patent-filing fees for SMEs and shortening the time for patent examinations.⁶

⁵ An “Act on Special Measure for Promotion of Venture Business” was implemented in 1997 to assist venture companies in start-up production, financing, workforce, technology, facilities, plant sites, and so on.

⁶ Based on the revision of Korean patent law in 2000, university and GRIs were entitled to a 50 % reduction of patent application fees and a 70 % reduction for individual inventors and SMEs until around the mid-2000s. Additionally, the average period of patent examination was reduced from 37 months in 1995 to 15 months in 2005.

A surge in domestic patenting in 2000s was accompanied by growth of university patenting activities under a Korean version of the US Bayh-Dole Act, the ‘Promotion of Technology Transfer Act’ and the government R&D support programmes. The number of patents applied by universities largely increased from 638 in 2000 to 14,500 in 2012 (see Fig. 3). This upward trend of university patenting can be responsive to the government S&T strategies to vitalize academic R&D as a key pillar of the KNIS. Emphasizing the important role of universities in the national innovation system, the Korean government launched the large-scale R&D support programs for universities, including the Brain Korea 21 program, Creative Research Initiatives, Excellent Research Center, and so on. As the ‘Promotion of Technology Transfer Act’ was enacted in 2000, universities were given autonomy to engage in commercial activities regarding academic R&D outcomes. Under the support of the Ministry of S&T, university faculty were encouraged to vigorously involve in patenting activities by offering a patent subsidy which can cover the costs of both international and domestic patent filings. The role of Korean universities, therefore, was redefined in a more entrepreneurial paradigm, transforming from education and research institutions to technology incubators commercializing technology breakthroughs.

When an active exploitation of academic research has been accentuated by the Korean government since 2000, patenting activities of GRIs have also steadily increased. According to Fig. 3, the number of patent applications filed by GRIs increased five-fold from 2000 to 2012. The reform of the late 1990s placing an emphasis on R&D performance of GRIs may, to some extent, influence their increasing patenting activities in accordance with the strong trends in the commercialization of public R&D outcomes. In 2000s, science sectors, university and GRI, were transformed gradually into the important entities of the KNIS, showing an upturn in the number of its patent applications.

Patent collaboration of UIG in Korea

In order to explore the development patterns of UIG collaborations in Korea, joint patent applications filed by UIG actors are analyzed. Patent collaborations of UIG from 1980 to 2012 are examined by the following four forms: (1) University-Industry; (2) Industry-GRI; (3) University-GRI; and (4) University-Industry-GRI. Figure 5 presents an overview of co-patenting activities between UIG for the last three decades. Two forms of patent collaborations, university-industry and industry-GRI are found to be most active in Korea. The first co-patenting activity was found in 1983, which appeared in the form of industry-GRI collaboration. Almost all co-patents were applied by industry and GRI in the 1980s and 1990s and its number exhibited continued growth until 1998, increasing from 3 in 1983 to 614 in 1997. This trend suggests that strategic partnerships between industry and GRI were at the center of collaboration activities in the early development of the KNIS, serving as a promoter of private R&D through providing industry with technical supports and top-quality researchers. However, the number of co-patents applied by industry and GRI drastically dropped by 50 % around the year 2000.

While the downward trend of patent collaborations between industry and GRI began with the reform of the GRIs’ funding system in 1999, the number of co-patents applied by industry and university skyrocketed from 62 in 2000 to 1382 in 2008. The increasing patent collaborations between university and industry may be invoked by remarkably growing patenting activities of universities right after the passage of the Promotion of Technology Transfer Act of 2000. The number of co-patents applied by university and GRI, in like manner, went up from 3 in 2000 to 203 in 2012. However, there were a very small number of co-patents applied by university, industry, and GRI the whole time, since the largest

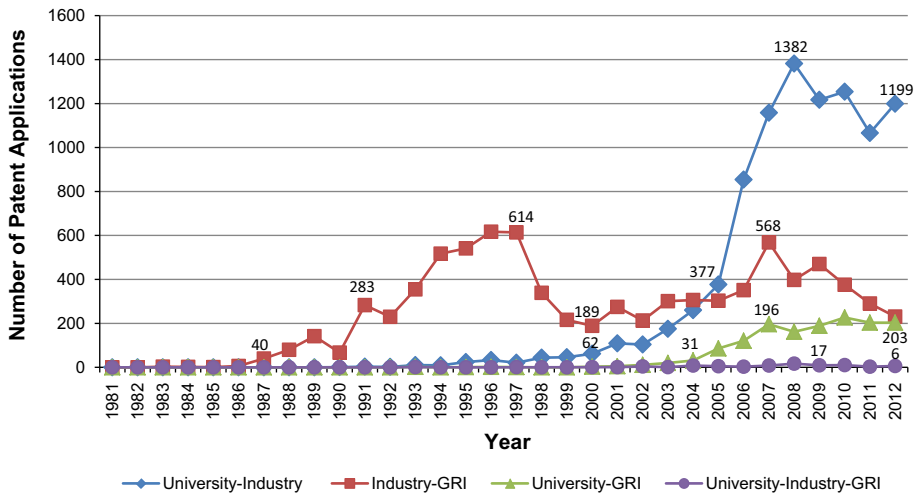


Fig. 5 Trends in co-patenting activities between UIG in Korea

number of their joint patent applications was only 17. This indicates that the tripartite collaboration of UIG is so insufficient that it has been a rare occurrence in Korea.

The top ten UIG co-assignees and their distribution in three time periods are examined to capture a more precise picture of the development patterns and trends of UIG collaborations in Korea. According to Table 2, over half of top co-patent assignees were a group of GRI and industry in the first two phases. The GRI was a key R&D partner for industry and the collaboration form of GRI-industry continued to prevail in science-industry collaborations. However, it should be noted that co-patenting activities tend to concentrate predominantly on only a few enterprises and GRIs at that time. For example, co-patents applied by the Electronics and Telecommunications Research Institute (ETRI) and KT Company account for the majority of domestic patent collaborations between 1980 and 2000. The KT was a public enterprise in the electronics and telecommunication industry founded in 1982 and became privatized in 2002. During the 1980s and 1990s, the ETRI and KT had long-term strategic R&D alliances arranged by the Korean government aimed at developing digital electronic switching systems, a series of TDX telecommunication switching machines. The successful commercialization of those digital electronic technologies from the R&D alliances resulted in the rapid growth of telephone penetration rates in the country. The ETRI and KT ranked first and second respectively in the first two periods, indicating that their technological collaborations were the driving force of the early development in the KNIS.

In the first phase, from 1980 to 1990, there was no university in the top ten list of co-assignees. The two university assignees firstly emerged in the second phase and increased to five in the third phase. The Korea Advanced Institute of S&T (KAIST) and Pohang University of S&T (Pohang Tech), known as the best science and engineering colleges in Korea, entered the list continually in the second and third time periods. This reflects the sharp upward trends in academic collaboration activities since the year 2000. As shown in Fig. 6, the number of industry assignees declined from six to three in the second phase and then stayed the same in the third phase. By contrast, the number of GRI assignees grew to five in the second phases and dropped to two in the last phase. Before there was a downward trend in the number of GRI assignees in the 2000s, they used to take a leading

Table 2 Top 10 UIG co-assignees in three time periods

Rank	80'–90'			91'–00'			01'–12'		
	Assignees	No.	UIG Type	Assignees	No.	UIG Type	Assignees	No.	UIG Type
1	Electronics and Telecommunication Research Institute	299	G	Electronics and Telecommunication Research Institute	3407	G	Samsung Electronics Co.	2945	I
2	KT Co.	287	I	KT Co.	3289	I	Electronics and Telecommunication Research Institute	2179	G
3	Korean Research Institute of Chemical Technology	15	G	Korea Institute of Science and Technology	158	G	Seoul National Univ.	1146	U
4	Korea Institute of Machinery and Materials	8	G	Korea Advanced Institute of Science and Technology	89	U	Korea Advanced Institute of Science and Technology	1110	U
5	Telecommunication Industry Technology Research Association	7	I	Pohang Univ. of Science and Technology	84	U	Korea Atomic Energy Research Institute	938	G
6	CJ Co.	5	I	Korean Research Institute of Chemical Technology	69	G	Korea Hydro and Nuclear Power Co.	888	I
7	KDC Co.	4	I	Korea Institute of Machinery & Materials	58	G	KT Co.	757	I
8	Kumho Industrial Co.	4	I	Mercury Co.	48	I	Yeonsei Univ.	723	U
9	LGEI Co.	4	I	Korea Electro-technology Research Institute	46	G	Pohang Univ. of Science and Technology	563	U
10	Korea Institute of Science and Technology	3	G	POSCO Co.	42	I	Hanyang Univ.	535	U

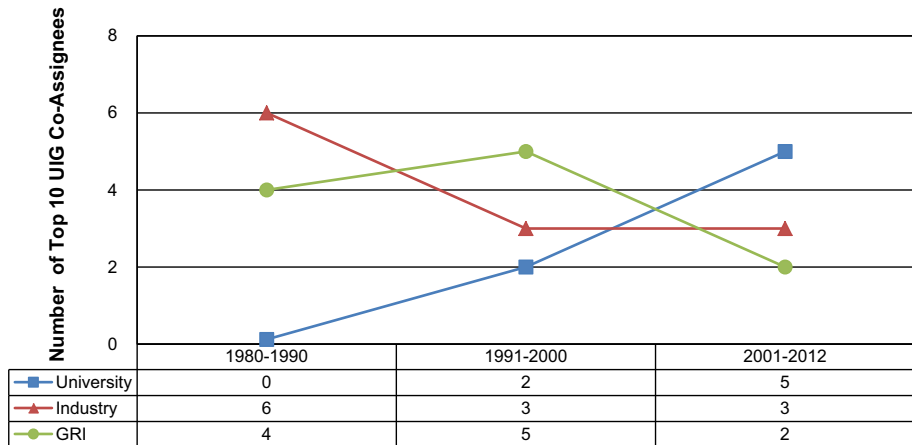


Fig. 6 Distribution of top ten UIG co-assignees in three time periods

role in collaboration activities. Such GRI assignees as the ETRI, Korea Institute of Science and Technology (KIST), Korea Institute of Machinery & Materials (KIMM), and Korean Research Institute of Chemical Technology (KRICT) appeared consistently in the list of the top ten co-assignees during the two time periods, 1980–1990 and 1991–2000.

The collaboration patterns and trends across the three time periods confirm the main innovation entities of the KNIS driving collaboration activities in each time period. The primary agents of collaborations among UIG were GRIs and industry in the first two phases and university in the last phase. Given that technological capabilities of industry were built and developed in the NRDP, where GRI was a facilitator of industrial innovations, the Korean model of innovation in the early phase is similar to Triple Helix I, in which government plays a dominant role as an innovation coordinator. Universities rarely engaged in R&D activities with no patent as mostly devoted to vocational education and training at that time. In the second phase, innovation capacities of industry were greatly enhanced, while GRIs continued a strategic role in supporting private R&D by engaging more in collaborations with industry. The last phase was characterized by academic commercialism in which the university is transformed into the “entrepreneur university” participating in innovation activities and joining collaborations with industrial firms and GRIs. The university has appeared as the most desirable collaborator for industry to carry out joint research projects mainly because of sufficient research resources and highly qualified human resources. Meanwhile, GRIs became independent partially from the direct controls of government during the reform period, where government imposed the competition-based funding system and reduction of R&D subsidy on GRIs. They have undergone a change from a strategic supporter of private R&D to an independent R&D performer involving in a variety of commercial activities.

Patent collaboration networks of UIG

In addition to co-patent analysis, the patent collaboration networks between 1980 and 2012 are analyzed to investigate the patterns of UIG collaborations, especially in terms of the size and density of the networks of UIG relations during the development process of the KNIS. Given that the proportion of co-patents in the total number of domestic patents was

extremely small, the patent count may be limited to capture a detailed picture of UIG collaboration development in Korea. Therefore, this section takes a close look at the evolution process of both bi- and trilateral collaboration networks between UIG in Korea.

Collaboration network of industry-GRI

Figure 7 displays the collaboration network of industry and GRI in three time periods. Overall, the network expanded in size with growth in the number of industry and GRI actors participating in collaborations across time periods. In the first period 1980–1990, the whole network is quite sparse, indicating an inactive pattern of industry-GRI collaborations. There were eight GRIs engaged in collaboration activities with thirty-one

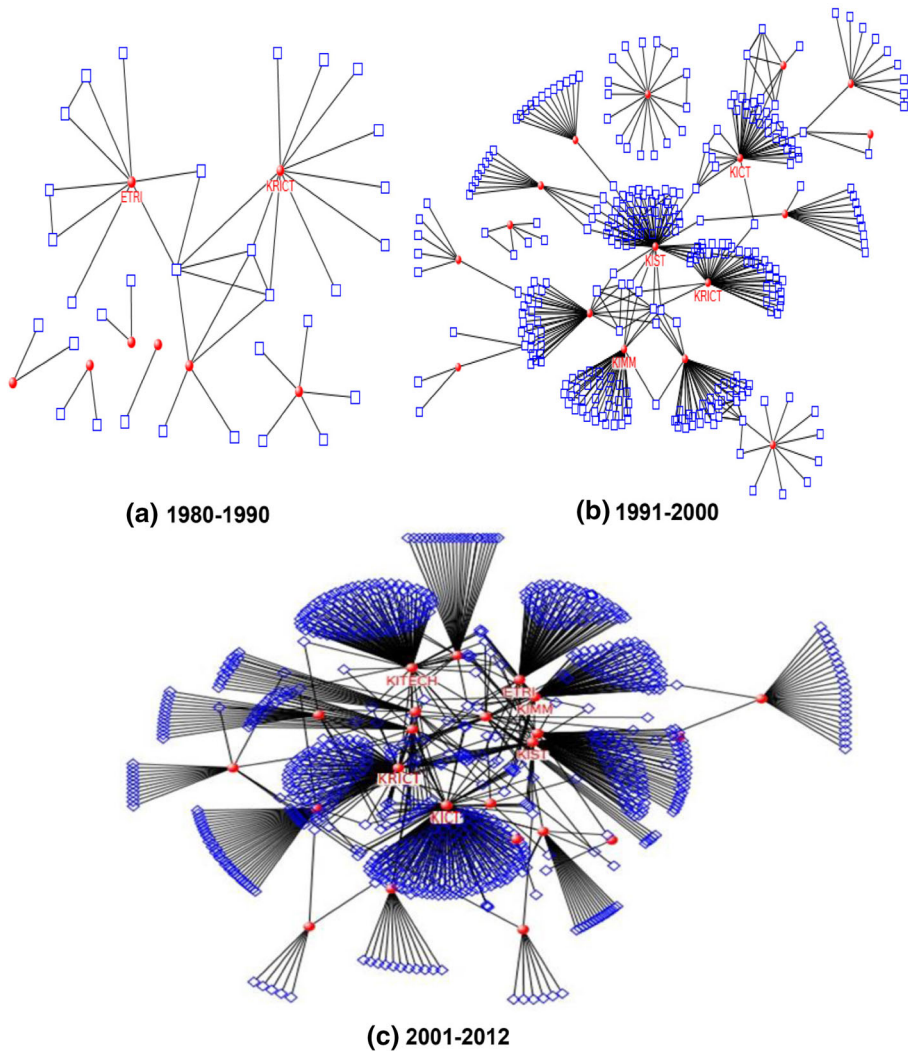


Fig. 7 Networks of industry-GRI relations in the three periods from 1980 to 2012. Note Red sphere and blue square nodes represent GRI and industry respectively. (Color figure online)

Table 3 Descriptive statistics of the collaboration networks of industry-GRI in three phases

	1980–1990	1991–2000	2001–2012
Number of actors	39	318	976
Number of components	6	3	4
Mean degree centrality	2.10	2.48	3.12
Network centralization (%)	21.91	20.17	24.04

Data compiled by the author for this study

enterprises, constructing six components of the network. As shown in Table 3, the mean degree centrality score for the network is 2.1 with the minimum degree of 1 and maximum degree of 10. The two GRIs, the ETRI and KRICT have the highest degree centrality, meaning that they were the center of the network at that time as the most important actors.

In the second period 1991–2000, the network size expanded in that the number of GRI and industry collaborators increased from 39 to 318. There were 17 GRIs and 300 enterprises participating in collaborations. The mean degree centrality score for the network also slightly increased to 2.48 with the minimum degree of 1 and maximum degree of 66. Especially, the four GRIs with the highest degree centrality, including the KIST, KRICT, KIMM, and Korea Institute of Construction Technology (KICT), comprise the largest components of the network. This indicates that they played a pivot role in building co-operation networks with enterprises.

In the third period 2001–2012, the number of industry and GRI actors increased to 976 and they belonged to four sub-networks. The nodes and links significantly increased, especially for industry actors. There were 23 GRIs and 953 enterprises involved in the collaboration network. From Fig. 7, the network of industry-GRI relations seems to be larger and more complex than the prior networks in the first two periods. The mean degree centrality score for the network also increased to 3.12 with the minimum degree of 1 and the maximum degree of 237. The three GRI players with the highest degree centrality identified as the KRICT, KICT, and Korea Institute of Industrial Technology (KITECH) took the most important position in the network. In all three periods, the KRICT was continually placed at the center of the network.

The overall network continued to expand in size as confirmed by the number of actors, from 39 in period one and 318 in period two to 976 in period three. The mean degree centrality of the overall network grew by 49 % from 1980 to 2012, indicating that the collaboration network of industry-GRI became closely connected over time.⁷ In addition, the degree centralization of the entire network is only around 20 %, illustrating that the collaboration network is not highly centralized around a few actors.⁸ However, as the size

⁷ The density is described as the proportion of collaboration ties in the network relative to the total number of all possible collaboration ties. If the number of nodes in a network is denoted as K and the number of total edge is denoted as L , then the density of the overall network (D) would be defined as follows: $D = \frac{L}{K(K-1)/2}$. The number between zero and one indicates the degree of how interconnected the actors are in the network. In this study, the density of most networks was found to be very low in that its value was almost close to zero across all periods. Network density usually shows the extents to which networks contain many ties between actors that is presumably cohesive with a tight structure. However, density may not be useful to measure the structural cohesion of the network, because it depends on the size of the overall network: thus, the larger the network, the lower the density. In this respect, mean degree centrality of all actors can be a better measure of overall cohesion than density, since it may not be influenced by network size and comparable between networks of different sizes (Nooy et al. 2005: 64).

⁸ Centralization measures the extent to which an entire network is centered on one or a few certain actors. If the centrality score of the most central actor is denoted as C^* and that of each actor is denoted as C_i , centralization measure (C) can be calculated from $C = \frac{100 \times \sum (C^* - C_i)}{\text{MAX} \sum (C^* - C_i)}$.

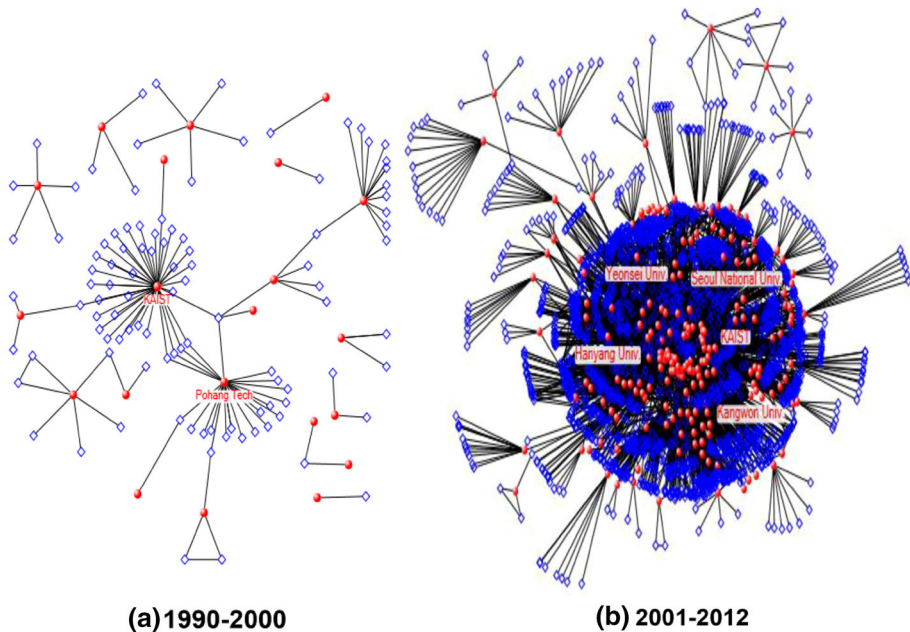


Fig. 8 Networks of university-industry relations in the two periods from 1990 to 2012. *Note Red sphere and blue square nodes represent university and industry respectively. (Color figure online)*

of a network got enlarged throughout the three periods, its degree centralization slightly fluctuated to 20.17 % in period two and rose to 24.04 % in period three.

Collaboration network of university-industry

The patent collaboration between university and industry was first found in the early 1990s. In the period 1990–2000, there were 21 universities and 103 enterprises belong to eleven components of the network. The two well-known engineering colleges in Korea, such as Pohang Tech and the KAIST, show the highest degree centrality among all actors, underlying the main structure of the largest component. Those universities played a leading role in the early formation of the university-industry collaboration network. Pohang Tech had committed to long-term R&D cooperation with the POSCO Corporation in the fields of the chemical, electronics, and IT. The KAIST was relatively well-equipped with R&D resources and technology capabilities, so it had been pointed to the most favorable R&D collaborator or strategic partner for industry.

As depicted in Fig. 8, the collaboration network of university-industry became greatly enlarged in size and scale in period two, for both nodes and links in the network increased significantly. There were 202 universities and 2060 firms engaging in the collaboration network and the total number of network actors increased nearly 18-fold. Compared to period one, more leading universities with the higher degree centrality were found in the center of the network, including Seoul National University (SNU), Yeonsei University, Hanyang University, and so on. This upward trend in university-industry collaborations has prevailed especially in the fields of electronics and telecommunications since the early

Table 4 Descriptive statistics of the collaboration networks of university-industry

	1990–2000	2001–2012
Number of actors	124	2262
Number of components	11	70
Mean degree centrality	1.92	3
Network centralization (%)	30.15	9.74

Data compiled by the author for this study

2000s. The number of co-patents applied by industry and university in those technology fields increased over 20 times in period two.

The network of university-industry relations became increasingly connected confirmed by its mean degree centrality, as revealed in Table 4, which increased from 1.92 to 3. Therefore, it can be viewed that the linkages between university and industry had been strengthened and the collaboration network did increase in scale. Along with the increasingly dense ties among actors, there was also a decentralizing trend detected in the evolving network of university-industry relations. Through two periods, the network centralization score declined from 30.15 to 9.74 %, implying that the links got more evenly distributed among actors within the network. Comparably, the network of university-industry relations grew more rapidly in period two than that of industry-GRI relations in terms of its size and scale and also showed a more decentralizing tendency.

Collaboration network of university-GRI

As the university first appeared as a main innovation actor of the KNIS in the late 1990s, the collaboration network of university-GRI was built and evolved during two periods of time, 1990–2000 and 2001–2012. In period one, the entire network is seemingly simple and sparse in that there are only three GRIs and seven universities composing three main components of the network, as shown in Fig. 9. It indicates the initial establishment of collaborative relationships between university and GRI during the period. The three GRIs, such as ETRI, KIST, and KIMM, represent each component of the network as the most influential actors who have the ability to manage and control the interactions with universities.

In period two, the number of university and GRI collaborators increased to 116 and all of them were connected to a large single component. There were 92 universities and 24 GRIs involved in the network. The ETRI has the highest degree centrality, indicating that they were the most important player in the network of university-GRI relations by occupying the most powerful position with the capability to exert its influence on the interactions with others.⁹ As shown in Table 5, the network became more densely connected and highly centralized confirmed by its mean degree centrality and centralization, which increased from 1.4 to 6.6 and from 22 to 58.75 %, respectively. Compared to the other bilateral collaboration networks of science-industry, the network of university-GRI relations is still in the initial phase of development and highly centralized on one particular actor, the ETRI.

⁹ The ETRI has the highest scores of all three centrality measures: degree centrality, closeness centrality, and betweenness centrality. Closeness centrality measures how closely an actor is related to others and easily obtains and spreads information. Closeness centrality of a vertex is calculated as the number of other vertices divided by the sum of all distances between the vertex and all others (Nooy et al. 2005). Betweenness centrality shows the extent to which an actor lies on the shortest paths between other pairs of actors in the network and estimates its influences and powers to others. Betweenness centrality measure can be calculated as the proportion of all shortest paths between pairs of other vertices that include the vertex.

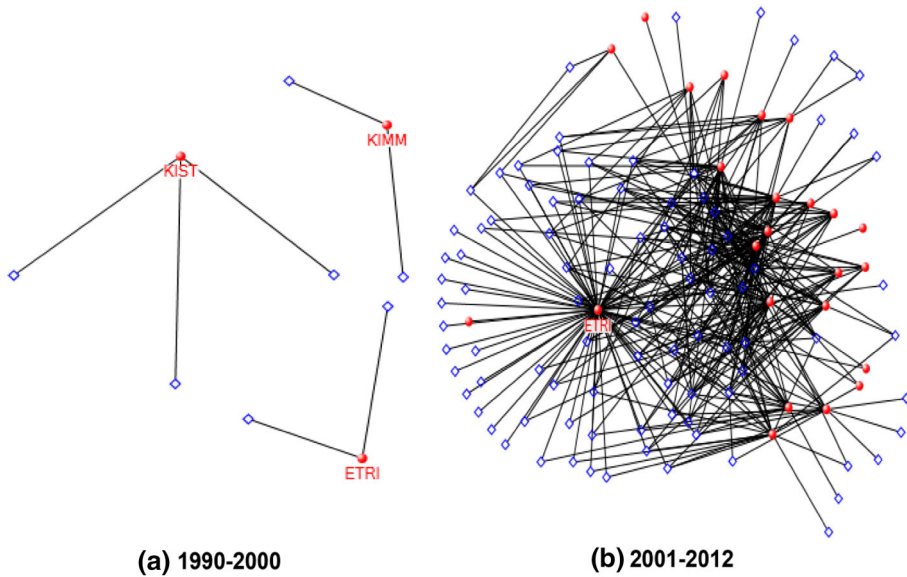


Fig. 9 Networks of university-GRI relations in the two periods from 1990 to 2012. *Note* Red sphere and blue square nodes represent GRI and university respectively. (Color figure online)

Table 5 Descriptive statistics of the collaboration networks of university-GRI

	1990–2000	2001–2012
Number of actors	10	116
Number of components	3	1
Mean degree centrality	1.4	6.6
Network centralization (%)	22	58.75

Data compiled by the author for this study

Collaboration network of university-industry-GRI

Since the trilateral patent collaboration of UIG emerged in the year 2000, the triple network of UIG relations was initially formed in Korea during the period 2000–2012. There were 39 universities, 16 GRIs, and 67 enterprises constituted seven sub-networks. As depicted in Fig. 10, the triple helix network of UIG relations has not been fully mature yet, as the network graph seems a little bit sparse and simple with relatively few nodes and links. The central actors in the network are a group of GRIs and universities, including four GRIs (the Korea Research Institute of Bioscience and Biotechnology (KRIBB), KICT, KIMM, and ETRI) and two universities (Sungkyunkwan University and University of Seoul). They played the most active roles, having the most ties to other actors in the network during the period.

Table 6 provides descriptive statistics of four types of collaboration networks among UIG in the period 2000–2012. In comparison with all the networks of the bi- and trilateral relations together, it found that the network of university-industry is larger in its size than any other types of the networks, indicating the most prevalent and developed form of collaborations among UIG in Korea. The network of university-industry relations also has

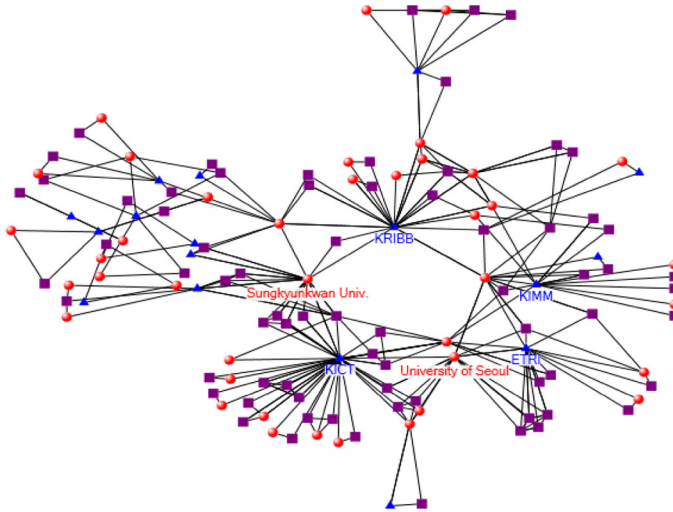


Fig. 10 Triple helix network of university-industry-GRI relations in the period 2000–2012. *Note* Red sphere, blue triangle, and purple square nodes represent university, GRI, and industry respectively. (Color figure online)

Table 6 Comparison of all the collaboration networks among UIG in the period 2000–2012

	Industry-GRI	University-industry	University-GRI	University-industry-GRI
Network size	976	2262	120	129
Network cohesion	3.12	3	6.5	3.88
Network centralization (%)	24.04	9.74	56.86	23.91

Data compiled by the author for this study

the most de-centralized tendency with the lowest score of network centralization. However, it has comparably weak connectedness between actors in the network. The other two types of collaborations, university-GRI and university-industry-GRI, are least developed forms of collaborations among UIG in Korea. Those networks seem to just enter onto the developmental trajectory with notable growth of the university's innovation activities in recent years. Despite the relatively small size, the structural cohesion of those two networks is higher than others. The collaboration network of university-GRI has the most centralized structure, followed by that of industry-GRI. Compared to the bilateral collaborations between science and industry, such as university-industry and industry-GRI, the tripartite collaboration of UIG has yet been developed and its network needs to be further strengthened in size and scale.

Conclusions

This study examines the innovation activities and collaboration patterns of UIG in Korea to explore the evolution process of the KNIS from 1980 to 2012. The study period can be

divided into three developmental phases of the innovation model in Korea. The collaboration status and networks of UIG relations in each development phase are historically traced and analyzed to reveal the transition in the dynamics of an innovation system regarding to the triple helix arrangements.

In the first phase 1980–1990, the strategic alliances between GRI and industry were established due to weak innovation activities of enterprises and their partnerships grew within the NRDP. The network of collaborations among UIG was initially set up in the form of a double helix of industry-GRI during the period. The GRI was a major national R&D performer facilitated the innovation activities of industry, whereas the university played a minor role in the production of technological knowledge as a provider of human resources. The UIG configuration of the KNIS in the first phase is close to Triple Helix I, where the government sector is the most important innovation entity managed to build the innovation platform for collaborations and coordinated the UIG relations.

In the second phase 1991–2000, the industry turned into a dominant innovation actor in the KNIS, firmly establishing its own large innovation domain. The R&D activities of *Chaebols* became internationalized and surpassed technology capabilities of the public sector in several technology fields. While Korean large enterprises built self-sufficient innovation capabilities, GRIs still continued to play a significant role in supporting industrial innovations by engaging more in collaborations with industry than the first phase. Meanwhile, the university could have their own independent sphere as a result of the revitalization of academic research by government R&D programs. The three hybrid spheres emerged from the bilateral UIG relations, whereas the trilateral interactions had not yet occurred. The overall collaboration networks expanded with the rise of both university-industry and university-GRI relations. In this vein, the Korean model of innovation in the second phase was placed between Triple Helix II and Triple Helix III.

The UIG configuration of the third phase 2001–2010 is close to Triple Helix III that is a global model of UIG mostly seen in developed countries. While the substantial roles of GRIs were reduced steadily after its reform of 1999, the government initiatives led to the establishment of a triple helix regime by changing the regulatory environment through the Korean Bayh-Dole Act. Korean universities have been transformed rapidly in the entrepreneurial paradigms and become the most desirable collaborators for industry. The strategic partner of industry in R&D shifted from GRI to university. University-industry collaborations have largely increased and their networks have been prevalently developed in the third phase. The trilateral collaboration has emerged from overlapping institutional spheres, but it has been a rather rare occurrence. Although Korea has finally reached the triple helix regime, its current UIG model seems to just enter the initial level of the triple helix.

Accordingly, the model of innovation systems in Korea has evolved from statist model towards a triple helix. While the triple helix framework well elucidates specific transition pathways in the development of the innovation system, the UIG model in Korea does not fit fully into three typical models of triple helix configurations. The strategic role of government sector had been highly influential as a strong interventionist agent in shaping and coordinating the UIG relations in the first two phases. However, it became riddled with ambiguity when industry finally gained technological competitiveness in the global markets and even withered with the rapid growth of academic sector in the third phase. The *laissez-faire* model, to some extent, might not be suitable for some of East Asian latecomer countries, such as Korea, where state intervention and the public sector had played a central role as a controlling force in developing NISs and creating a dynamic environment for innovation. This contrasts with the US, Sweden, and some western countries, which adhere to a *laissez-faire* approach. When Korean government turned into a modest

interventionist in the last phase, there seemed to be more room for both private and science sectors to jointly engage in networked relations through collaborations.

Several findings confirm the trends of domestic innovation activities and collaboration patterns of UIG and provide some policy implications. Three characteristics of the Korean model of innovation system have been revealed. First, only a few major Korean *Chaebols* have played a dominant role in domestic innovation activities, denoting that they have been at the center of the KNIS. However, there has long been a growing concern over SMEs regarding to its relatively weak innovation capabilities. There should be more policy considerations to strengthen collaborative linkages between SMEs and science sector as a vehicle of enhancing the innovation capabilities of SMEs. This, in turn, is closely related to the critical issue of sustainable development of the KNIS. Second, since the university-industry collaborations have been progressing rapidly, its network is the most decentralized and largest collaboration network among others. This trend proves the important role of the university as the main innovation entity of the KNIS as well as the major cooperator for industry. As far as the innovation activity of the GRIs is concerned, it is expected to actively engage in more entrepreneurial activities in the future, since they have focused on the commercialization of their R&D results to cope with the reduction of its government subsidy. From a policy perspective, the science sectors, both GRI and university, need to serve as the facilitator of technology transfer and commercialization to stimulate innovation entrepreneurship and encourage innovation activities of SMEs. The effective mechanism for the commercialization of public R&D should also be established and developed in the public sphere. Last, the innovation model in Korea becomes close to Triple-Helix III, but it should be cautious about drawing the conclusion. The formation of the collaboration networks of UIG at the trilateral level signifies the entrance to the new development phase of the KNIS, but whether UIG actors have voluntarily participated in collaborations and their collaboration networks have evolved beyond the realm of government are still questionable. In so far as government funds for cooperative R&D projects have continued to increase rapidly, collaborations among UIG may be triggered and fostered by government R&D programs in most cases. Given that government interventions have been influential in the development of the KNIS by guiding and allocating R&D resources, the role of government may be still prominent rather than lessened in the triple helix model in Korea. In this regard, the important policy issue may be raised for the Korean model of innovation in the near future: how to promote voluntary collaborations among main innovation actors in the KNIS. Since most of UIG cooperative programs have been largely supported by government funds, policy strategies may need to consider reducing the heavy dependence on government for financial supports. In order to shift toward more voluntary and sustainable modes of UIG collaborations, first of all, the Korean government should further diversify sources of funding for the national cooperative R&D programs by encouraging academic and industry sectors to embark on the mid- to long-term financial planning on their own to take an active part in the collaborations; second, there should be more policy efforts to generate a variety of collaborative arrangements and expand the range of participants from both private and public spheres through the establishment of incentive and reward systems; and most importantly, government should undertake the role of a mediator by dealing with conflicts of interests among stakeholders in the consortium, ensure collective benefits from UIG collaborations, and create the collaborative research culture based on the stakeholder win-win relationships.

In this study, a modest attempt has been made to explore the innovation activities and patterns of technology collaborations among UIG in Korea by using reliable patent statistics but several limitations need to be acknowledged. First, patent statistics are widely

accepted as useful indicators of innovation activities and innovation outputs, but research findings can be inevitably constrained by the patent information. In addition, patents can neither represent all innovation activities nor capture the quality and value of individual patents. Future studies should embrace alternative indicators besides patents, such as patent citation and scientific publication data, to reduce measurement errors. In order to provide a more reliable foundation for measuring innovation activities, co-patenting by UIG actors at the USPTO may also be taken into account in future studies. Second, the findings of the present study are unable to identify whether UIG collaborations have been developed voluntarily, or it has grown mostly in the national R&D programs. This actually leaves room for further research.

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