Evolution of the Little Dragons' Science Network with the Rise of China: A Bibliometric Analysis

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China has emerged as a science superpower in the first decade of the 2000s. In the world of science, where collaborative research has become the norm, China may have a great influence over the international scientific research collaboration (ISRC) network. In this exploratory study, we focus on the ISRC of the Little Dragons (LDs) (i.e., South Korea, Taiwan, and Singapore), which have grown to advanced economies and have thus emphasized science as a facilitator of further development. Using the method of cosine similarity analysis and social network analysis, we trace the evolutionary changes in the ISRC of the LDs and the position of China within the ISRC network from 2002 to 2012. The differences among the three LDs are discussed and the implications are drawn.

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Collaborative research has become the norm in science, and collaboration across national boundaries is generally increasing, as reflected in the international co-authorship of many research articles. As much as 25% of the world's science and engineering (S&E) articles had international co-authors in 2012, up from only 8% in 1988.[1]

International scientific research collaborations (ISRCs) have been on the rise because of its various acknowledged advantages, including access to overseas talents and facilities, sharing risks and financial burden, and increased probability of getting more citations and academic popularity from a broader base of readers. Moreover, ISRCs seem to have recently been further facilitated by the fact that many of the 21st century's challenging global problems should be solved with new scientific knowledge, which is more likely created by ISRCs. Increased recognition of ISRCs as an alternative diplomatic tool for managing and enhancing international relationship may be an additional push.[2]

Another important recent development, which is also closely related to the aforementioned changes, is that ISRCs are not confined to Western developed

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[1] National Science Board, *Science and Engineering Indicators 2014* (Arlington VA: National Science Foundation, 2014): Chapter 5: 40; National Science Board, *Science and Engineering Indicators 2012 Overview* (Arlington VA: National Science Foundation, 2012): 10.

[2] Royal Society, *Knowledge, networks and nations: Global scientific collaboration in the 21st century* (London: Royal Society, 2011): 57-62; Royal Society, *New frontiers in science diplomacy, navigating the changing balance of power* (London: Royal Society, 2010); Eric Archambault, *30 years in science: secular movements in knowledge creation* (Montreal: Science-Metrix, 2010); Maria Bordons and Isabel Gomez, "Collaboration networks in science", in *The Web of Knowledge*, eds. Blaise Cronin, Helen Barsky Atkins (Medford: Information Today, Inc., 2000): 197-213.

countries and are expanding worldwide. Specifically, international collaboration involving scientists in Asia has been proved to be increasing more rapidly than the global average. One may even argue that a fundamental shift is taking place in the geography of science.[3]

A key driving force behind the change is the emergence of China as a leading science power in the last decade.[4] In terms of the number of scientific research papers published in Science Citation Index Expanded (SCIE) journals, which are widely accepted as major scholarly journals in the S&E fields, China is now second only to the United States (Table 1).

[Insert Table 1]

According to our calculation, which was based on the Web of Science (WOS) online database, of the 1,123,396 journal articles published across all S&E fields in 2012, about 26.5% and 15.2% were authored or co-authored by researchers in the United States and China, respectively. They were followed by the traditional scientific powerhouses, Germany, Japan, England, and France, accounting for 7.2%, 6.4%, 6.1%, and 5.1%, respectively.

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3 Jonathan Adams, "The Rise of Research Networks," *Nature* Vol. 490 (2012): 335-6; Stefanie Haustein, Dirk Tunger, GeroldHeinrichs, and GesaBaelz, "Reasons for and Developments in International Scientific Collaboration: Does an Asia-Pacific Research Area Exist from a Bibliometric Point of View?", *Scientometrics* 86 (2011): 727-746.

4 Zhou Ping and Loet Leydesdorff, "The Emergence of China as a Leading Nation in Science", *Research Policy* 35(1) (2006): 83-104; Eun Jong-Hak, "An Exploration into China's Scientific Research Capabilities: Academic Leadership and International Research Network" (in Korean), *China Research* 47 (2009): 449-477.

The changing relative position of China vis-à-vis the Western advanced countries (especially, the United States and the European Union) in the world of science has been well documented, and the collaborative linkage between them has recently been examined in multiple studies.[5] However, only a few studies have explored the *regional* structure of scientific collaboration network formed around China.[6] Particularly, the neighboring Little Dragons have rarely been the focus of studies examining the changing scientific collaboration linkages to the rising China.

Against this backdrop, the present study explores the international scientific collaboration networks of South Korea, Taiwan, and Singapore, which are commonly called Little Dragons (LDs).[7] These LDs, as the metaphor of the dragon implies, are culturally and geographically close to China but traditionally have strong

[5] Caroline S. Wagner, Lutz Bornmann, and Loet Leydesdorff, "Recent Developments in China-US Cooperation in Science", presented at the Conference on China's International S&T Relations (Arizona State University, April, 2014); National Science Board, 2014, op. cit.; Albert C. T. Li, "Beyond Competition: Past, Present and Future on EU-China Science and Technology Collaboration", *European Foreign Affairs Review* 19 (2014): 97-118; Eun Jong-Hak, 2009, op. cit.; He Tianwei, "International scientific collaboration of China with the G7 countries", *Scientometrics* 80(3) (2009): 571-582; Royal Society, 2011, op. cit.; Zhou Ping and Loet Leydesdorff, 2006, op. cit.

[6] Niu Xiao Si, "International scientific collaboration between Australia and China: A mixed-methodology for investigating the social processes and its implications for national innovation systems", *Technological Forecasting & Social Change* 85 (2014): 58-68; Subbiah Arunachalam and M. Jinandra Doss, "Mapping international collaboration in science in Asia through coauthorship analysis", *Scientometrics* 79(5) (2000): 621-628; B. M. Gupta and S. M. Dhawan, "India's collaboration with People's Republic of China in science and technology: A scientometric analysis of coauthored papers during 1994-1999", *Scientometrics* 57(1) (2003): 59-74.

[7] Hong Kong, which returned to the People's Republic of China in 1997, is not included in this comparative study of Little Dragons, although it has passed for one of the four LDs. A practical reason of the exclusion is the difficulty in collecting Hong Kong's bibliographic data comparable to other LDs, which, unlike Hong Kong, are treated as independent countries in the WOS DB.

ties with Western countries in scientific research collaboration. Therefore, in the current study, we examine how the ISRC networks of the LDs evolved with the rise of China as a science superpower from 2002 to 2012, when China attached great importance to science and technology and intensified related investments under then President Hu Jintao.

For a long time, the LDs have been mainly portrayed as successful *developing* countries and often regarded as a homogenous group sharing common factors, such as small size, Confucian tradition, export-oriented development strategy, and impressive economic performance.[8] As a group, the LDs have been contrasted with, for instance, Latin American countries in discussions on specific models of economic growth. However, some authors, including Hobday and Wong, have found meaningful differences among the LDs and further differentiated the development model of each LD.[9]

This study follows the line of discussion of and pay special attention to the commonalities and differences among the LDs. Nevertheless, we also contribute to

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8 World Bank, *The East Asian Miracles* (Oxford: Oxford University Press, 1993); Asian Development Bank, *Emerging Asia Changes and Challenges* (Manila: Asia Development Bank, 1997);Henry S. Rowen (ed.), *Behind East Asian Growth: The Political and Social Foundations of Prosperity* (New York: Routledge, 1998); Danny M. Leipziger (ed.), *Lessons from East Asia* (University of Michigan Press, 2001).

9 Michael Hobday, "East versus Southeastern Asian innovation systems: Comparing OEM- and TNC-led Growth in Electronics", in Linsu Kim and Richard R. Nelson (eds.) *Technology, Learning, and Innovation* (Cambridge: Cambridge University Press, 2000); Poh-Kam Wong, "National innovation systems for rapid technological catch-up: An analytical framework and a comparative analysis of Korea, Taiwan and Singapore", presented at the DRUID Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy (Rebild, Denmark, 1999).

the literature on the development model(s) of the LDs by recognizing them as highly *developed* countries that should consider scientific research as a springboard for the next stage of development and deal with China's emergence as a science superpower as an issue of strategic importance.[10]

Certainly, the distinctive features of the ISRC networks of the LD cannot be solely attributed to the development policy intentions of these countries, as they can also be affected by various country-specific factors, including historical path and geographical and cultural affinity with specific partner countries.[11] However, the network characteristics may have a certain implication for each country's future pattern of development because they can function as a facilitator for some activities and as a constraint for others, and because new businesses may emerge from the pre-existing organizations and networks of scientific research they based.[12] Particularly,

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[10]According to the International Monetary Fund's statistics of year 2013, Singapore is one of the richest countries with per capita GDP (PPP) $78,762 (ranked 3rd in the World). Also, Taiwan ($41,539, 22nd) is ranked higher than Japan ($36,654, 27th) closely followed by South Korea ($33,791, 30th). http://en.wikipedia.org/wiki/List_of_countries_by_GDP_(PPP)_per_capita (accessed 5 November 2014). Acknowledging that South Korea and Taiwan have accumulated fairly strong indigenous science and technology capabilities, Singapore has recently tried to enhance indigenous research capabilities and emphasized the commercialization of the research results. Poh-Kam Wong and Annette Singh, "From technology adopter to innovator: Singapore", Charles Edquist and Leif Hommen (eds.) *Small Country Innovation Systems: Globalization, Change and Policy in Asia and Europe* (Cheltenham: Edward Elgar, 2008): 71-112; Poh-Kam Wong, Yeun-Ping Ho, and Annnette Singh, "Towards an "entrepreneurial university" model to support knowledge-based economic development: The case of the national university of Singapore", *World Development* 35(6) (2007): 941-958.

[11]Diane H. Sonnenwald, "Scientific collaboration", *Annual Review of Information Science and Technology* 41(1) (2008): 643-681.

[12]Henry Etzkowitz, "Research groups as 'quasi-firms': The invention of the entrepreneurial university", *Research Policy* 32 (2003): 109-212.

China, a huge and populous developing country with many challenging problems to be solved with the help of new scientific knowledge, could be a land of opportunities for future science-based businesses and thus an invaluable research partner for other countries.[13]

By examining and comparing the unique features of the ISRC networks of the LDs and China's changing position and role within the three distinct networks, we can open a new round of discussions on the development of the three dynamic economies at a more advanced stage, which existing studies have rarely addressed. Additionally, the present study can serve as a tentative evaluation of China's achievement in enhancing its scientific influence over the East Asian region in Hu's era (2003–2012).

Therefore, we attempt to answer the following research questions: [RQ1-1] How have the LDs adjusted to the changing environment that now involves China as a leading science superpower? [RQ1-2] To what degree, if ever, have the major partner countries of the LDs in the ISRC changed in favor of China over Western advanced countries? [RQ2-1] How has the bi-lateral relationship of the LDs with China in science evolved during Hu's 10 years? [RQ2-2] How could the evolutionary trajectory of each LD be characterized and differentiated from other LDs? [RQ3-1] How have the ISRC networks of the LDs been reconfigured during Hu's 10 years?

[13] Eun Jong-Hak, "Development Pattern and Structure of the Chinese Science and Technology", in Lee Chang Kyu (ed.) *The Rise of China and Korea's Strategy* (in Korean) (Seoul: Korea Institute for International Economic Policy, 2009): 645-701.

[RQ3-2] How has the position of China changed in the ISRC network of each LD?

[RQ3-3] How do the LDs actually perceive these changes?[14]

Research Approach and Methodology

We used bibliometrics in this comparative study of the ISRCs of the LDs. Bibliometrics is a set of methods used to quantitatively analyze academic literature considered to provide reliable evidence on the nature of a country's scientific activity.[15]

We accessed the WOS online database, which contains bibliographic information about journal articles indexed in SCIE, and identified all the SCIE journal articles published in 2002 and 2012 with addressed from any of following countries: South Korea, Taiwan, and Singapore. Within the distinct datasets of the three LDs, we further narrowed down the research focus to *internationally co-authored* articles.[16] The SCIE journal articles identified through the aforementioned process constituted the main objects of analysis in the following analyses (Table 2).

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14 We assumed that a cognitive gap between the real and perceived worlds of science exists because scientific research collaborations are now underway in such a massive scale and with great complexity, which is not always matched by people's acknowledgement.

15 Fu Hui-Zhen, Chuang Kun-Yang, and Wang Ming-Huang, "Characteristics of research in China assessed with Essential Science Indicators", *Scientometrics* 88 (2011): 841-862.

16 In this research, we used international co-authorship as a proxy of international research collaboration, and identified internationally co-authored articles by detecting articles that have more than one country in the address field.

[Insert Table 2]

A careful description of the datasets generated from the bibliometric exploration could provide some clues for research questions [RQ1-1] and [RQ1-2]. However, to verify the findings and answer the other research questions raised in the previous section, we conducted the following analyses.

First, we conducted the cosine similarity analysis (CSA). Cosine similarity is a measure of similarity between two vectors. If the value of the cosine similarity is equal to 1, the two vectors have the same shape (regardless of magnitude), whereas a value of 0 implies no commonality between the two vectors. Therefore, two objects being compared (e.g., two countries or a country at two different points in time) are more similar when the value of the cosine similarity coefficient is closer to 1. In the following equation, the vectors t_k and q_k represent the distribution of scientific studies across various S&E fields in each of the two countries.

$$\sigma(D,Q) = \frac{\sum_k (t_k \times q_k)}{\sqrt{\sum_k (t_k)^2} \times \sqrt{\sum_k (q_k)^2}}.$$

Using this process, we could compare the distribution of scientific research activities of two (i.e., China and one of the LDs) countries across various fields (241 in total) of science.[17] Furthermore, by combining the results of the CSAs with the

[17]The distribution of a country's research publications across different fields may reflect the country's research priorities or different national demand configurations for knowledge. Recognizing the significance of this meaning, many previous studies tried to compare distributions across countries. However, whether because of convenience or the restrictions in data availability, these comparative analyses tended to divide the S&E field into small (especially in the case of international comparisons) numbers of sub-fields (between 5 and 40). See, for instance, Ali Gazni, Cassidy R. Sugimoto, and Fereshteh Didegah, "Mapping world scientific collaboration: Authors, institutions, and countries" *Journal of the American*

separately measured strength of each LD's bi-lateral ISRC tie with China, we could characterize the changes in the LDs in their relationship with China within a conceptual framework that illustrates four possible types of relationship. Through these methods, we obtained the answers for research questions [RQ2-1] and [RQ2-2].

Second, we performed the social network analysis (SNA) to go beyond discussing the bi-lateral aspects of the LDs' ISRC and to examine the various features of the LDs' ISRC networks formed with multi-lateral links to many other countries and the distinctive position (or role) of China within each of the three networks.

SNA is a methodical analysis of social networks assumed to consist of nodes and links. The nodes represent individual actors within the network, and the links represent the relationships among the actors. In our case, the nodes represent individual countries, including the LDs. The links represent the international linkages formed by co-authorship of scientific articles among scientists from different countries.

Although the preceding CSAs may reveal some aspects of the LDs' ISRC networks, the structural characteristics of the networks and the shifting position of

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Society for Information Science and Technology 63(2) (2012): 323--335; Fu et al., "Characteristics of Research in China Assessed with Essential Science Indicators"; Kim Mee-Jean, "Korean science and international collaboration, 1995--2000", *Scientometrics* 63(2) (2005): 321--339; Wang Yan, Wu Yishan, Pan Yuntao, Ma Zheng, and Ronald Rousseau, "Scientific Collaboration in China as Reflected in Co-authorship" *Scientometrics* 62(2) (2005): 183--198. Although this technique may reveal some salient features of a country, subtle differences could easily get lost. Therefore, in this study, we used the most fine-grained categorization available in the online WOS database that breaks the whole S&E field into as many as 241 sub-fields.

China within the networks remain to be explored. Therefore, we explored the LDs' ISRC networks using various analytical tools (i.e., Gini coefficient, degree centrality, closeness centrality, link connectivity, and ego network density, each of which will be discussed in more detail in the following sections) available in the SNA-specialized NetMiner 3 software.[18] Through this process, we tried to answer the research questions [RQ3-1], [RQ3-2], and [RQ3-3].

In both the CSA and SNA, entities (e.g., individual research fields or collaborating partner countries) that account for less than 0.1% of the relevant total were removed to guarantee higher reliability of analyses. The research results presented below show significant robustness with various threshold levels other than 0.1%.

Recent Development of the LDs' ISRC and Major Partners

Before discussing the results of CSA and SNA in the subsequent sections, we first review the overall development of the LDs' ISRC in the last decade or so. From a series of bibliometric analyses, we traced the recent development of the three LDs, particularly in terms of their degree of engagement in the ISRC and the main countries with which they collaborated.

[Insert Figure 1]

[18] To ensure comparability in analyzing the three LDs' ISRC networks, we normalized the number of links in each LD's network by dividing it by the total number of SCIE papers published by the LD.

Singapore has conducted an increasing number of ISRCs in recent years. However, its research without international collaboration has not shown any notable increase since 2005 (Figure 1). Broken down further, the statistics shows that, since 2005, China has already caught up with the United States as the most frequent ISRC partner of Singapore. If we exclude Hong Kong, then this change has occurred since 2008. In addition, the gap between the two countries appears to be widening in favor of China (Figure 2). Singapore seems to have maintained a relatively high growth rate of scientific publications by facilitating ISRCs, particularly with mainland China (Table 3).

[Insert Figure 2]

[Insert Table 3]

Although South Korea has recorded an even higher growth rate than Singapore (Table 3), the growth has been driven to a lesser degree by international collaboration. Since 2008, South Korea has shown a distinctively fast increase in scientific research conducted without foreign collaborators.

South Korea has been relatively slow in embracing China as a key scientific collaborator. It seems to remain heavily dependent on the United States in ISRCs (Figures 1 and 2).

In the case of Taiwan, although its own research has increased more quickly than that of Singapore, the overall growth rate falls short of that of Singapore because of Taiwan's relatively slow increase in international collaboration (Table 3). In general, Taiwan seems to have more commonalities with South Korea than with Singapore in choosing partners for ISRC, although its degree of lopsidedness toward the United States is milder than that of South Korea.

Relationship of the LDs with China in Science: Evolutionary Changes and Cross-LD Comparison

In this section, we characterize each LD's bi-lateral relationship with China in science and trace the changes during Hu's 10 years. We conducted a series of CSAs for years 2002 and 2012. The CSAs in this study enabled us to measure how similarly the scientific research of the two selected countries is distributed or the degree of similarity in the scientific research portfolio of the two countries across 241 science fields. Moreover, using the CSAs, we compared different pairs of countries or a pair of countries at different points in time.

Through these analyses, we found that all three LDs are more similar to China than to the United States in terms of their scientific research portfolio (Table 4). This result could be partly attributed to the following two facts. First, countries with limited physical and human resources (due to either their size or level of development) tend to focus on a narrower scope of research fields than resource-affluent countries, such as the United States. Second, East Asian countries, including China, tend to focus on physical sciences and engineering fields, which are presumed to be more relevant to their current industrial competences than other fields, whereas the United States has attached more importance to biomedical and other life sciences.[19]

[Insert Table 4]

As a further step in analyzing the changes from 2002 to 2012 in the research relationship of the LDs with China and in comparing them, we developed a conceptual framework that could illustrate such evolutionary changes (Figure 3).

[Insert Figure 3]

The horizontal axis shows the degree of scientific research collaboration between two countries (e.g., Singapore and China). The vertical axis denotes the degree of similarity in scientific research portfolio between two countries.

If two countries have strong collaborative ties and a high degree of similarity in their main research fields, their relationship is called collaborative conversion (upper right quadrant). If two countries have strong collaborative ties but their main fields of research are different, their relationship is called as collaborative division (lower right quadrant). The other two quadrants, which show weak collaborative ties, are labeled competitive conversion and competitive division, according to the high and low degrees of similarity in the countries' research fields, respectively.

Now, we illustrate the changes in the scientific research relationship of the LDs with China in the conceptual framework developed above with real data, as shown in Figure 4. Our operational definition of a collaborative tie (horizontal axis) is the

[19] National Science Board, op.cit. (2012): 10.

percentage share of exclusive bi-lateral research collaboration the country has with mainland China (excluding Hong Kong) in the country's total ISRCs. The similarity in research portfolio (vertical axis) between an LD and mainland China is captured with the cosine similarity index.

The values on the horizontal axis run from 0% to 25%, and those on the vertical axis run from 0.700 to 1.000. We selected the zone because all four countries are located within this zone. However, as showing wider or narrower zones is possible, each country's research relationship with China cannot be characterized in any one of the four categories on an *absolute* basis. What we can do is compare the countries on a *relative* basis and at different points in time.

Next, let us examine the research relationships of the three LDs with China. Singapore, which has shown the most drastic changes during the 10 years, has much stronger scientific research ties with China and a greater degree of similarity in research portfolio. Therefore, one may argue that Singapore is more firmly positioned in the state of collaborative conversion with China than the other LDs.

[Insert Figure 4]

In terms of the direction of change, the three LDs are almost the same. However, the degrees of change and their relative positions differ, as shown in Figure 4. As mentioned above, Singapore has shown the most marked change from 2002 to 2012. Given this finding, one may argue that Singapore has been the most agile in adjusting to the changing environment with the rise of China. However, such an assertion needs to assume that China has been indifferent to the three LDs in choosing ISRC partners, which is not fully verified in this study.[20]

Although on the same trend, South Korea has been relatively slow to embrace China as a key scientific collaborator while it remains heavily dependent on the United States, its traditional collaborator. Relatively, South Korea has a competitive conversion relationship with China. A high degree of similarity in the scientific research portfolio, coupled with a relatively low level of direct linkage between the two countries, seems to add competitive pressure. However, this situation could also mean greater potential for collaboration based on *commonality*.

During the Hu decade, Taiwan escaped from a competitive division relationship with China. However, among the three LDs, Taiwan has the lowest level of similarity to China in terms of scientific research portfolio. This finding implies that Taiwan has a distinct knowledge portfolio.

Structural Characteristics of the ISRC Networks of the LDs and the Position of China in these Networks

In this section, we examine the structural properties of the ISRC network of each LD as a whole (i.e., macro-level analysis) and the location of China (especially in comparison with the United States) in each of the three distinct networks (i.e., micro-

[20] The indifferent China assumption seems plausible as to the best of the author's knowledge no directive has been issued from the Chinese central government or national level authorities asking Chinese scientists to discriminate scientists from the three different countries as ISRC partners. Nevertheless, this issue should be further verified in future research.

level analysis). Furthermore, we construct a new set of networks what-we- call virtually subjective networks (VSNs), which may better reflect the *subjective* perception of the world from the perspective of each LD, and discuss how each LD actually perceives China in the world of science.

(1) Macro-level SNA: Structural Characteristics of the ISRC Networks of LDs

Figure 5 shows that the ISRC network of each LD is composed of a huge number of links and is further complicated by the increasing number of links from 2002 to 2012. Therefore, determining any hidden features of each network using intuition alone is difficult. We resort to several analytical tools developed in network theories.[21]

[Insert Figure 5]

A useful tool to capture the characteristics of a network as a whole (i.e., macro-level analysis) is the Gini coefficient. The Gini coefficient is most often used to discuss income inequality, but we use this tool in this research to measure the distribution of collaborative links between an LD and its international research partners.[22]

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[21] Stanley Wasserman and Katherine Faust, *Social Network Analysis: Methods and Applications* (Cambridge: Cambridge University Press, 1994); David Knoke and Yang Song, *Social Network Analysis* (Thousand Oaks: Sage Publications, 2008).

[22] As in the case of income inequality, a Gini coefficient of 0 expresses perfect equality. By contrast, a Gini coefficient of 1 expresses maximal inequality.

The results show an identical trend in the ISRC networks of all the LDs (Table 5). The LDs have become less dominated by a few major countries over time (from 2002 to 2012) because large-scale scientific studies that include researchers from different countries have become increasingly common.

[Insert Table 5]

However, the three LDs differ in terms of the absolute level of their Gini coefficients. Singapore has the highest value, followed by South Korea and Taiwan. This result implies that a small number of countries account for a major share of the linkages in the Singaporean ISRC network. By contrast, linkages among the collaborating countries are more evenly distributed in the Taiwanese ISRC network. South Korea is positioned somewhere between these two countries.

This result implies that Singapore is more willing to participate in bilateral (or multilateral, with fewer countries involved) collaborative schemes with a few major countries. By contrast, Taiwan participates in large-scale research projects as one of the many collaborating countries. In fact, the number of significant partner countries (which have contributed to at least 0.1% of the relevant total SCIE publications of the LDs) increased to a larger degree in Taiwan (30 → 62: growth rate = 106.7%) and South Korea (34 → 61: 79.4%) than in Singapore (34 → 54: 58.8%) from 2002 to 2012.[23]

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[23] A clue to the rapid increase in Taiwan's partner countries can be found in Nobuko Miyairi and Chang Han-Wen, "Bibliometric characteristics of highly cited papers from Taiwan, 2000-2009", *Scientometrics* 92 (2012): 197-205. Using data until 2009, they found that Taiwan has increasingly collaborated with European countries, which frequently collaborate with each other, rather than with its neighboring countries in Asia.

Taiwan may be less willing or less able to launch international research projects that include a small number of countries as its key collaborators. Although Taiwan seems balanced with a more even distribution of linkages, this characteristic may erode the meaningfulness or influence of Taiwan in its ISRC network. This tentative interpretation is verified in the subsequent section on ego network density.

(2) Micro-level SNA: Position of China in the ISRC network of each LD

In our micro-level analyses, we focus on the changing positions of individual countries (especially the LDs and China in comparison with the United States) in the ISRC networks of the three LDs. We use several relevant SNA tools, including degree centrality, closeness centrality, line connectivity, and ego network density, each of which is discussed in the subsequent sections.

(i) Degree centrality

Degree centrality is a simple and the most direct measure of actor centrality. The idea is that central actors must be the ones who have more ties to other actors in the network. Degree centrality is computed simply by calculating the portion of nodes adjacent to each node.

[Insert Table 6]

Table 6 shows that the United States maintained its status as the most active actor in the networks of all three LDs over the 10-year period.[24] Meanwhile, China closed the gap and is currently positioned firmly as the second most active partner in the Taiwan and Singapore networks. In the case of South Korea, China moved up one notch to third by 2012, whereas Japan, one of the most important research collaborators of Korea in 2002, considerably moved down the ladder. The relative status of Japan also weakened in Taiwan but not in Singapore. The position of Japan in the South Korean, Taiwanese, and Singaporean networks changed in the last decade from 2nd to 17th, 6th to 24th, and 6th to 6th, respectively.

A senior vice-president of Exploit Technologies, a technology commercializing vehicle under the Agency for Science, Technology, and Research of the Singapore government, verified the status of Japan in the research network of Singapore. He claimed that Japan has become more active in collaborating with Singapore than with South Korea and Taiwan. He considered this condition to reflect their mindset after a decade-long recession and the erosion of their technological edge because of tougher challenges from neighboring countries, particularly South Korea.[25]

Table 6 shows that the higher values of degree centrality are assigned to more countries within the Taiwanese ISRC network than to those that in South Korea and Singapore. All Taiwanese ISRC partner countries in 2012 listed in Table 6 are assigned with greater than five degree centrality, whereas South Korea and

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[24] Technically, ranked first in Table 6 are the LDs themselves only because the key actors in each column are found within the designated international research network of LD. Therefore, a meaningful discussion on the major partners should start from the entry below the LD itself.

[25] The author's interview on May 3, 2013.

Singapore only have one and two partner countries, respectively. Consequently, Japan, one of key traditional collaborators for Taiwan, is not in the top 20 list in 2012.[26] This finding implies that the Taiwanese ISRC partner countries are more densely interconnected among themselves than that of their South Korean and Singaporean counterparts. A micro-level verification of the abovementioned macro-level phenomenon also confirms that linkages among the countries within the Taiwanese ISRC network are more evenly distributed.

Singapore has simultaneously enhanced its linkages to traditional collaborators in the British Commonwealth (e.g., England, Australia, and Canada), China, and Japan.[27] Singapore shares politics and language (i.e., English) with the British Commonwealth nations, and shares history, language (i.e., Chinese), and geographical region with China. The multifaceted (or bilingual and bicultural) features of Singapore are achieved in its international scientific collaboration and competitiveness.[28]

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[26] However, this does not necessarily mean that Japan does not function as a key collaborator for Taiwan. The degree centrality of Japan is as high as 5.22, which is even higher than its value in the networks of South Korea and Taiwan. What is special in the Taiwan network is not that Japan is not a key player but that Japan is one of many key players.

[27] Frame and Carpenter argued that the size of the national scientific effort and a number of extra-science factors, such as history, geography, politics, and language, play a strong role in determining how much international collaboration occurs and who collaborates with whom in the international scientific community. See Davidson J. Frame and Mark P. Carpenter, "International research collaboration", *Social Studies of Science* 9 (1979): 481-497. In addition, Adams noted the links formed between the United Kingdom and Commonwealth countries that share a language (i.e., English) and adopt similar research structures. See Jonathan Adams, op.cit. (2012): 336.

[28] The collaboration of Singapore with India in scientific research is not as active as that of Singapore with South Korea. Although its collaboration with India has increased in absolute

(ii) Closeness centrality

Closeness centrality focuses on how close an actor is to all the other actors in a network. An actor is central if it can quickly interact with all the others. An actor with a high closeness centrality is assumed to have a strong influence over the other members in a network. Closeness centrality is measured by the inverse of the sum of the distances from a node to all the other nodes, which is then normalized by multiplying by (n-1).

By using the measure of closeness centrality, we examine how directly each LD is connected to all other nodes (i.e., the entire group of collaborating countries). Given that the nodes of the network in this study are the group of direct collaborators with an LD in a designated year, the closeness centrality of the LD is, by definition, 1. Therefore, what we should pay attention to are the positions of major partner countries especially the traditional and emerging science superpowers, that is, the United States and China, respectively.

The status of an individual country (e.g., the United States or China) evaluated using the closeness centrality could reflect its potential influence over all the countries in the network. However, this potential is evaluated only by the *structural* feature of links the country has in the network, regardless of the *strength* of the links (i.e., frequency of collaboration).[29]

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terms, comparatively speaking, it has decreased.

[29] The measure of closeness centrality does not consider the weight of the link.

[Insert Table 7]

Table 7 shows that China has gained more structural advantage to influence Taiwanese research collaborators, surpassing the United States in that aspect, although the gap between China and the United States in 2012 is marginal (0.94 vs. 0.93). China has also enhanced its influence in the networks of South Korea and Singapore, but the United States remains dominant in these two cases. Singapore stands out in 2012 because it invited Australia, a British Commonwealth member country, to be a more influential partner than China.

We also need to know that the closeness centrality of the United States and China in the network of Singapore has increased rapidly in the last decade (0.62 to 0.80 (29.0%), 0.61 to 0.74 (21.3%), respectively). This increase indicates that both G2 countries have expanded their research links to Singapore and its partner countries. The closeness centrality of the United States and China in the network of South Korea has only increased slightly by 11.1% and 15.9%, respectively. In Taiwan, the figures are 5.7% and 22.1%, respectively.

(iii) Line connectivity

Line connectivity of a pair of nodes is the minimum number of links that must be removed to sever the linkage between two countries, showing the strength of the connection between the two countries (in particular, between an LD and the United States/China).

Table 8 shows the result of the line connectivity analysis. China has emerged as the most connected partner for Taiwan, overtaking the United States, a traditional ally of Taiwan. Although China has also enhanced links with South Korea and Singapore, the United States remains its strongest partner. The considerable research connections of Singapore with the British Commonwealth member countries stand out.

[Insert Table 8]

(iv) Ego Network Density

An ego network consists of a focal node and a set of alter nodes adjacent to the focal node. The ego network density measures how densely the alter nodes around the focal node are interlinked with themselves. If the ego network density of a node (country) is high, then that node does not contribute greatly to the network because it does not add large extra values. Consequently, the node could easily be substituted by others. In other words, a high value of ego network density means a less meaningful focal node in the network.

[Insert Table 9]

Table 8 shows that all three LDs have increasing values of ego network density, implying that the world is becoming more interconnected, thus reducing the relevance of individual countries. The differences among the three LDs (Taiwan 〉 South Korea 〉 Singapore) have been largely maintained during the last decade, although the magnitude of the differences has declined. Taiwan seems to be most vulnerable to a possible substitution, whereas Singapore is relatively secure.

(3) Virtually Subjective Networks and the Cognitive Gap for China

In the previous network analyses, we assumed that a network is composed of ISRC links weighted by the number of co-authored papers (with the exception of closeness centrality that does not account the weight of the link). In this section, we construct and examine a new set of networks, in which the links are weighted not by the objective number of co-authored papers but by the percentage share of each international partner country from the standpoint of each focal country.

Consequently, in this new set of networks, a link is evaluated with different weights by the two connected countries. A link has a high weight value for a country that only has a few other links, whereas the same link has a lower weight value for a country that has more links with multiple external collaborators (Figure 6).

[Insert Figure 6]

Networks drawn according to this new principle may better reflect the subjective perception of the world from the point of view of each country. Therefore, we call the new networks virtually subjective networks (VSNs) to differentiate them from the objective networks (ONs) examined so far. By examining a VSN, we can see how popular a specific country is as a scientific collaborator for countries included in the ISRC network of the LD, assuming that each country has an equal opportunity to evaluate others regardless of its scientific capability or frequency of participation in ISRC.

With a *directed* network such as VSN, we can calculate two different measures of degree centrality, namely, in degree and out degree.[30] In degree is a count of the number (or weight) of links coming into the node, and out degree is a count of the number (or weight) of links going out of the node. When links are associated to some positive aspects, such as friendship or collaboration, in degree is often interpreted as a form of *popularity* (or *receptiveness*) and out degree as *gregariousness* (or *expansiveness*).[31] Therefore, using the in degree centrality, we can examine how the United States, China, and other major countries are perceived as a scientific research collaborator by the groups of countries in the research networks of South Korea, Taiwan, and Singapore.

[Insert Table 10]

The results show that the United States remains the most popular research collaborator as it was a decade earlier in the research network of each LD (Table 10). Although China is also perceived as one of the major countries, its status and improvement in this regard is not as significant as in the previous sections.

In each community of countries networked with South Korea and Singapore, the relative popularity of China as a scientific research collaborator even diminished (third to seventh and second to fourth, respectively) in the last decade. By contrast, the community of countries networked with Taiwan recognized the enhanced

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[30] If relations (links) in a network are directed (arrow headed) from one actor (node) to another, then the network is called a directed network.

[31] Stanley Waserman and Katherine Faust, op.cit. (1994): 125-127.

popularity of China. Yet, different from the value in Table 6, China is perceived by Taiwan and its partner countries to rank below Germany and England (Table 10).

The above findings imply the existence of a cognitive gap. In other words, the recognition of China as a key scientific research collaborator by the LDs and their partner countries falls short of the enhanced involvement of China in each research network of the LD over the 10-year period.

The results also indicate no clear sign of enhanced regional collaboration among the Asian countries (e.g., South Korea, Taiwan, Singapore, and Japan). The relative popularity of neighboring Asian countries in the research community of each LD is generally diminished. Additionally, member countries of the British Commonwealth have recently been recognized as being more important in the research network of Singapore than neighboring Asian countries (Table 10).

Summary and Discussions

With the rise of China reshaping the pattern of global production and international trade in the last several decades, the drastically enhanced scientific research capacity of China may have considerable effect on the world of scientific research. In particular, as scientific research has increasingly become dependent on international collaboration, the emergence of China as a science heavyweight may have a significant influence on the research collaboration networks of many countries.

The effect of the emergence of China in the field of science is more likely to be felt earlier and more strongly in its neighboring countries. Nevertheless, neighboring countries are rarely the focus of studies that examine the changing scientific research collaboration with the rising China. Particularly for South Korea, Taiwan, and Singapore, which have grown to become highly developed countries and attached greater importance to scientific research, how to deal with emerging China as a science superpower is a question of strategic importance.

Examining the newly reconfigured ISRC between the LDs and the Big Dragon (i.e., China) has implications for the next stage development of the region. Therefore, we explored how the ISRCs of the LDs have been reshaped by the rise of China, how the position of China has changed, and how such changes are actually perceived in the ISRC networks of the three LDs.

Our bibliometric evidence reveals that, in the ISRC networks of the three LDs, China has commonly, although in different degrees, enhanced its position and influence from 2002 to 2012 when President Hu attached great importance to science. Moreover, the LDs and China have converged in scientific research portfolios, and the bilateral scientific research relationship between the LDs and China has become more collaborative in general. However, each LD also has its distinct features mainly in the scientific research relationship with the traditional Western collaborators and the rising China, as summarized in the subsequent paragraphs.

Singapore strengthened its collaborative research linkage to China more rapidly than other LDs. However, at the same time, Singapore strikes a balance by maintaining a strong research collaboration network with traditional Western collaborators and Japan.

Although on the same trend, South Korea has been relatively slow to embrace China as a key scientific collaborator. South Korea remains dependent on the United States, its traditional collaborator. However, a growing similarity in the scientific knowledge portfolio between South Korea and China, coupled with a relatively inactive direct linkage between the two, increases competitive pressure but also leads to a broader collaboration based on this commonality. In the South Korean research network, China has caught up with, but not surpassed, the United States in any sense. However, China has surpassed Japan, another major traditional collaborator of South Korea.

Taiwan, with relatively low similarity to China in research portfolio, has diversified its collaborators across the globe but has come under a structural framework in which China can wield a stronger influence over Taiwan and its collaborators than the United States. Despite the fact that Taiwan has a balanced international research collaboration network, China has moved to a more structurally important position in this network by a larger degree than South Korea and Singapore.

The distinctive features of these LDs have implications for the future development of the three countries because their scientific knowledge bases, on which they will increasingly rely for the next step in development, may be affected by the changing structure of the ISRC. Singapore may be in a better position to bridge the Western and Chinese knowledge sources and exploit new opportunities that emerge around the boundary. South Korea, with its greater potential to collaborate with China in common fields of research despite being mainly in alliance with the United States even in scientific research, may have to take a more sophisticated strategic maneuvering to materialize its potential. Taiwan, under the greater influence of

China directly or indirectly, may have to find a way to utilize its closer relationship with China to facilitate its development.

However, the findings and implications of the study should be dealt with caution because this study is, by nature, an early-stage exploration that relies on the bibliometric analyses on SCIE journal articles only. Therefore, the tentative conclusions of this study should be verified further in future studies as more evidence becomes available.

Furthermore, the objective state of things is not always perceived as such as we discovered in the VSN analyses. The recognition of China as an ISRC partner by the LDs and their partner countries is far below that of the United States and falls short of the enhanced actual involvement of China in the ISRC network of each LD. This notion may only be a *perception lag*, but it may frame future developments. Therefore, where exactly the current evolutionary processes would lead to in the future remains to be seen.

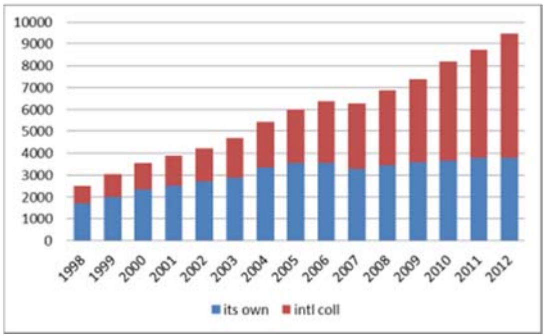
Table 1. *Rise of China in Scientific Research*

Rank	Y2012	N=1,123,396	Y2007	N=895,150	Y2002	N=706,423	Y1997	N=641,560
1	USA	26.48%	USA	29.17%	USA	31.54%	USA	33.24%
2	CHINA	15.18%	CHINA	9.53%	JAPAN	10.03%	JAPAN	9.64%
3	GERMANY	7.20%	JAPAN	8.01%	GERMANY	8.21%	GERMANY	7.97%
4	JAPAN	6.37%	GERMANY	7.42%	ENGLAND	7.26%	ENGLAND	7.50%
5	ENGLAND	6.06%	ENGLAND	6.65%	FRANCE	5.88%	FRANCE	5.88%
6	FRANCE	5.11%	FRANCE	5.34%	CHINA	4.77%	CANADA	4.48%
7	ITALY	4.43%	ITALY	4.65%	ITALY	4.58%	ITALY	4.25%
8	CANADA	4.42%	CANADA	4.58%	CANADA	4.27%	RUSSIA	3.15%
9	S.KOREA	4.06%	INDIA	3.53%	RUSSIA	3.28%	SPAIN	2.70%
10	INDIA	4.02%	SPAIN	3.48%	SPAIN	3.18%	AUSTRALIA	2.68%
11	SPAIN	3.90%	S.KOREA	3.12%	AUSTRALIA	2.78%	NETHERLANDS	2.55%
12	AUSTRALIA	3.40%	AUSTRALIA	2.96%	INDIA	2.64%	INDIA	2.40%
13	BRAZIL	2.62%	RUSSIA	2.63%	NETHERLANDS	2.53%	CHINA	2.38%
14	NETHERLANDS	2.55%	NETHERLANDS	2.43%	S.KOREA	2.42%	SWEDEN	2.06%
15	RUSSIA	2.25%	BRAZIL	2.12%	SWEDEN	2.07%	SWITZERLAND	1.75%

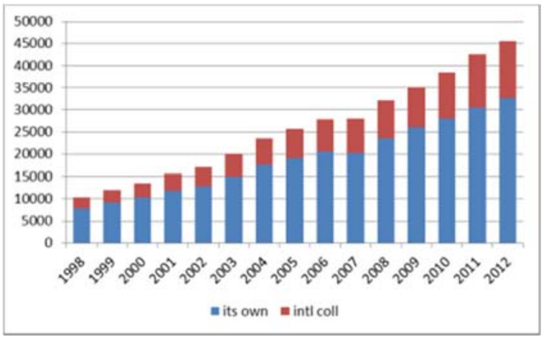
Source: The author; from the WOS database

Figure 1. *Production of Scientific Papers in the Three LDs*

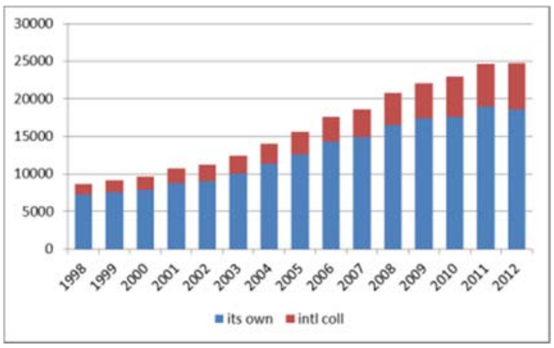
(Singapore)



(South Korea)



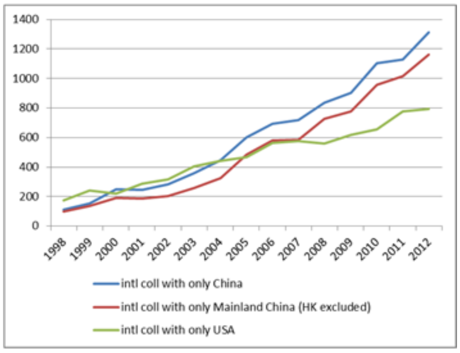
(Taiwan)



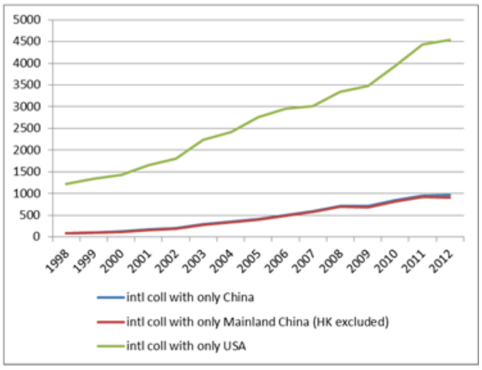
Source: The author; from the WOS database

Figure 2. *Bilateral Research Collaboration Partners of the LDs: US vs. China*

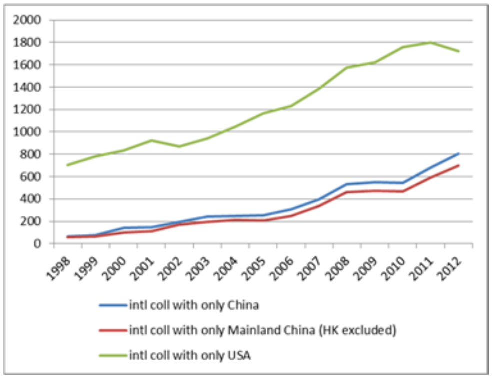
(Singapore)



(South Korea)



(Taiwan)



Source: The author; from the WOS database

Table 2. *SCIE Journal Articles of the Three LDs Analyzed in this Study*

		Y2002	Y2012
South Korea	total	17,062	45,561
	internationally co-authored	4,345	12,929
Taiwan	Total	11,269	24,746
	internationally co-authored	2,185	6,113
Singapore	Total	4,217	9,462
	internationally co-authored	1,521	5,677

Table 3. *Average Annual Growth Rate of Scientific Publications (2002–2012)*

	total	purely domestic	internationally co-authored
Singapore	8.4%	3.5%	14.1%
South Korea	10.3%	9.9%	11.5%
Taiwan	8.2%	7.4%	10.8%

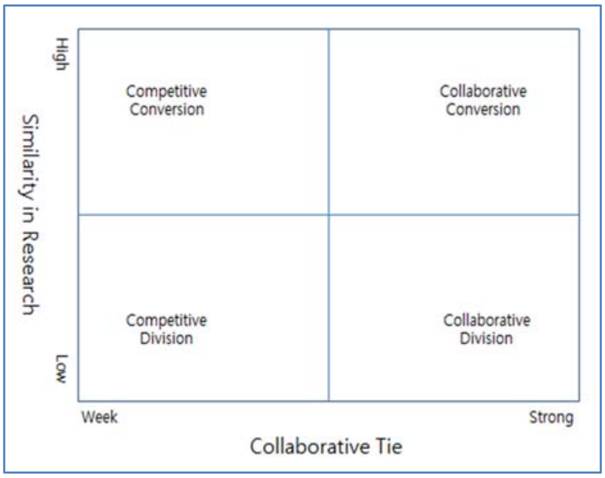
Source: The author; from the WOS database

Table 4. *Degree of Similarity in the Scientific Research Portfolios (2002 vs. 2012)*

	Y2002			Y2012		
	with China	with Mainland China (Hong Kong excluded)	with USA	with China	with Mainland China (Hong Kong excluded)	with USA
South Korea	0.886	0.856	0.723	0.927	0.923	0.801
Taiwan	0.789	0.738	0.740	0.874	0.864	0.746
Singapore	0.779	0.732	0.602	0.911	0.906	0.697

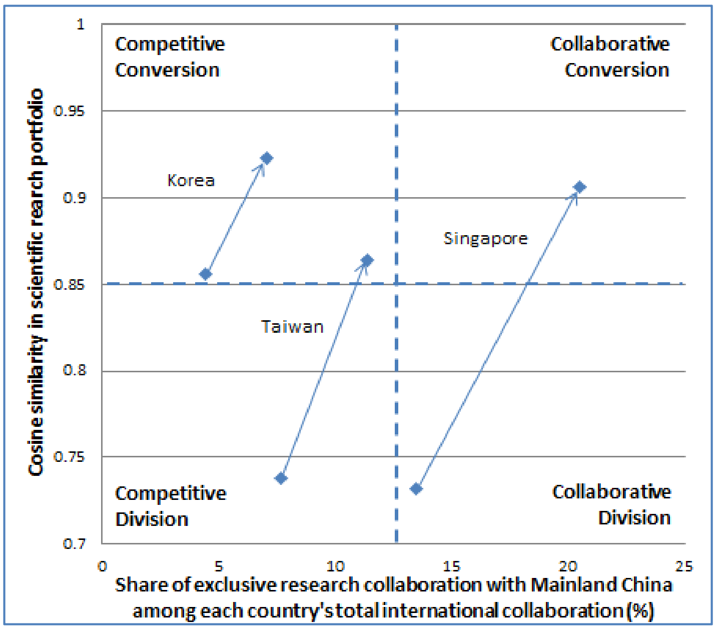
Source: The author

Figure 3. *Conceptual Framework*



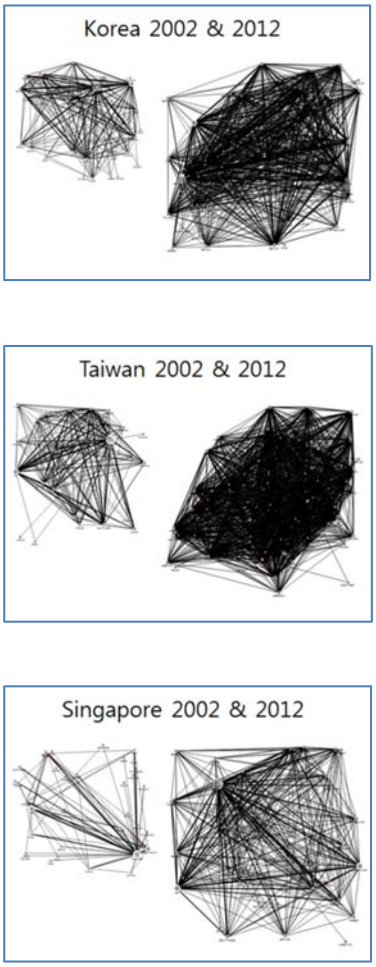
Source: The author

Figure 4. *Evolutionary Changes in the Scientific Relationship of the Three LDs with China*



Source: the author

Figure 5. *ISRC Networks of the LDs (2002 and 2012)*



Source: The author; using NetMiner 3

Table 5. *Gini Coefficients of the ISRC Networks of the LDs*

	Y2002	Y2012
South Korea	0.855	0.667
Taiwan	0.751	0.501
Singapore	0.961	0.897

Source: The author

Table 6. *Degree Centrality: Key Actors in the Network of Each LD (2002 vs. 2012)*

Rank	Y2002						Y2012					
	South Korea		Taiwan		Singapore		South Korea		Taiwan		Singapore	
0	S.KOREA	10.88	TAIWAN	10.42	SINGAPORE	13.28	S.KOREA	8.99	TAIWAN	12.36	SINGAPORE	18.06
1	USA	7.00	USA	7.18	USA	4.29	USA	6.10	USA	9.65	USA	7.39
2	JAPAN	3.55	CHINA	3.42	CHINA	3.54	GERMANY	3.29	CHINA	7.62	CHINA	6.19
3	RUSSIA	2.63	S.KOREA	3.34	AUSTRALIA	2.07	CHINA	3.22	GERMANY	7.37	ENGLAND	3.53
4	CHINA	2.09	GERMANY	3.28	ENGLAND	1.92	ENGLAND	2.93	ENGLAND	7.07	AUSTRALIA	3.43
5	TAIWAN	1.85	RUSSIA	3.18	CANADA	0.96	RUSSIA	2.63	ITALY	6.77	GERMANY	2.35
6	GERMANY	1.84	JAPAN	3.02	JAPAN	0.89	FRANCE	2.62	SPAIN	6.69	JAPAN	2.01
7	SWITZERLAND	1.62	SWITZERLAND	2.77	GERMANY	0.68	SPAIN	2.59	RUSSIA	6.66	FRANCE	1.98
8	INDIA	1.58	INDIA	2.50	TAIWAN	0.56	ITALY	2.57	SWITZERLAND	6.61	CANADA	1.78
9	ITALY	1.32	ITALY	1.68	INDIA	0.53	INDIA	2.49	FRANCE	6.61	NETHERLANDS	1.54
10	CANADA	1.19	SPAIN	1.59	FRANCE	0.43	SWITZERLAND	2.28	GREECE	6.23	ITALY	1.46
11	ENGLAND	1.13	CANADA	1.54	S.KOREA	0.27	TAIWAN	2.05	POLAND	6.04	INDIA	1.40
12	SPAIN	1.02	AUSTRALIA	1.49	THAILAND	0.26	CZECH REPUBLIC	2.04	AUSTRIA	6.01	TAIWAN	1.36
13	POLAND	1.00	POLAND	1.30	NEW ZEALAND	0.24	POLAND	2.01	CZECH REPUBLIC	5.99	S.KOREA	1.33
14	FRANCE	0.92	FRANCE	1.15	IRELAND	0.19	BRAZIL	2.00	BRAZIL	5.94	SWEDEN	1.23
15	AUSTRALIA	0.84	AUSTRIA	1.14	MALAYSIA	0.18	FINLAND	1.91	AUSTRALIA	5.72	SPAIN	1.14
16	NETHERLANDS	0.64	ENGLAND	1.13	BRAZIL	0.15	GREECE	1.91	COLOMBIA	5.69	SWITZERLAND	1.12
17	AUSTRIA	0.63	SLOVENIA	1.04	SWEDEN	0.14	JAPAN	1.89	TURKEY	5.66	MALAYSIA	0.93
18	SCOTLAND	0.63	HUNGARY	0.94	ISRAEL	0.13	MEXICO	1.79	PORTUGAL	5.65	DENMARK	0.90
19	SLOVENIA	0.55	NETHERLANDS	0.83	SCOTLAND	0.12	AUSTRIA	1.70	BYELARUS	5.61	THAILAND	0.76

Note: Japan and India ranked 24th with a value of 5.22 and 42nd with a value of 3.11 in the network of Taiwan in 2012, respectively.

Source: The author

Table 7. *Closeness Centrality: Key Actors in the Network of Each LD (2002 vs. 2012)*

Rank	Y2002						Y2012					
	South Korea		Taiwan		Singapore		South Korea		Taiwan		Singapore	
0	S.KOREA	1.00	TAIWAN	1.00	SINGAPORE	1.00	S.KOREA	1.00	TAIWAN	1.00	SINGAPORE	1.00
1	USA	0.81	USA	0.88	USA	0.62	USA	0.90	CHINA	0.94	USA	0.80
2	RUSSIA	0.76	GERMANY	0.81	CHINA	0.61	GERMANY	0.82	USA	0.93	AUSTRALIA	0.75
3	TAIWAN	0.71	S.KOREA	0.81	ENGLAND	0.59	ENGLAND	0.81	GERMANY	0.91	CHINA	0.74
4	SWITZERLAND	0.71	RUSSIA	0.81	AUSTRALIA	0.58	SPAIN	0.81	ENGLAND	0.91	ENGLAND	0.74
5	JAPAN	0.69	SWITZERLAND	0.81	TAIWAN	0.56	CHINA	0.80	AUSTRALIA	0.91	GERMANY	0.71
6	CHINA	0.69	CHINA	0.77	CANADA	0.54	ITALY	0.80	SPAIN	0.90	FRANCE	0.71

Source: The author

Table 8. *Line Connectivity of the United States and China with the LDs (2002 vs. 2012)*

Rank	Y2002						Y2012					
	South Korea		Taiwan		Singapore		South Korea		Taiwan		Singapore	
1	USA	26	USA	26	USA	13	USA	54	CHINA	58	USA	40
2	RUSSIA	23	GERMANY	23	CHINA	12	GERMANY	48	USA	57	AUSTRALIA	35
3	TAIWAN	20	S.KOREA	23	ENGLAND	10	ENGLAND	47	GERMANY	56	CHINA	34
4	SWITZERLAND	20	RUSSIA	23	AUSTRALIA	9	SPAIN	47	ENGLAND	56	ENGLAND	34
5	JAPAN	19	SWITZERLAND	23	TAIWAN	7	CHINA	46	AUSTRALIA	56	GERMANY	31
6	CHINA	19	CHINA	21	CANADA	5	ITALY	46	SPAIN	55	FRANCE	31

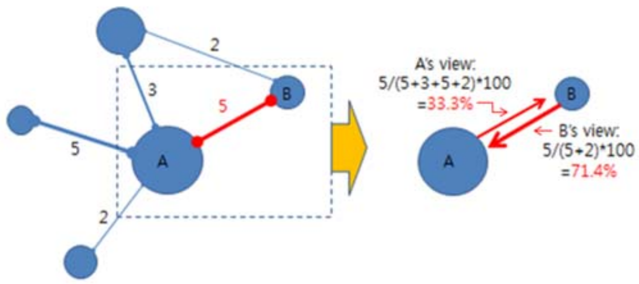
Source: The author

Table 9. *Ego Network Density of the LDs in their Networks (2002 vs. 2012)*

	Y2002	Y2012
South Korea	0.27	0.47
Taiwan	0.42	0.66
Singapore	0.07	0.24

Source: The author

Figure 6. *Objective Network vs. Virtually Subjective Network*



Note: In an objective network (left, undirected network), the link in the dotted rectangle is given a weight of 5 because five papers were co-published by A and B. However, the same link is weighted as 33.3% from A's view and 71.4% from B's view in the virtually subjective network because this link accounts for 33.3% of the total research collaboration with others for country A, but 71.4% for country B.

Table 10. *In degree Centrality of Key Actors in the VSN (2002 vs. 2012)*

Rank	2002						2012					
	South Korea		Taiwan		Singapore		South Korea		Taiwan		Singapore	
1	USA	0.490	USA	0.578	USA	0.090	USA	0.634	USA	0.775	USA	0.297
2	RUSSIA	0.342	S.KOREA	0.422	CHINA	0.061	GERMANY	0.518	GERMANY	0.717	ENGLAND	0.185
3	CHINA	0.239	RUSSIA	0.419	TAIWAN	0.032	ENGLAND	0.473	ENGLAND	0.690	AUSTRALIA	0.161
4	JAPAN	0.236	GERMANY	0.414	ENGLAND	0.032	SPAIN	0.451	CHINA	0.690	CHINA	0.139
5	TAIWAN	0.234	SWITZERLAND	0.378	THAILAND	0.031	RUSSIA	0.449	ITALY	0.672	GERMANY	0.124
6	SWITZERLAND	0.203	CHINA	0.354	AUSTRALIA	0.026	ITALY	0.437	SPAIN	0.669	FRANCE	0.104
7	INDIA	0.199	INDIA	0.330	FRANCE	0.023	CHINA	0.437	RUSSIA	0.661	CANADA	0.094
8	ITALY	0.141	ITALY	0.257	PHILIPPINES	0.013	FRANCE	0.432	FRANCE	0.658	ITALY	0.088
9	FRANCE	0.123	SPAIN	0.246	INDIA	0.012	SWITZERLAND	0.394	SWITZERLAND	0.657	NETHERLANDS	0.083
10	SPAIN	0.117	JAPAN	0.238	JAPAN	0.005	INDIA	0.393	GREECE	0.635	SPAIN	0.073
11	POLAND	0.114	FRANCE	0.196	S.KOREA	0.005	CZECH REPUBLIC	0.370	POLAND	0.622	SWEDEN	0.070
12	AUSTRALIA	0.095	HUNGARY	0.170	GERMANY	0.004	BRAZIL	0.366	AUSTRIA	0.620	JAPAN	0.068
13	CANADA	0.094	NETHERLANDS	0.164	MALAYSIA	0.004	GREECE	0.365	BRAZIL	0.618	DENMARK	0.051
14	GERMANY	0.093	ROMANIA	0.158	CANADA	0.004	FINLAND	0.363	CZECH REPUBLIC	0.617	TAIWAN	0.049
15	ENGLAND	0.090	BULGARIA	0.148	SPAIN	0.003	POLAND	0.361	COLOMBIA	0.598	INDIA	0.043
16	AUSTRIA	0.077	CYPRUS	0.147	SWEDEN	0.001	TAIWAN	0.349	TURKEY	0.596	S.KOREA	0.036
17	ROMANIA	0.074	AUSTRALIA	0.128	NEW ZEALAND	0.001	MEXICO	0.345	PORTUGAL	0.595	SWITZERLAND	0.033
18	SLOVENIA	0.064	POLAND	0.116	IRELAND	0.001	HUNGARY	0.327	BYELARUS	0.591	THAILAND	0.032
19	NETHERLANDS	0.056	AUSTRIA	0.101	BRAZIL	0.001	AUSTRIA	0.326	SERBIA	0.589	MALAYSIA	0.031
20	SCOTLAND	0.050	CANADA	0.100	ISRAEL	0.000	CROATIA	0.320	ARMENIA	0.588	NORWAY	0.025

Source: The author