

**Has Globalization Strengthened South Korea's National Research System?
National and International Dynamics of the Triple Helix of Scientific Co-authorship
Relationships in South Korea¹**

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Abstract

We trace the structural patterns of co-authorship between Korean researchers at three institutional types (University, Government, and Industry) and their international partners in terms of the mutual information generated in these relations. Data were collected from the Web of Science during the period 1968-2009. The traditional Triple-Helix indicator was modified to measure the evolving network of co-authorship relations.. The results show that international co-authorship relations have varied considerably over time and with changes in government policies, but most relations have become stable since the early 2000s. In other words, the national publication system of Korea has gained some synergy from R&D internationalization during the 1990s, but the development seems to stagnate particularly at the national level: whereas both university and industrial collaborations are internationalized, the cross-connection within Korea has steadily eroded.

Key words: Co-authorship, International Collaboration, University-Industry-Government Relationship, South Korea, Triple Helix, R&D Internationalization, Globalization, National Research System, Innovation

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Introduction

In the age of globalization, a country's competitiveness in terms of its knowledge base has become increasingly dependent on various international dimensions. Science is globalized in terms of scientific communication and research implementation (Altbach, 2007). Furthermore, because of the globally networked research environment, national institutions can no longer be considered as isolated components of an international system of research, technology, and innovation. The exchange of knowledge across national (regional) borders has become increasingly common in recent decades.

From this perspective, the Triple Helix (TH) of university-industry-government (UIG) relationships has been particularly useful for examining how effectively institutional actors in national science systems work together across institutional boundaries and for determining the consequent status of the interaction-based knowledge infrastructure in national or regional innovation systems (Etzkowitz & Leydesdorff, 2000). However, the most salient development has been the role of international co-authorship relationships (Wagner, 2008; Persson et al., 2004). Collaborations with international researchers in the formal literature—as indicated, for example, by the *Science Citation Index* (SCI)—may influence the role of traditional knowledge holders and knowledge seekers in regional or national systems. Leydesdorff and Sun (2009) showed that networks of foreign co-authorship relationships have become the most important mediator in Japan's national innovation system.

In the case of South Korea (hereafter “Korea”), the exploitation of international linkages has played a critical role in enabling the country's national R&D system to rival that of other countries (Chung, 2005). However, few studies have provided an empirical analysis of the role of international cooperation in the dramatic growth of national science systems in recent decades (e.g., in the cases of Korea and Taiwan). Although Park and Leydesdorff (2009) were the first to apply TH indicators to the case of Korea, they considered only domestic actors. Furthermore, previous empirical studies of international co-authorship in countries such as Korea have been limited to descriptive, not statistical, analyses of international scientific collaboration (e.g., Kim, 2005; Yun & Ahn, 2002).

In this study, we trace the underlying patterns of collaborations between Korean researchers and their international partners by using longitudinal data from the SCI. Specifically, this study investigates the connection between Korean institutional actors (i.e., the government, academia, and industry) and their international co-authorship relationships. This study uses a network-based system indicator to measure the evolving TH network of Co-authorship relationships between national and international actors in Korea. Using this indicator, we analyze whether international research collaboration has had a synergetic effect on Korea's research system. In other words, we are guided by the following research question: To what extent have international knowledge exchange processes strengthened Korea's research system?

International Research Collaboration and Scientific Advancement

There is growing interest in measuring research collaboration (Katz & Martin, 1997; Laudel, 2002). Although some studies have argued that the common measure of collaboration in academic research is co-authorship (Savanur & Srikanth, 2010), others have argued that not all collaborators appear as coauthors (e.g., collaboration can also be mentioned in acknowledgements). Furthermore, not all types of collaborative efforts are formally expressed in papers (e.g., advice on the research process) (Melin & Persson, 1996; Gordon, 1980). However, research collaboration and co-authorship are positively related (Glänzel & Schubert, 2004). Some studies have found that research collaboration plays an important role in scientific productivity (e.g., Lee & Bozeman, 2005) and academic quality (e.g., Rigby & Edler, 2005). Empirical studies have examined research collaboration not only at the individual level but also at the organizational (Adams et al., 2005; Ramsden, 1994) and national (Godin & Gingras, 2000; Katz & Hicks, 1996) levels.

Recent decades have witnessed dramatic increases in international scientific collaboration (NSF-NSB, 2010; Wagner & Leydesdorff, 2006; Gränzel, 2001; Georghiou, 1998). For example, between 1990 and 2000, the share of internationally coauthored papers doubled (Wagner & Leydesdorff, 2005). It was shown in a number of studies that international collaboration is a good indicator of both the quantity and quality of research

efforts (Bordons et al., 1996; Van Raan, 1998; Smeby & Try, 2005; Abramo et al., 2009). In the Korean context, several researchers found that domestic as well as international collaboration are the most significant determinants of productivity (Shin & Cummings, 2010) and quality (Kim et al., 2010) of Korean academics. However, in the case of Spain, Gomez et al. (2009) found that international, and not domestic co-authorship was correlated with the number of publications in top journals. Furthermore, a large number of previous studies have demonstrated that internationally coauthored papers tend to be cited more frequently (e.g., Persson et al., 2004; Katz & Hicks, 1997; Narin, 1991; Narin et al., 1991), although some recent studies have cast doubt on this epistemic authority of internationally coauthored papers (He, 2009; Schmoch & Schubert, 2008).

In a similar vein, Ponds (2009) found that collaborative research efforts between academic and nonacademic actors are more likely to occur domestically than internationally. However, according to Wagner (2008) and Leydedoff and Wagner (2008), international networks based on research collaboration are different from the national dynamics involving domestic actors (e.g., universities, firms, and governments). In other words, there may be network effects changing the relationships between domestic and foreign actors. However, few studies have examined this effect. To our knowledge, no study has employed an indicator for directly measuring the network effect on scientific innovation system at the international or national level. From this perspective, Leydesdorff and Sun (2009) suggested a novel method based on information theory for conducting an empirical analysis of the role of foreign actors in the Japanese national research system. Because this method can estimate the synergy effect between various actors in the system, they found that foreign coauthors have reduced uncertainty over the Japanese research system since the mid-1990s.

Several studies have analyzed international research collaboration between developed and less developed countries and suggested that scientists in developing countries are not isolated from the international scientific community (Shrum & Campion, 2000) and that the number of international coauthors in developed as well as less developed countries has been increasing in the last few decades (Lemarchand, 2010; Glänzel & Schubert, 2004; Braun & Glänzel, 1996). Focusing on the effect of international research collaboration on the scientific capability of developing countries, Ordonez (2008) found that the type of

collaboration as well as the type of partner influenced this effect in the case of Columbia. Wagner et al. (2001) analyzed research networks in developing countries and suggested that international collaboration plays an essential role in effort of developing countries to build scientific capacity.

Few studies have addressed international research collaboration by focusing on the unequal relationship between scientifically developed and less developed countries (Hwang, 2008). Nevertheless, in the context of rapid economic and scientific growth, some studies provided some descriptive explanations. According to Albuquerque (2001) and Chung (2005), the rapid development of national science systems (in particular, those in countries characterized by rapid economic growth, such as Korea and Taiwan) has typically been a result of international research collaboration. Leydesdorff and Wagner (2008) noticed increased collaborative links among the core group researchers in scientifically developed countries and suggested that this is due to their careful choice of research partners. Thus, because Korea is located in the grey area between developing and developed countries (Hwang, 2008), Korean authors can be expected to collaborate more with scholars in other scientifically developed countries than with less developed ones (Wagner et al., 2001). In sum, this study is the first to provide an empirical analysis of the international dynamics of the research system in Korea, a rapidly catching-up country.

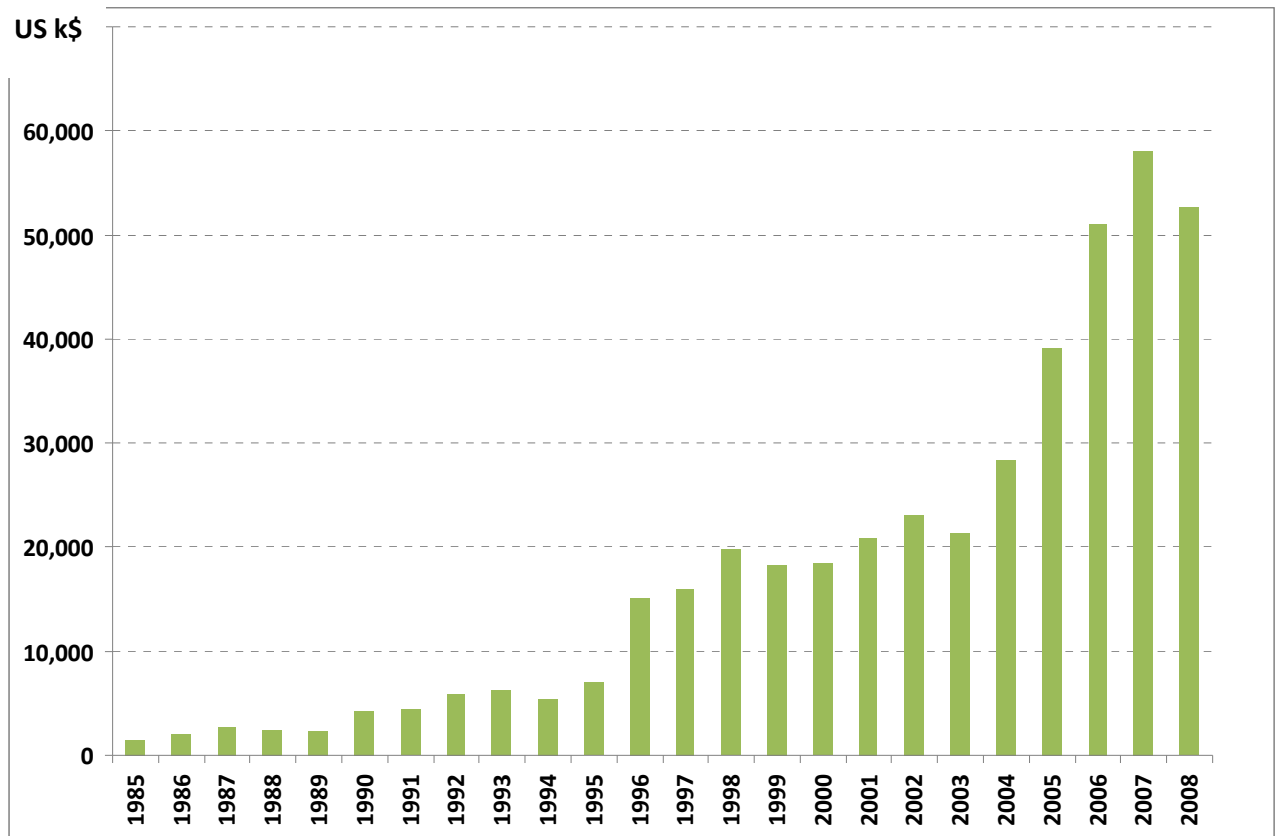
Development of the Korean Science System and the Role of Foreign Actors

In early stages (i.e., in the 1950s and 1960s), as in other public science systems in developing countries, Korean universities typically trained standardized industrial labor and provided the industry with technical support instead of conducting scientific research (Kwon, 2009). In addition, because Korean academics were not sufficiently qualified to teach students in cutting-edge scientific disciplines, the government implemented various programs for researchers to obtain overseas training (Kim, 1997). In this period, U.S. institutions have played a critical role in fostering Korean scientists. For example, between 1954 and 1973, half of the Korean students in foreign institutions were studying science and engineering (MOE, 1974). However, research was typically considered an individual activity for Korean scientists and thus left to their discretion, and research equipment and funding were often

inadequate for quality research (Bak, 2006).

The 1980s can be characterized as the first decade of bilateral internationalization in Korean science and technology, whereas previous internationalization efforts were dependent on unilateral overseas aid from developed countries (Yim et al., 2008). In the 1980s, the Korean government initiated various programs to promote cooperative research involving foreign actors. For example, the Ministry of Science and Technology introduced the R&D Internationalization Program in 1985. Figure 1 shows the funding for this program. The Korean government used this initiative to stimulate research projects requiring international networks. Such cooperative programs are different from previous international R&D programs in that they are based on mutual benefits, not on unilateral technology transfer (Chung, 2005). However, these programs have typically supported small and medium-sized projects, and Korea's infrastructure for international research (e.g., research facilities) had generally remained modest during the time (Yu et al., 1999). Thus, these programs have had a very limited impact on Korea's efforts to internationalize R&D.

Figure 1: Funding for the R&D Internationalization Program



Source: MOST (2003) and KICOS (2008).

Korea's scientific community and its internationalization efforts were revitalized in the 1990s in terms of the country's R&D expenditure as well as its research output. According to MOST (2001), the number of Korean papers published in SCI journals increased from 1,613 in 1990 to 13,458 in 2000 (an eightfold increase). Furthermore, international actors emerged as important research partners for Korean researchers in public research institutes and industries during the same period. In particular, since the Asian financial crisis of 1997, the Korean government has prioritized R&D internationalization by emphasizing the collaboration with foreign researchers in globally-recognized institutions (Chung & Seol, 2010).

For example, a number of new criteria, including the number of papers published in foreign journals, have been widely adopted for the evaluation of publicly funded R&D programs. This focus on international journals has had considerable influence on the

internationalization of Korea's scientific community. Furthermore, all the government-funded R&D programs related to internationalization have been integrated into the R&D Internationalization Program since 1997, implying that the government has recognized the internationalization of science as an independent policy area. In 1996, the government doubled the funding for the R&D Internationalization Program (Figure 1).

Another initiative for R&D internationalization during this period was a policy program encouraging the knowledge exchange between domestic scientists and their international peers. For example, the Korea Institute of Science and Technology (KIST) established the KIST-Europe Institute in Germany in 1997, which has enabled high-quality cooperative research between Korean and German scientists. In addition, Korean scientists began to participate in important international projects (e.g., the Human Genome Project and the Human Frontier Science Program). In the past, Korea seemed to fail to make meaningful contributions to the global scientific community because many individual researchers lacked cutting-edge scientific capabilities. However, one may be able to upgrade one's scientific capabilities through cooperative experiences with foreign partners (Chung, 2005).

Korea's R&D internationalization efforts in the 2000s can be characterized by the pursuit of large and complex scientific endeavors and the enhancement of the R&D infrastructure for cooperative research. This period witnessed the invitation of foreign research centers (e.g., Institut Pasteur Korea), the initiation of multi-lateral international programs (e.g., the International Thermonuclear Experimental Reactor), the participation in the EU Framework Program, and the implementation of science and technology ODA (official development assistance) programs for developing countries. In particular, the Korean government has made efforts to transform domestic researchers into global players. For example, the government has emphasized high-quality cooperative research at the international level through the WCU (World Class University) and WCI (World Class Institute) programs by inviting internationally renowned scholars.

As shown in Figure 1, the funding for the R&D Internationalization Program doubled again during the first decade of the 21st century. This increase was largely due to the introduction of new programs such as the Global Research Laboratory and the Global

Biodiversity Network (KICOS, 2008). The former aims at facilitating world-class research programs composed of domestic and foreign research groups, whereas the latter is managed through a network of various research institutes in Korea and field centers in China, South America, South-East Asia, and Africa. Another distinctive feature of R&D internationalization during this period has been the initiation of science and technology ODA. Based on this initiative, the Korean government has made efforts to generate mutual benefits by strengthening its research relationship with developing countries, although the Korean ODA expenditure in the R&D sector has accounted for only a small portion of total amount (e.g., 4% in 2007) (Lee et al., 2008).

In this section, we have provided a brief review of the Korean government's international R&D policy and the development of the national science system, which went through four stages. At each stage, Korea's policy initiatives pursued different aims and programs but reflected the capacity of its science system, and thus, the role of foreign actors also varied. In the initial stages, foreign actors provided unilateral assistance (e.g., giving a lecture rather than interactive cooperation) based on Korea's scientific infrastructure and human resource training. Most recently, Korean researchers started to play a role as global research partners to those researchers in developed as well as less developed countries. In the following sections, we propose a network-based system indicator that takes into account co-authorship (i.e., research collaboration between domestic and foreign actors) to provide a quantitative analysis of exchanges in international and national relations.

Method

The mutual information in two dimensions (or transmission T) can directly be derived from the well-known Shannon formulas (Shannon, 1948). T is defined as the difference in uncertainty when two probability distributions are combined. As follows:

$$\begin{aligned}
 H_i &= -\sum_i p_i \log_2(p_i); H_{ij} = -\sum_i \sum_j p_{ij} \log_2(p_{ij}) \\
 H_{ij} &= H_i + H_j - T_{ij} \\
 T_{ij} &= H_i + H_j - H_{ij}
 \end{aligned} \tag{1}$$

T_{ij} is zero if the two distributions are completely independent and positive otherwise (Theil, 1972). We use “u” for “university”; “i” for “industry”; and “g” for “government” and formulate the mutual information in these three dimensions as follows (Abramson. 1963, p. 129):

$$T_{uig} = H_u + H_i + H_g - H_{ui} - H_{ug} - H_{ig} + H_{uig} \quad (2)$$

The resulting indicator varies (positive, negative, or zero) according to the size of the contributing terms. For example, a negative value indicates a decrease in uncertainty at the national level. McGill (1954) referred to this negative uncertainty as “configurational information” (Jakulin & Bratko, 2004). Because this is configurational information, any change in the level of uncertainty cannot be attributed to one of the contributors or its realations. The verge of these network effects is systemic and nonlinear. On the one hand, loops in the configuration (in this case, at the national level) generate redundancies whereas, on the other hand, new variation adds to the uncertainty which prevails. The mutual information T can be considered as measure of the difference between these two dynamics or, in other words, as the imprint of the self-organizing knowledge base of the system on the historical network relations (Krippendorff, 2009; Leydesdorff, 2010)

We are interested not only in information in domestic UIG relationships but also in international co-authorship relationships. Accordingly, we measure the TH model by using mutual information in three and four dimensions. In addition, we quantify the interaction between national and international researchers and their networks.

We shall use both the three- and four-dimensional indicator below and also provide the decomposition terms in two dimensions. Accordingly, by adding the fourth dimension “f” for “foreign coauthor,” one can formulate as follows:

$$T_{uigf} = H_u + H_i + H_g + H_f - H_{ui} - H_{ug} - H_{uf} - H_{ig} - H_{if} - H_{gf} \\ + H_{uig} + H_{uif} + H_{ugf} + H_{igf} - H_{uigf} \quad (3)$$

The value of “f” (in H_f , etc.) is estimated as in Leydesdorff and Sun (2009). All

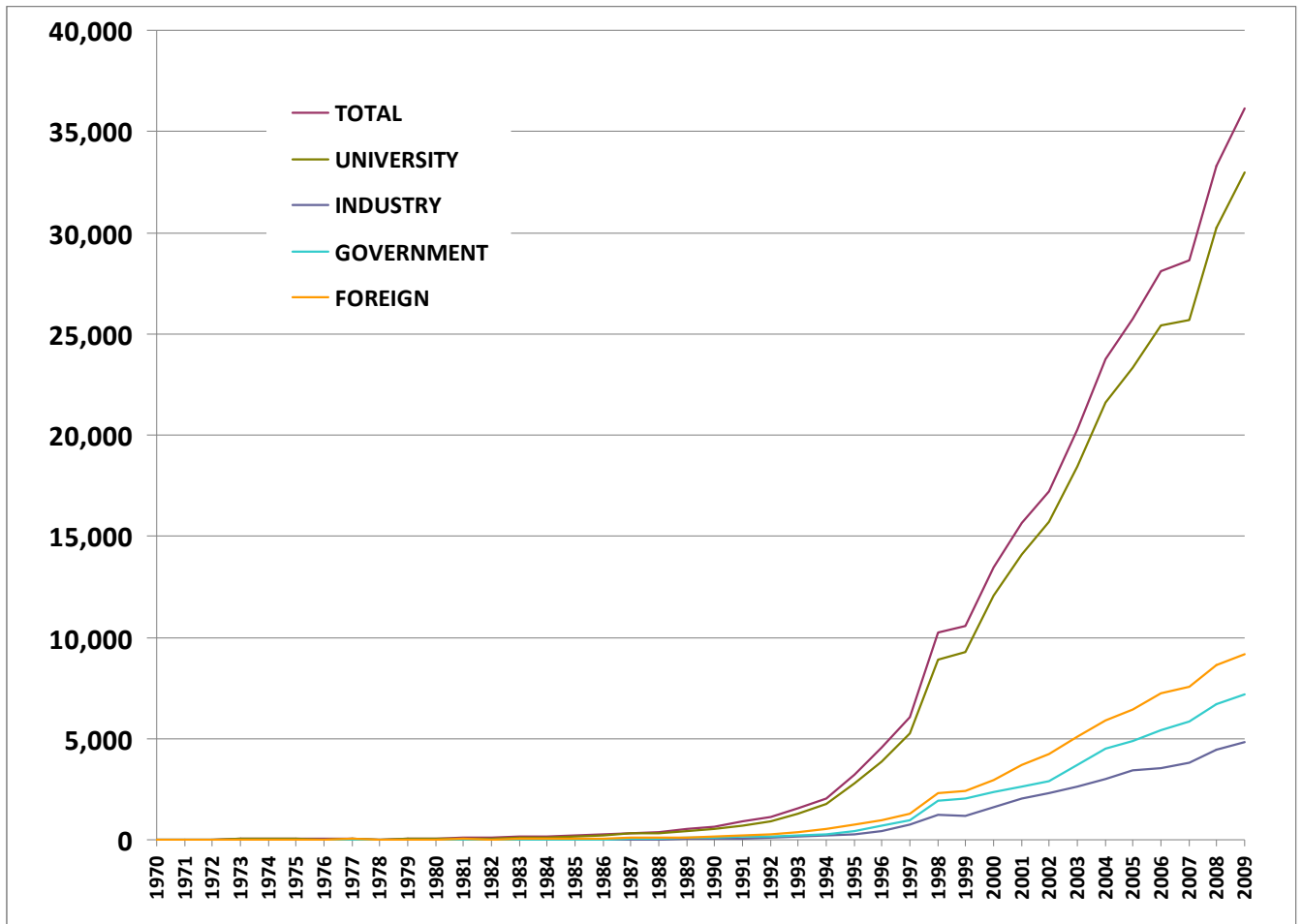
distributions used for the computation are maintained in the data, except for the number of foreign publications *without* a Korean address. However, this number is needed for the computation of H_f . While one cannot assume that all non-Korean publications in the international database are relevant for the Korean system, we add the total of all publications in the set with at least one non-Korean address as a proxy for the *relevant* non-Korean environment. For reasons of proper normalization, the sum total of SCI publication is increased with this number in the four-dimensional case.

Data

We collected the data from the Web of Science (WoS) of Thomson Reuters. The data included 189,460 papers with at least one Korean address which were abstracted in the SCIE (Science Citation Index Expanded), during 1968–2009.

Figure 2 shows the increase in the number of SCI papers by actor. As discussed in previous sections, the mid-1990s can be characterized as a period of research vitalization, which was largely due to universities' efforts. Note that the number of foreign co-authors is larger (since 1990) than that of papers with addresses of governmental institutes or industry.

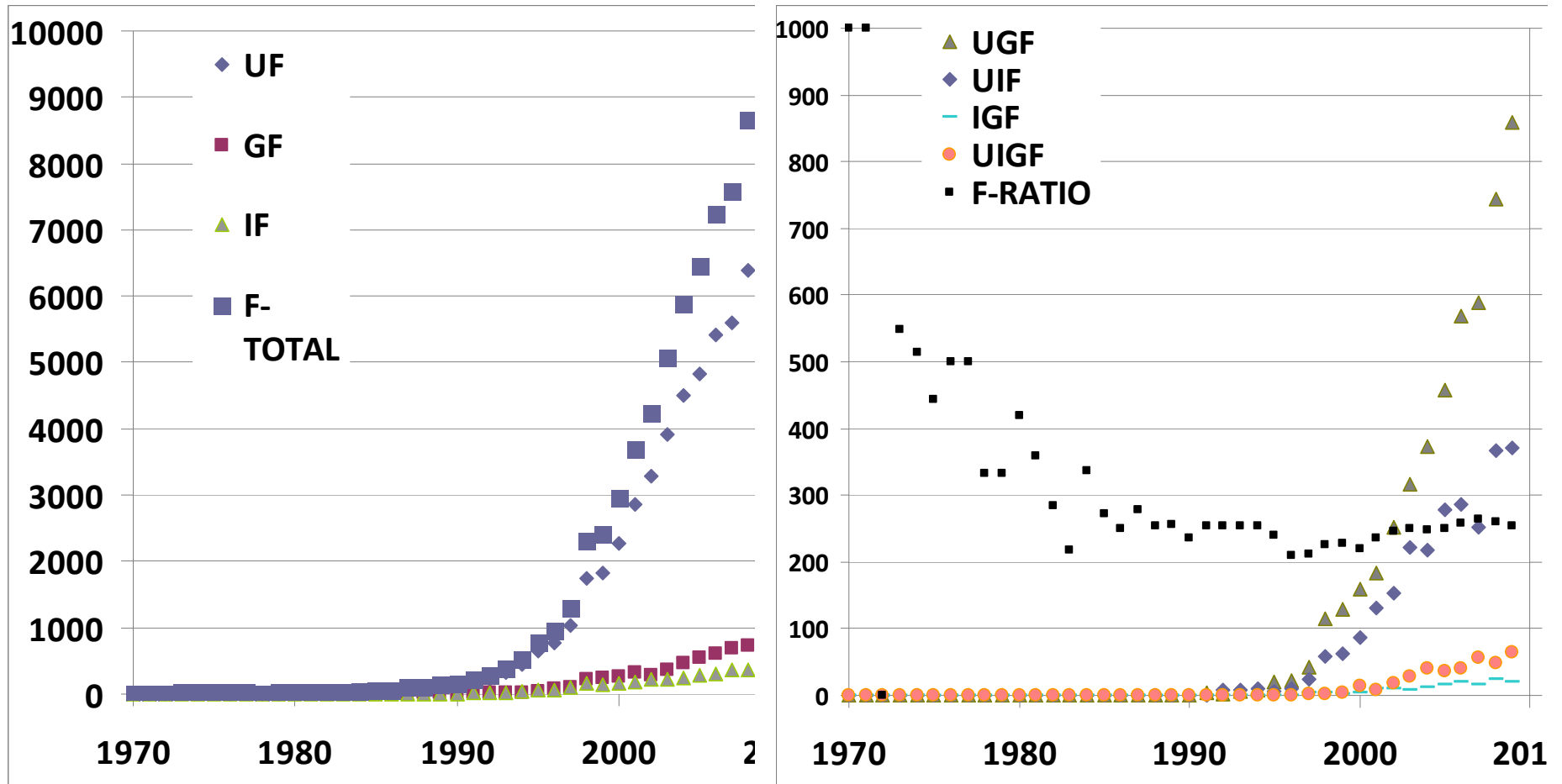
Figure 2: Publications by domestic and foreign authors in Korea



Source: WoS SCIE data.

Figure 3 shows the longitudinal trend in SCI papers by domestic actors, foreign actors, and domestic actors with foreign actors. Recent decades have witnessed a large number of research collaborations between Korean universities and international authors. Because the Korean government placed great emphasis on high-quality academic research in the 1990s, the number of SCI papers with foreign actors increased steadily. In particular, after declining till the mid-1990s (Kim, 2005), the proportion of papers coauthored with foreign actors (indicated as the F-RATIO in the right side figure in Figure 3) first stabilized and then increased from 21% in 1996 to 25% in 2009. The growth in international co-authorship relations thus outpaced the growth in the publication numbers with a Korean address.

Figure 3: Papers Coauthored by Domestic and Foreign Actors

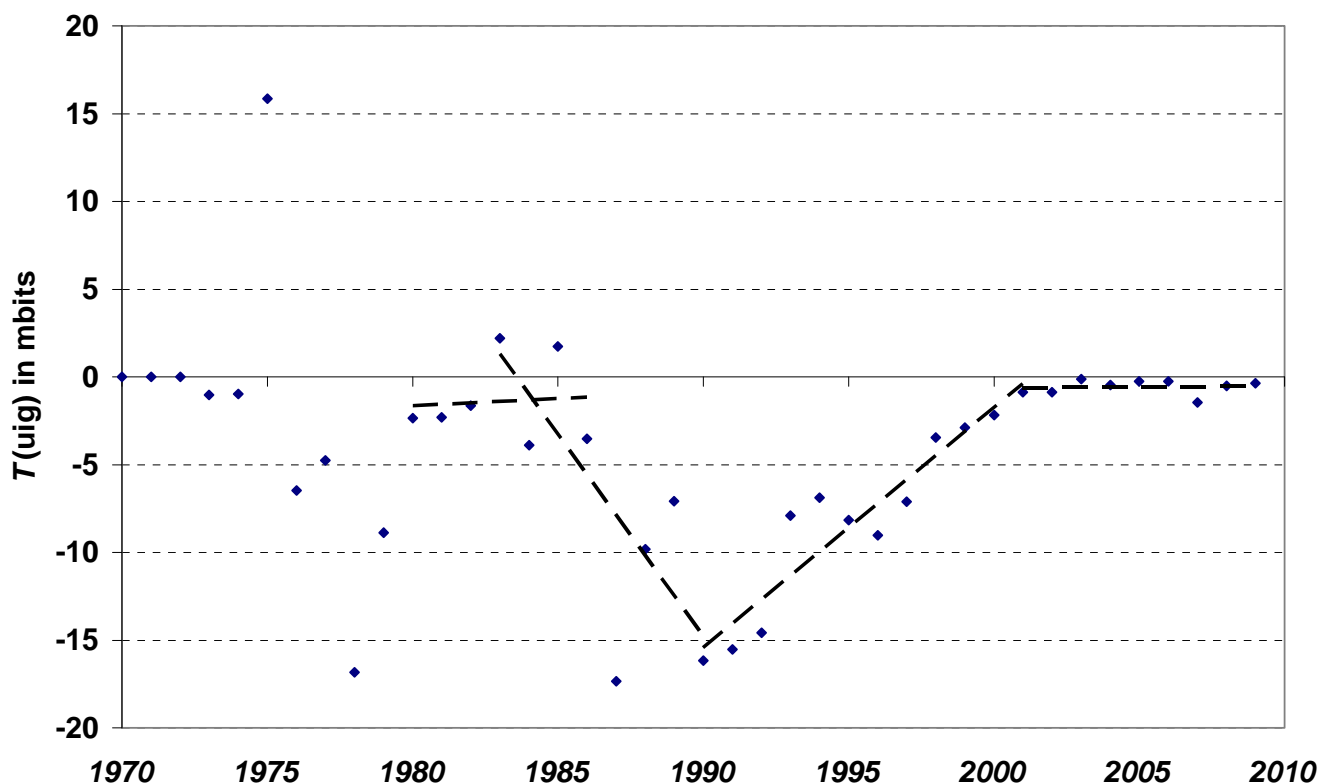


Source: WoS SCIE data.

Results

Figure 4 shows the results for the national TH system, which were obtained without considering international relationships. The longitudinal trend shows a decrease in uncertainty for UIG actors in Korea's publication system between the mid-1980s and 1990s after a relative stable period in the early 1980s, which implies that Korea's domestic research system benefited from UIG synergies during this period. Noteworthy is that mutual information exchange among the three actors decreased in the 1990s but remained relatively stable in the last decade. Accordingly, the 1990s can be characterized as a period in which Korea failed to vitalize its science system based only on domestic actors (for a detailed analysis of the this development in the national TH system in Korea, see Park & Leydesdorff, 2010).

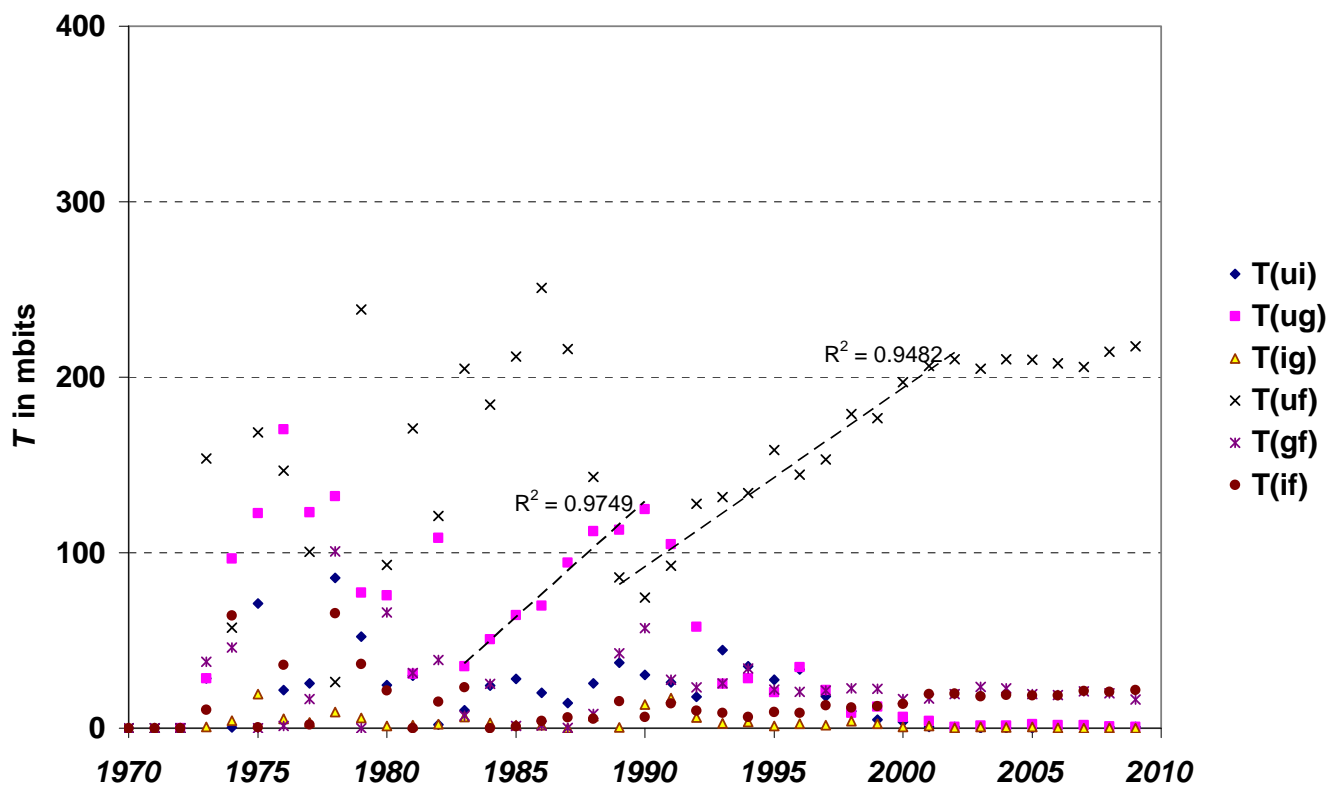
Figure 4: Mutual Information in Trilateral Domestic TH Relationship in Korea



Source: WoS SCIE data.

Figure 5 extends this analysis by including the international dimension. The addition of this new dimension provided very different TH dynamics. Mutual information exchange in the bilateral UF relationship increased rapidly after 1990 but remained relatively stable in the 2000s. This dynamic replaced the growth in publishing between university and government agencies during the 1980s. GF research collaboration (T_{gf}) was the second strongest value, followed by the IF relationship (T_{if}) around 2000, but recent years saw a reversal of this trend. The major development, however, has been the internationalization of academic research during the 1990s which seems no longer to increase during the last ten years.

Figure 5: Mutual UIGF Relationships in Korea

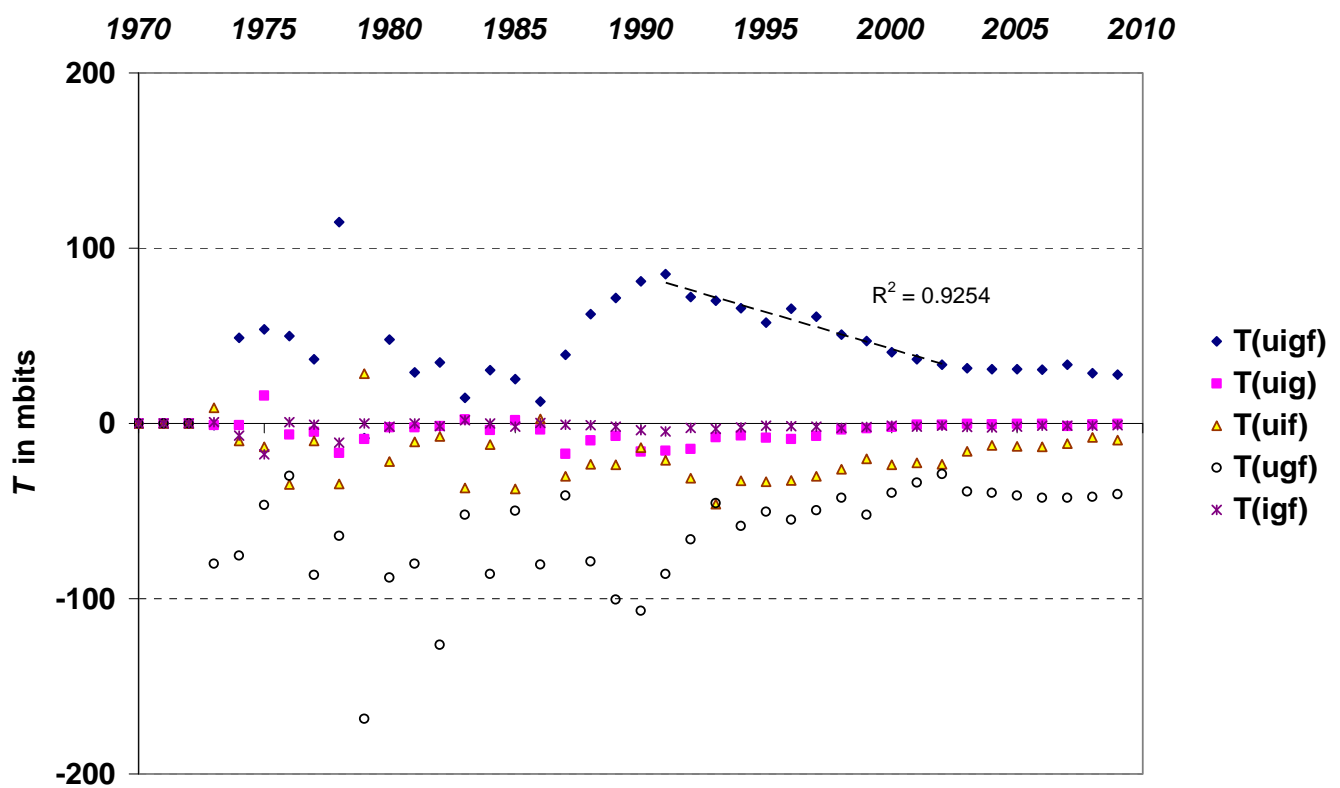


Source: WoS SCIE data.

Figure 6 shows the longitudinal trend for the three- and four-dimensional indicators and indicates an interesting path. First, the TH dynamics of the UIGF relationship in both the

three or four dimensions varied considerably until the mid-1980s. Mutual information exchange among the four actors (T_{uigf}) started to increase in 1985 and continued to increase steadily until 1990. However, there was a steady decline in uncertainty among UIGF actors in Korea's publication system during the 1990s (the period of active internationalization), when the Korean government integrated international research collaboration into its national research system, resulting in a decrease in uncertainty.

Figure 6: Mutual Information in Three and Four Dimensions



Source: WoS SCIE data.

By contrast, as shown in Figure 4, there was a decreasing synergy between domestic actors during the 1990s. In summary, the international dimension cannot be considered separately when examining the vitalization of Korea's national research system after 1990. As discussed in Section 2, Korea's policy measures during this period, which encouraged international cooperation, were intensified. Our results indicate that foreign actors

(particularly those from scientifically developed countries such the U.S. and Japan) emerged as essential collaborators in accordance with the policy efforts of the Korean government during the 1990s.

Overall, the system has been very stable since 2002. However, the UIF relationship eroded in this period. Although bilateral relationships (i.e., the UF and IF relationships) increased in these two relations, the synergy between the UF and IF relationships was no longer harvested at the national level. This suggests a need for new policies that would foster the internationalization of the UI relationship. Unlike Japan (Leydesdorff & Sun, 2009), Korea seems not able to retain national synergy from the internationalization of these two types of relations.

Discussions

Using a network-based systems indicator, we determined whether the internationalization of scientific publications has vitalized Korea's research system. The results indicate that the effectiveness of Korea's national research capability can be enhanced beyond national border by taking into account the international relationship and that this allows for new collaborations to be driven at the network level.

The results of this study show first the effects of the efforts of the Korean governments to achieve rapid economic growth in the past four decades. The internationalization of the Korean research system began during the 1980s. Since the 1990s (the period of R&D internationalization), the Korean government has attempted to strengthen the national research system by narrowing the gap in scientific excellence between Korea and Western countries. In particular, Korea's use of quantitative criteria (e.g., the number of papers published in SCI journals) for recruiting and promoting faculty members has encouraged academics to pursue international research collaboration for increasing the possibility to publish research findings in top-ranked journals (Park & Leydesdorff, 2008).

Foreign authors have played an increasingly important role in Korea's national TH system because of the dramatic changes in the country's knowledge environment. The

interdependency between complex technological changes and advances in scientific disciplines has strengthened over time, and thus, Korea can secure a competitive advantage through cooperative partnerships in both industrial and scientific domains. However, the relations at the national level seem to have eroded. Perhaps, the Korean government has tended to neglect public intervention in fostering knowledge-based innovation capabilities across the country (Shapiro et al., 2010).

The Korean government has recently introduced a few programs reflecting the goal to organize excellence nationally (e.g., in WCUs and WCIs). However, these national initiatives could focus more on systematic efforts (e.g., encouraging international research collaboration by attracting foreign authors) to further strengthen the national science and innovation systems in effectively interacting with international environments. These international environments have paradoxically become part of the national system.

This study focused on co-authorship, but international research collaboration is not confined to co-authorship. For example, the establishment of large-scale research facilities (e.g., the ITER) and the international exchange of researchers can be important channels of research collaboration. Thus, future research in this direction might provide a better understanding of the mechanisms underlying network-based indicators by elaborating case studies (e.g., about scientific specialties or specific technologies) in more detail (e.g., Leydesdorff & Rafols, 2011).

Conclusions

In a series of case studies of national research systems, co-authorship relations between Korean scientists have been often examined. For example, Kim (2005) analyzed the co-authored publication between Korean and their international partners. In other words, only bilateral relations were studied. Park and Leydesdorff (2010) examined university-industry-government (“Triple Helix”) relations among domestic researchers. Shapiro, So, and Park (2010) have also investigated inter-regional co-authorships between scientists across provinces. As Leydesdorff and Sun (2009) argues, international and domestic collaboration have hitherto been studied separately. But Korea can no longer be entirely considered as a

national system of innovations since 1990s given a rapid globalization of the knowledge bases of both industries and academia (Park & Leydesdorff, 2008). Furthermore, there have been explicit policies to increase collaboration synergies between domestic and international researchers at the level of the central government. The findings of the current paper show that in Korea university-industry-government-foreign relations had frequent ups and downs, but the patterns seem to have stabilized since 2000. This may be regarded as empirical evidence for internationalization in the national research system.

Nonetheless, policy makers as well as analysts must not jump to conclude from the findings that university-industry-government relations within national boundary can adversely affect the intensification of R&D internationalization and/or the national innovation capacity. National research system cannot evolve spontaneously by adding international dimension only. The choice of international collaboration partner is dependent on the other's scientific systems that national technology-specific or sector-based innovations have long developed. In Korea, despite some decrease in TH collaboration, we still need to promote some policies in order to stimulate such relations and the full success of these policies may be visible in a later stage.

With globalization accelerating, as seen in Japanese case (Leydesdorff & Sun, 2009), it is unavoidable that a nation's competitiveness increasingly depended on its international dimensions. We expect that this may lead to different forms of integration and differentiation within national system. In a recent study, Lengyel and Leydesdorff (2011) have shown that, in the case of Hungary, the capital (Budapest) has successfully replaced the centrally coordinated national innovation system with its own *glocalized* system. This transition was made possible because of gradual accession to the larger European Union's system (e.g., foreign direct investment). Therefore, instead of giving up national research system, we suggest that the Korean government takes a dual approach. A state-led innovation system is probably necessary for less-internationalized provinces and sectors. On the other hand, government can let the capital city and its satellites compete with other such cities (including Tokyo, HongKong, etc.) in order to find more integration in *internationalized* innovation systems.

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