Scientometrics (2014) 100:173–188
DOI 10.1007/s11192-013-1201-7

The scientific impact and partner selection in collaborative research at Korean universities

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Received: 4 September 2013 / Published online: 10 December 2013

Abstract This study seeks to bridge the gap between scientometrics literature on scientific collaboration and science and technology management literature on partner selection by linking scientists' collaborator preferences to the marginal advantage in citation impact. The 1981–2010 *South Korea NCR* (National Citation Report), a subset of the Web of Science that includes 297,658 scholarly articles, was used for this research. We found that, during this period, multi-author scientific articles increasingly dominated single-author articles: multi-university collaboration grew significantly; and the numbers of research publications produced by teams working within a single institution or by a single author diminished. This study also demonstrated that multi-university collaboration produces higher-impact articles when it includes "Research Universities," that is, top-tier university schools. We also found that elite universities experienced impact degradation of their scientific results when they collaborated with lower-tier institutions, whereas their lower-tier partners gained impact benefits from the collaboration. Finally, our research revealed that Korean universities are unlikely to work with other universities in the same tier. This propensity for cross-tier collaboration can be interpreted as strategic partner selection by lower-tier schools seeking marginal advantage in citation impact.

Keywords Knowledge production · Scientific collaboration · Multi-university research · Citation impact · Partner selection

JEL Classification C81 · D74 · D83 · I23 · N75

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Introduction

Exploration of knowledge production has been conducted by scientists from various research areas for several decades. Of particular interest is scientific collaboration, which has become the mainstay of knowledge creation (Katz and Martin 1997; Sonnenwald 2007). Previous studies have illustrated a relationship between the increasing dominance of scientific collaboration and the scientific impact of new knowledge (Beaver 2004; Guerrero-Bote et al. 2013; Wray 2002).

Many scholars have examined the increase in collaborative research. Cronin et al. (2003) illustrated the growing importance of collaboration in psychology and philosophy literature during the twentieth century. Adams et al. (2005) found that the number of authors on a scientific paper written at American universities increased by 50 % between 1981 and 1999. Gazni et al. (2012) also discovered that multi-entity publications increased worldwide during the period 2000–2009. Additionally, not only is scientific collaboration on the rise, it also has been shown to benefit collaborators and the research itself. Observed advantages of collaborative research include mentoring or teaching (Collins 1974), varied insights from different disciplines (Hoch 1987), better research productivity (Lee and Bozeman 2005), and improved quality of research results (Franceschet and Costantini 2010).[1]

Aside from these merits, citation impact is the most popular and frequent measure of the benefit of cooperative research. For example, Beaver (2004) quantitatively affirmed that collaborative research has greater epistemic authority (which correlates with citation impact) than research performed individually. Many studies, such as Guerrero-Bote et al. (2013), have used scientific impact to analyze the benefits of international scientific collaborations. Using a functional explanation for the persistence of scientific collaboration, Wray (2002) argued that cooperation helps scientists successfully access required resources, enabling the more effective realization of epistemic research goals.

Meanwhile, for the past several decades, science and technology management researchers have focused on research and development (R&D) alliance issues. Partnership subjects have been particularly popular in knowledge management literature. In many R&D alliance studies, counterparts in scientific alliances have been regarded as a key factor for improving a firm's performance. The partner effect, or nature of the relationship, has been shown to influence R&D alliance outcomes (Saxton 1997). The type of R&D partner (e.g., competitors, suppliers, customers, or universities and research institutes) also impacts a firm's performance (Belderbos et al. 2004). Research strands on alliances regard partner selection as a particularly important strategic activity. Van der Valk et al. (2010) studied inter-organizational collaboration among Dutch life science firms in order to better understand the partner selection process for inter-organizational R&D collaboration. Later, Diestre and Rajagopalan (2012) developed a theoretical framework to explain the decision making process when selecting partners.

While scientometrics studies have examined the benefits of collaborative research, collaborative issues such as partner selection have received little attention in scientific knowledge production literature. Although some studies have examined collaboration types or patterns, they did not investigate preferences or patterns at partner selection for the collaborative research. Sooryamoorthy (2009) reported that citation counts received by a research paper vary not only depending on whether the research is collaborative, but also

[1] Research collaboration is also regarded as being useful from a technological perspective: for example, the quality and value of patents are positively influenced by research collaboration (Lee 2008).

by type of collaboration (e.g. international, external-institutional, internal-institutional, or domestic). Gazni and Didegah (2011) compared the influence of collaboration on the citation impact of publications by categorizing collaboration patterns into intra-institutional, inter-institutional, domestic, and international collaboration, and found that the number of institutions involved in a publication positively correlated to the number of citations received. These studies on scientific collaboration have limits that they merely concern the benefits as results of cooperative research rather than examining partnership tendency at the foundation stage of scientific collaboration. Consequently, strategic decision making in scientific cooperation such as partner selection has received little attention. To our knowledge, only Jones et al. (2008) has investigated a tendency to choose a scientific alliance in multi-university collaborations, where a tendency toward social stratification was observed.[2]

This study attempts to bridge the gap between scientometrics (specifically scientific collaboration), and knowledge management (specifically partner selection), by examining scientists' preferences when choosing research collaborators, and linking this process to the goal for the scientific collaboration, i.e., marginal citation impact. To accomplish this, we analyzed a large data set of scientific research articles written by authors from 213 Korean universities.

We first conducted a descriptive analysis to show the growth of collaborative research at Korean universities over the last three decades, using bibliometric data covering all subject fields in science, technology, and engineering between 1981 and 2010, provided by the web of science's (WoS) science citation index expanded (SCIE) feature. To our knowledge, our study covers the longest time span and the largest range of disciplines at Korean universities, and thus addresses the limitations of previous studies examining knowledge production in Korea.

To perform an in-depth investigation of partner selection at Korean universities, we disaggregated the schools into four tiers based on epistemic authority, as measured by total number of citations received. Since our analyses are restricted to similar institutions in one small country using a single language, we have likely eliminated all potential considerations for partner selection other than scientific specialty.[3] The scientific ability to produce successful research, therefore, can be regarded as the key factor driving collaborator selection among Korean university scientists. Consequently, our data selection validates tier disaggregation, and confirms that the issue of scientific partner selection at the institutional level can be adequately examined by school tier.

After looking into the rise in scientific collaboration from various angles, we analyzed the impact advantages of collaboration by school tier. The probability that a scientific article belongs to the high-impact papers was calculated and compared across authorship structures. Moreover, the marginal advantages of between-school collaboration over within-school teamwork were estimated across tiers using an econometric technique. Finally, partner selection was analyzed in terms of propensity ratios, as expressed by ratios of the observed frequency and the hypothetical random rates for tier combinations. After doing so, we observed a 'cross-tier' preference phenomenon; that is, Korean university

[2] Jones et al. (2008) found that American universities are likely to collaborate within their own tier. They refer to these tendencies as the social stratification in multi-university collaboration and showed that the stratification has increased over time.

[3] When seeking out possible partners for scientific alliances, one may take some factors into consideration such as scientific specialty (Frenken 2002), national characteristics (Gazni et al. 2012), institutional differences (Leydesdorff and Sun 2009), physical distance (Hoekman et al. 2010; Katz 1994), and linguistic border effects (Narin et al. 1991). Since our sample is restricted to universities in a single nation, most of these factors, with the exception of scientific specialty, can be excluded from analysis.

scientists were unlikely to select scientific partners from same-tier universities. The motive underlying this phenomenon will, of course, be clarified.

The first contribution of this study is adding wide-range, long-term description of knowledge production for Korean academia, specifically concentrating on scientific collaboration among universities. In terms of authorship structure, multi-university collaboration has increased while intra-university teamwork and single-author research has declined. Secondly, this study supplements empirical evidence of the beneficial effects of collaboration. Alliances between universities yield stronger impact than intramural teamwork if partnerships include elite universities. Top-tier institutions, however, show a negative marginal advantage in citation impact when engaging in collaborative research, whereas schools from other tiers exhibit positive benefits from between-school collaboration. Lastly, the main contribution of this study is to examine the foundation phase of scientific collaboration from the standpoint of strategic partner selection. We analyzed Korean universities' propensity for tier matches in two-university collaborations and found that cross-tier cooperation is preferred to within-tier cooperation. Based on this finding, we suggest that lower-tier universities need to strategically select partners for scientific alliances to enhance the impact of knowledge created, as this appears to be the main cause for inter-tier preference in scientific collaboration between separate schools.

The remainder of this research paper is organized as follows. "Data and methodology" section explains our data set, key terms, and methodology. "Empirical results" section provides results from descriptive and other empirical analyses. The final section presents a brief conclusion.

Data and methodology

Data

We used the 1981–2010 *South Korea NCR* (National Citation Report), a subset of the WoS database for the empirical investigation. The database includes bibliographic and citation information on 297,658 regular scientific articles published between 1981 and 2010 that have at least one author with a Korean address. Our sample focuses on a set of papers written by university scientists and belonging to the SCIE database, including the WoS Subject Categories (WC) of science, technology, and engineering.[4]

In the original data, each paper lists affiliation addresses of all authors. This, however, makes huge difficulties in cleaning information on affiliations since the original authors might have used their own methods of translating Korean addresses to English. To solve this problem, we re-translated the name variations of Korean universities into our own university codes using custom algorithms. By filtering all papers published by 213 Korean universities, we acquired 149,457 articles in 171 WCs between 1981 and 2010.

Authorship structure and team size

Authorship structure, also referred to as the type of collaboration, is a popular criterion for classifying scientific collaboration. Kim (2006) used four different types of authorship

[4] The *1981–2010 South Korea NCR* also contains articles from social science, arts, and humanities disciplines. For the sample used in this study, however, the portion of the database comprised of these fields is insignificant. Therefore, we used only science and technology disciplines, which comprise 97.78 % of total papers. This portion is believed to be representative of the knowledge production of Korean universities.

structure to examine changes in distribution of scientific papers written by Korean physicists between 1982 and 2000: international collaboration, institution-external collaboration, institutional-internal collaboration, and no collaboration. In order to investigate the frequency of collaborations between scientists at different US universities, Jones et al. (2008) compared it with the number of sole-authored research papers and the amount of research papers published by collaborators at the same university. As mentioned above, Sooryamoorthy (2009) found that the number of citations received by a research article is affected by not only existence of collaboration but also the types of collaboration. Gazni and Didegah (2011) estimated the impact of the number of authors, institutions, and foreign nations on the number of citations by investigating research papers and books published by Harvard University from 2000 to 2009. They found that the numbers of authors and institutions have a significantly positive correlation with the number of citations, whereas the number of foreign collaborating countries does not.

To describe the knowledge production characteristics or patterns at Korean universities, we categorized authorship structure into three types: solo, within-school collaboration, and between-school collaboration. Team size was defined as the number of authors working on a paper. The solo authorship structure refers to papers are written by a single author. Hence the team size is one. Within-school collaboration indicates scientific research articles produced by multiple authors belonging to the same university. The team size of this structure is larger than one, and the number of collaborating schools equals one. Between-school collaboration signifies research articles co-authored by a number of scholars from various universities. The number of participating schools and the team size are both larger than one. From a scientific alliance perspective, between-school collaboration between two universities is especially useful for examining partner selection preferences through a rate ratio (also known as relative risk in the health sciences).

The variable “team size” indicates the number of authors in an article. Team size has grown over time and is generally regarded as being helpful in gaining higher number of citations. Adams et al. (2005) analyzed 2.4 million scientific articles written by 110 US universities between 1981 and 1999 and found that team size increases the influence of scientific results. Franceschet and Costantini (2010) identified a positive relationship between the number of authors and the number of citations received as well as judgments from peer reviewers using the national research assessment of Italian universities. In the present study, we used regression analysis to control for the effect of team size when estimating the marginal advantage of multi-university collaboration.

Rank and tier of school

To further investigate the characteristics of Korean universities’ collaborative research activities, we disaggregated the institutions into four tiers based on epistemic authority, which is measured by the total number of citations received by within-school publications from each university in the corresponding period. Here, “within-school publications” include sole-authored papers and within-school collaborating papers. The consideration of these two authorship structures is sufficient for examining university rankings (Jones et al. 2008). The top 4 %, the top 10 %, and the top 22 % were used to define the boundaries between the four different tiers.

Citation impact

The main result of scientific collaboration is the production of new knowledge, and the quality of a scientific article is measured by the number of citations received. According to Beaver

(2004), collaborative research possesses more significant epistemic authority than research conducted by an individual, and the epistemic authority is associated with the number of citations gained, probability of citation, and citation lifetime. Guerrero-Bote et al. (2013) used the scientific impact indicator to analyze the benefits derived from international scientific collaboration and concluded that the more countries involved, the higher impact gained. For this study, we determined high-impact papers and marginal citation impacts of various authorship structures based on citation counts.

High-impact paper

To analyze certain issues on citation impact, we defined articles receiving more than the average number of citations in the same publication year and WC as high-impact papers. An indicator for whether a publication has high impact was used to calculate the probability that a paper would earn above-average citations; this indicator was also used as the dependent variable of the regression analyses in estimating the marginal citation impact advantage.

Marginal citation impact advantage

We used regression analysis to estimate the impact advantage of collaborations. The regressions were linear models in which a dummy variable for a high-impact paper is regressed on an indicator variable for authorship structure, subfield (WC), team size, and publication year.

Propensity for tier combination

For between-school collaborations, we focused on collaborative works in which only two universities participated. Two-university cooperation facilitates the examination of the nature of multi-university partnerships. This is especially true for partner selection, which reveals universities' tendency to choose tiers from which their scientific counterparts are.[5] To accomplish this, we first estimated the expected rates of randomly matched collaborations using bootstrapping and then compared those rates with the actual frequency of tier combinations. The ratio of two probabilities, frequently referred to as the rate ratio or relative risk,[6] is a popular way to measure the effect of a difference between two outcomes. Those two outcomes or circumstances are actual-matching frequency and expected random-matching rates. Jones et al. (2008) referred to this ratio as the "propensity ratio," and used it to illustrate that multi-university collaborations in the US "are increasingly stratified by in-group university rank."

Probability of two-university paper

When we defined the probability that multi-university collaborative research includes a university from tier j as P_j, the probability that a two-university paper includes tiers j and k under random matching, P_{jk}, is $P_j \cdot P_k$ if j equals k, and $2 \cdot P_j \cdot P_k$ if j does not equal k.

[5] In the science and technology management literature, many alliance structure issues are investigated from a dyadic perspective. Gulati (1998) outlined the study of strategic alliances.

[6] The rate ratio and other effect size measures are thoroughly explained by Fleiss and Berlin (2009). In the health sciences, the ratio of two probabilities is referred to as the risk ratio or relative risk.

$$P_{jk} = \begin{cases} P_j \cdot P_k (j = k) \\ 2 \cdot P_j \cdot P_k (j \neq k) \end{cases} \quad (1)$$

Expected frequency

We estimated expected frequency using non-parametric resampling of our two-university sub-sample. The following is our algorithm for a non-parametric bootstrap:

1. Sample n observations randomly without replacement, and obtain a bootstrap data set.
2. Count the number of each tier-matching pair, and calculate the sample rate. For tier j, that rate is P_j^*.
3. Calculate the sample probability that a two-school collaborative work includes tiers j and k, P_{jk}^*, with P_j^* and P_k^* from step 2.
4. Repeat steps 1–3 a large number of times (we chose 1999)[7] and calculate the average of sample rates $P_{jk}^{*,1}$, …, $P_{jk}^{*,1999}$ to obtain the expected rate P_{jk}^E for all combinations of j and k.

We obtained, conclusively, 10 P_{jk}^E s from P_{11}^E to P_{44}^E.

Propensity ratio

We refer to the ratio of the actual frequency of a given tier combination, P_{jk}^A, to its expected frequency in the random-matching situation, P_{jk}^E, as the propensity ratio for the given tier paring, R_{jk}.

$$R_{jk} = \frac{P_{jk}^A}{P_{jk}^E} \quad (2)$$

This ratio of two probabilities is referred to the propensity ratio (Jones et al. 2008). If it is greater than unity, an actual tier match is preferred to a counterfactual one under a random-matching scenario; vice versa.

Empirical results

Increase in teamwork

We explored trends in collaborative research using various descriptive techniques.

Figure 1 illustrates the trend of authorship structure during the study period (1981–2010). Within-school collaboration is a dominant authorship structure throughout the whole period, although its share has decreased from 77 % in 1981 to 63 % in 2010. Solo papers also decreased steadily, halving from 13 to 6 %. Only one authorship structure, between-school collaboration, increased its portion from 10 to 31 %. In the earliest years of the study period, from 1981 to 1985 except 1983, solo papers outnumbered between-school collaborations; after 1985, however, solo constitutes the smallest among the three authorship structures.

Figure 2 shows that the incidence of multi-university publications generally grew regardless of team size. After disaggregating multi-authored papers by the number of

[7] Note that repeating for 1999 iterations leads to simple calculations of confidence intervals for common significance levels, e.g. 95 % (Carpenter and Bithell 2000).

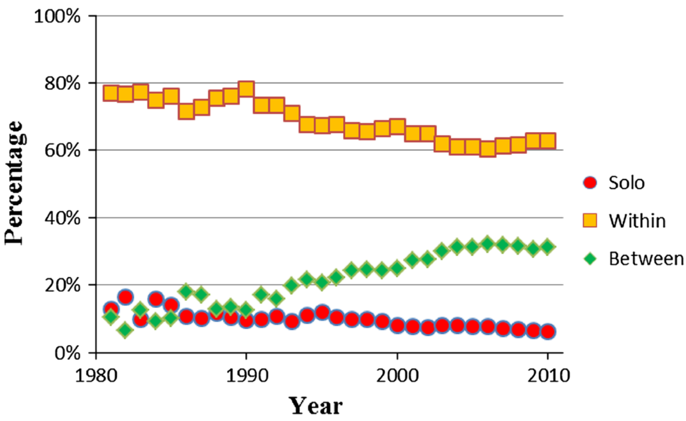

Fig. 1 Trend in share of authorship structures

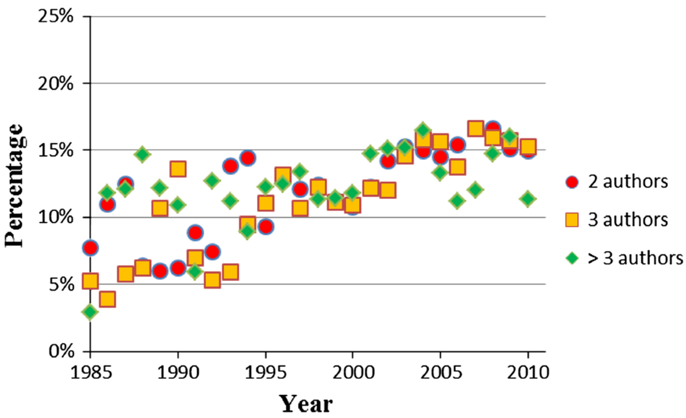

Fig. 2 Trend in fraction of multi-university cooperation by number of authors

authors, we calculated the fraction of multi-university collaborations for each team size. Multi-university collaboration increased not only in the larger-group research outputs (more than three authors) but also in papers written by small groups (two or three authors).

To examine the rising patterns of collaborative research further, we compared the average fraction of collaboration articles in the first 5 years studied (1981–1985) with that of the last 5 years studied (2006–2010) for each subject field in science, technology, and engineering (Table 1). The rise in within-school teamwork is a phenomenon seen in more than half of the subjects, yielding a 57.9 % share (99 out of 171). In addition, 95.9 % of the subject fields of science, technology, and engineering demonstrate an increasing share of collaborative research between universities when the first 5 years of our study are compared with the last 5 years (164 out of 171).

Before ranking the universities and defining the school tiers for further investigation, we examined the number of schools participating in each collaboration. Figure 3 presents the share of the number of universities in collaboration during the study period. With the exception of two-university projects, collaboration across multiple universities increased over time. Although their share has decreased, two-university collaborations represent the

Table 1 Increasing collaboration by subject fields (WCs)

Total subfields	Subfields in which collaboration has risen			
	Within-school collaboration		Between-school collaboration	
171	99	(57.9 %)	164	(95.9 %)

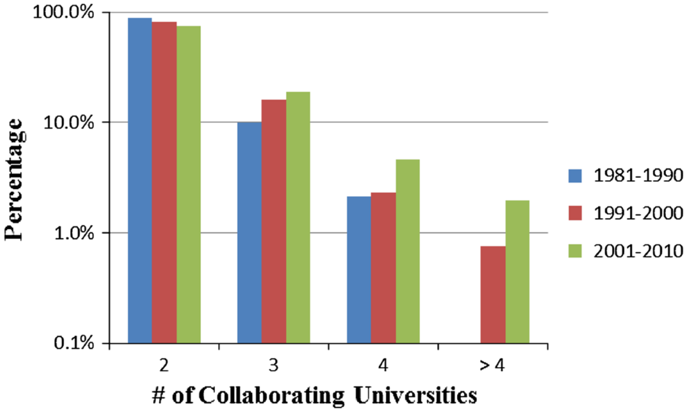

Fig. 3 Percentage of the number of universities participating in collaborative research

most significant portion of scientific research paper production. This dominant portion validates the assumption that two-university collaboration is an acceptable measure of the characteristics of multi-university collaborative scientific research.

Impact advantage of collaboration

We calculated the probability that an article gains more citations than the average in the same year and within the same subject field during the period between 2001 and 2009. The citation information in 2010 was not used because it lacks integrity. We compared the probability across authorship structures with respect to school tiers. Regardless of authorship structure, the higher tier had a stronger likelihood of high impact. Collaborative papers within all four tiers also had a higher impact than single-author articles. These results are depicted in Fig. 4.

The reason for higher citation rates of collaborative papers has been a matter of interest in literature. Wray (2002) and Beaver (2004) noted the epistemic merits, Katz and Martin (1997) posited that the visibility of a paper causes the more citations earned. These factors may contribute to higher quality of the publication and lead to higher citation counts.

To investigate the impact of between-school collaboration in depth, we categorized collaboration between universities into two additional collaboration types: between with higher tiers and between with lower tiers. Higher tiers refers to tiers I and II, and lower tiers indicates tiers III and IV. The results are depicted in Fig. 4. Among between-school collaborations, collaborative research with higher-tier schools shows higher probability than collaboration with lower-tier universities, and this phenomenon spans all tiers. Collaborative work within a tier I school has a probability of 0.37, while collaboration between a tier I university and a lower-tier institution records 0.33. This signifies that a tier I school's within-school collaborative research is more likely to be high-impact than its

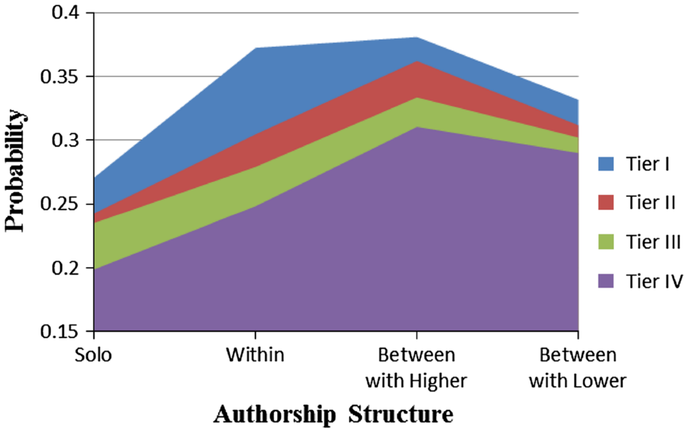

Fig. 4 Probability that a scientific article belongs to the high-impact papers (2001–2009). *Note* solo and within represents sole-authored papers and papers resulting from collaboration within a school, respectively. Between with higher (or lower) indicates between-school collaboration with a partner university from tiers I and II (or tiers III and IV)

between-school collaboration with a lower-tier counterpart. In tiers II, III, and IV, the authorship structures of between-school collaboration with both higher and lower tiers exhibit higher probabilities of high impact than other authorship structures, such as solo authorship and within-school collaboration.[8]

To calculate the marginal advantage in citation impact of collaboration between schools over collaboration inside a single university, we ruled out influence of subject field (WC), team size, and publication year using regression models.[9] Figure 5 decomposes the marginal advantage of multi-university alliances by tier, in which each bar indicates a separate panel for each tier. In the 2001–2009 period, collaborative research between two Korean universities was 0.98 % less likely to be of high-impact than within-school teamwork.[10] For tier I specifically, the marginal advantage of between-school partnership is −3.41 %, meaning that between-school teamwork in tier I is likely to have a lower scientific impact than collaboration within a single university. On the other hand, universities not belonging to tier I have positive values for the marginal advantage of between-school partnerships (2.11, 3.02, and 4.42 % for tiers II, III, and IV, respectively). Thus, for universities in tiers II, III, and IV, collaboration between schools is more likely to receive more citations than within-school teamwork. Additionally, the marginal advantage increases as school rank

[8] The probabilities of high impact for between-school collaboration with lower tiers are 0.31, 0.30, and 0.29 at tiers II, III, and IV, respectively. These values are greater than numbers for within-school collaboration (0.30, 0.28, and 0.25, respectively).

[9] These factors potentially influencing citation counts are stressed by prior research. Waltman et al. (2011) control for the effects of research fields and year in calculating indicators of citation impact. The number of authors is also regarded as a positive predictor for highly cited papers (Adams et al. 2005; Franceschet and Costantini 2010). Therefore, citation-based studies are likely to consider all these differences for obtaining specific influences.

[10] This finding is contrary to that of investigation by Jones et al. (2008) that US universities gain stronger marginal impact from between-school collaboration than they acquire from inside-school teamwork. This difference inspired us to investigate the reasons behind Korean university schools' collaborative research.

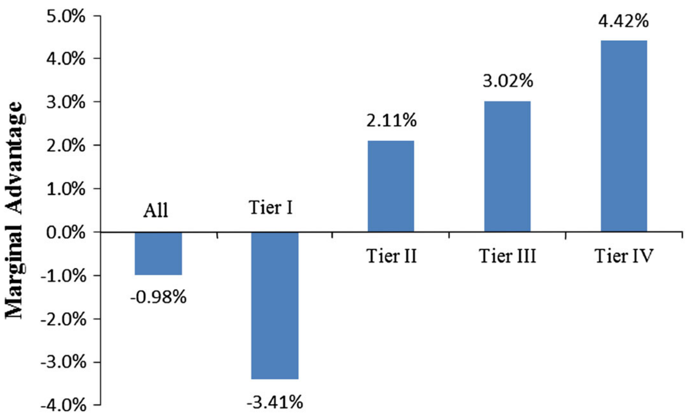

Fig. 5 Marginal advantage of between-school collaboration compared to within-school teamwork (2001–2009). *Note* each *bar* represents a separate panel for a given tier

Table 2 Marginal advantage of alliances between universities by school tier (2001–2010)

Tier of school	Tier of partner			
	Tier I	Tier II	Tier III	Tier IV
Tier I	0.86 %	−2.35 %***	−4.92 %***	−5.98 %***
Tier II	4.50 %***	0.80 %	0.34 %	−3.68 %***
Tier III	4.44 %***	3.55 %***	0.43 %	0.49 %
Tier IV	7.29 %***	3.10 %**	4.33 %***	0.39 %

Notes Significance levels ***$p < 0.01$; **$p < 0.05$

Each value indicates a separate regression result. Schools in the row-tier receive a marginal advantage of between-school collaboration over within-school collaboration when they select a partner from the column tier

decreases; the lower-tier schools gained the more impact from between-school collaborative research.

We further disaggregated the marginal advantage of between-school collaboration over within-school teamwork by the tier of the counterpart institution. In Table 2, each row (hereafter, row-tier) indicates a separate panel for a given tier, and each column (hereafter, column-tier) represents a partner of the row-tier. Numbers in this table provide the degree of marginal advantage over within-school collaborations where universities in the row-tiers benefit from collaborations with schools in the column-tiers. In the case of tier I schools, cooperation with schools from other tiers has a statistically significant marginal disadvantage in citation impact over within-school team research. This signifies that tier I schools' collaboration with other tiers leads to a loss in the impact of the scientific knowledge created. Schools in tiers II, III, and IV show positive advantages of collaboration over within-school teamwork for cooperation with a tier I school. Schools in tiers III and IV also show positive marginal advantages of cooperation with another school in tier II. Tier IV universities obtained a positive impact advantage from collaborative research with tier III universities. All the aforementioned marginal advantages and disadvantages are statistically significant at least at a 5 % level.

Partner selection in scientific alliance

As mentioned above, we calculated the propensity ratio for tier combinations by dividing the actual frequency of papers by the expected frequency. The expected fractions were obtained using non-parametric resampling. The results are listed in Table 3. The left panels of this table display the actual shares of papers in all tier pairings over three sub-periods. Schools in tier I, which encompasses the top 4 % of Korean universities, collaborated on almost 60 % of the multi-university publications during the entire research period: 59.6 % from 1981 to 1990, 62.0 % from 1991 to 2000, and 62.3 % from 2001 to 2010. The proportion of tier I schools did not change over time, but the proportion of publications co-authored by a tier IV institution (column sum, actual frequency) diminished rapidly: 62.9 % from 1981 to 1990, 43.3 % from 1991 to 2000, and 30.1 % from 2001 to 2010. This signifies that the-lowest-ranking universities have been alienated from cooperative research between schools.

The right panels of Table 3 exhibit the propensity ratios for tier combinations. As stated previously, a ratio of greater (or less) than unity indicates that the actual fraction of a given tier match is greater (or less) than the corresponding expected value. Intra-tier collaboration (main diagonal, propensity ratio) was less common than expected in every period and every tier (the only exception is tier I during 2001–2010), indicating Korean universities' disinclination to collaborate with schools in the same tier. For example, the actual

Table 3 Fraction of papers in tier combinations and propensity ratio for tier pairings

	Actual frequency				Propensity ratio			
	Tier I (%)	Tier II (%)	Tier III (%)	Tier IV (%)	Tier I	Tier II	Tier III	Tier IV
(1981–1990)								
Tier I	8.7	7.1	13.1	30.7	0.83	0.66	1.21	1.40
Tier II		1.6	5.6	16.9		0.54	0.98	1.47
Tier III			1.1	11.3			0.39	0.99
Tier IV				4.0				0.34
(1991–2000)								
Tier I	9.9	12.5	19.4	20.2	0.83	0.92	1.30	1.21
Tier II		3.5	8.6	10.6		0.91	1.01	1.12
Tier III			2.8	8.1			0.60	0.77
Tier IV				4.4				0.76
(2001–2010)								
Tier I	12.8	18.2	18.4	12.9	1.03	1.09	1.09	1.07
Tier II		4.5	11.6	7.5		0.79	1.03	0.93
Tier III			4.4	7.6			0.77	0.93
Tier IV				2.1				0.72

Note Actual frequency is the proportion of papers published by collaboration between two schools; the one school belongs to the row tier, the other belongs to the column tier

Propensity ratio is the ratio of the actual frequency of a given tier combination to the expected frequency; a value greater (or less) than unity indicates greater (or less) propensity than the corresponding expected value share was 66 % less than expected in tier IV-tier IV partnerships during 1981–1990. However, this tendency appears to have weakened over time, yielding propensity ratios of intra-tier collaboration greater than 0.7 in all tier matches during 2001–2010. This propensity for inter-tier collaboration can be seen as a distinctive feature of Korean universities' knowledge production, and is highly strategically interpreted, especially with regards to alliance selection.

Motive of cross-tier scientific collaboration

When scientists choose a partner for collaborative research, they consider many factors, such as scientific ability, national differences, institutional characteristics, geographical proximity, and language. Frenken (2002) divided collaboration rationales into economic and intellectual benefits, and described the latter as follows: "Collaboration is intellectually required when specialized knowledge and skills are distributed among different persons." It is obvious that scientific abilities such as research specialty or epistemic significance are major considerations in scientific partner selection. Meanwhile, Gazni et al. (2012) noted that scientifically developed countries are more likely to collaborate with other countries, but added that other elements, such as culture and politics, can also affect collaborative behavior.

At the national level, co-authored publications across various economic sectors have been used to indicate the Triple Helix (university, industry, and government) model for studying knowledge-based economies (Leydesdorff and Sun 2009). On the other hand, Hoekman et al. (2010) showed that physical distance is a barrier to collaboration, and that territorial borders affect the level of co-publication. Katz (1994) also found that research collaboration decreases exponentially as physical distance increases.

At the same time, linguistic, historical, and cultural factors were found to affect the degree of international co-authorship (Narin et al. 1991). In spite of various other factors affecting partner selection, we were able to focus our analysis on the universities' epistemic power. Since our analyses are restricted to a single institutional sector (university) in one small country using a single language, the only differentiating factor between institutions is scientific specialty. The desire for a successful research result, therefore, can be regarded as the strongest factor inducing Korean university scientists to collaborate. Consequently, Korean universities' preference for cross-tier cooperation over intra-tier teamwork can be explained by considering both the propensity ratio and the marginal citation impact advantage.

Figure 6 depicts the marginal advantage of inter-tier collaborations, which links citation impact to partner selection. Statistically significant figures from Table 2, which lists marginal advantages of inter-tier collaborations, were used for this purpose. In inter-tier university alliances, all lower-tier schools enjoyed significant advantages in citation impact; higher-tier schools, however, clearly seemed not to experience delight.

Taking both the marginal advantages and the propensity ratios into consideration, lower-tier schools appear to exploit strategic partner selection in order to benefit from scientific alliances. This may suggest that the willingness of lower-tier schools to produce better scientific outputs is stronger than higher-tier schools' reluctance to work with lower-tier counterparts. Especially for universities in Korea, scientific success is not only the key factor for increasing collaborative research but also the main reason for the higher propensity for inter-tier cooperation.

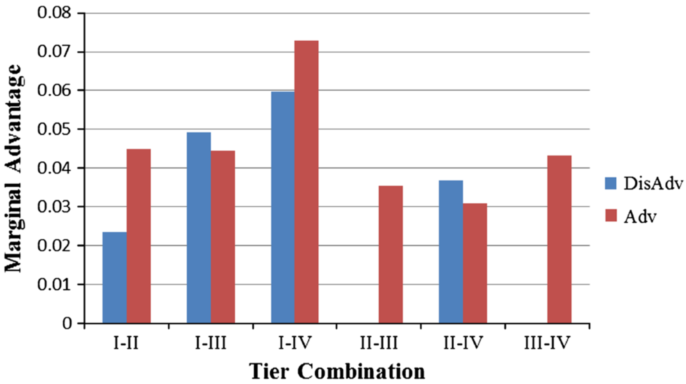

Fig. 6 Marginal impact advantages for cross-tier scientific alliances. *Note* Adv (or DisAdv) represents the positive (or negative) value of the marginal advantage. Statistically insignificant values are excluded. *Left bars* represent marginal disadvantages of cooperation if a higher-tier school works with a lower-tier school. Similarly, *right bars* represent marginal advantages of collaboration if a lower-tier school forms an alliance with a higher-tier school

Conclusion

This study examined the characteristics of knowledge production investigating scientific journal articles published by Korean universities from 1981 to 2010. Above all, scientific collaboration between universities is described as the cross-tier cooperative tendency that schools prefer a different level of publication ranking over the same level for partners in collaborative research. Although the reasons for inter-tier partner selection might vary, scientific motive seems to be the key factor driving Korean universities to cooperate with others.

Papers from between-school cooperative research grew in terms of volume during the study period, whereas publications from other authorship structures (solo and within-school collaboration) did not. Regardless of the number of authors (team size), multi-university research outcomes rose. The increase in multi-university collaboration spanned almost every scientific discipline. Although two-school alliances continue to form the majority of collaborations between universities, the number of participating schools also grew.

In terms of citation counts received, collaborative papers performed better than single-author papers. Additionally, cooperation with a higher-tier school yielded a higher citation impact than collaboration within a single university. Tier I universities, ranking in the top 4 % of universities by publication citation and being involved in 60 % of multi-university articles, sacrificed their citation impact for the advantage in the marginal impact of schools from other tiers (tiers II, III, or IV).

The propensity ratios of tier combinations revealed that Korean scientists prefer inter-tier to intra-tier collaboration. This tendency could be the result of strategic partner selection by lower-tier universities, with the ultimate end goal of achieving scientific success by generating higher-impact knowledge.

As mentioned, our viewpoint is restricted to only universities to determine patterns of and reasons for collaborative research. However, the domain of partner selection for scientific alliances can be extended to domestic industries and governments. In addition, international collaborative research can be studied. Although broadening the scope of this research may be complicated, it will undoubtedly lead to a deeper understanding of scientific collaboration strategies. Another limitation of this study is that we did not investigate disadvantages or costs of collaborative research. We believe that additional consideration of benefits and costs in future research will further enhance collective understanding of the scientific knowledge production process.

Acknowledgments This research was jointly supported by: Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2012R1A1A1013071); the BK21 PLUS through the National Research Foundation of Korea (NRF) funded by the Ministry of Education; ICT R&D Program 2013 funded by the Ministry of Science, ICT & Future Planning; and MOT Graduate School Program through the Korea Institute for the Advancement of Technology (KIAT) funded by the Ministry of Trade, Industry & Energy.

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