

# Rapid growth of international collaboration from articles indexed in Scopus database by researchers in Korea from 2006 to 2015

Yeonok Chung<sup>1</sup>, Kihong Kim<sup>2</sup>

<sup>1</sup>Department of Social Welfare, Jangan University, Hwaseong; <sup>2</sup>Department of Physics, Ajou University, Suwon, Korea

### Abstract

It aimed at analyzing the trends of international collaboration from articles indexed in Scopus by researchers in Korea from 2006 to 2015. The number of articles coauthored by researchers in Korea and those in selected foreign countries was obtained from document searches of the Scopus database. The growth of research collaboration in various academic disciplines was also studied. There were 22 countries which produced over 2,000 papers in collaboration with researchers in Korea during the ten-year period between 2006 and 2015. The average of the average annual growth rate taken over these 22 countries was 12.9%. In 9 additional Asian, Latin American, and African countries, more rapid growth of international research collaboration was clearly seen. Though research collaboration is most active in the field of physics and astronomy with most countries, it was found that the growth of collaboration in medicine was most remarkable in Southeast Asian countries. It may be originated from the intimate relationship between Korea and Southeast Asia and the leadership of Korean physicians in that region.

### Keywords

Bibliometrics; Internationality; Internet; Republic of Korea; Research personnel

### Introduction

In recent years, there has been a rapid increase in international collaborations in research and development [1,2]. It may be originated from a variety of reasons, such as the movement of globalization, the development in communication, information, and transportation technologies, and the general increase of human interactions across the world. One crucial factor may be the development of the internet which made it possible to have very efficient and fast academic communication among researchers. The internet made not only international but also domestic collaboration much easier, which resulted in the substantial increase of the average number of authors per paper [3]. In this article, we aimed to study this phenomenon using the yearly num-

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**Correspondence to** Kihong Kim  
[khkim@ajou.ac.kr](mailto:khkim@ajou.ac.kr)

**ORCID**  
Yeonok Chung  
<http://orcid.org/0000-0003-0008-5772>  
Kihong Kim  
<http://orcid.org/0000-0001-9965-3535>

ber of research publications coauthored by researchers in Korea and those in 31 foreign countries, which were published from 2006 to 2015 and indexed in the Scopus database. We also searched for the factors causing the growth of international collaboration. The results will be able to show the trends of international collaboration by researchers in Korea.

## Methods

We used the Scopus database to find the number of publications jointly written by researchers in Korea and those in foreign countries. The Scopus database was searched in January 9, 2017. When using the document search function of the Scopus database, we restricted the search to three types of documents, which were “articles”, “reviews”, and “conference papers”, and to two affiliation countries, “Korea” and “each designated country”. The numbers of documents published each year from “2006” to “2015” and the total number of documents during the ten-year period were retrieved. For example, the query string, (AFFILCOUNTRY(Korea) AND AFFILCOUNTRY(Japan)) AND

DOCTYPE (ar OR re OR cp) AND PUBYEAR=2006, gives the number of articles, reviews, and conference papers jointly written by researchers in Korea and those in Japan in 2006. The Scopus database provides the search data which break down the number of documents by subject areas. We also retrieved these numbers to find out the changes in each subject area separately. The search was performed for bi-national collaborations between Korea and another country. Multi-national collaborations by researchers from more than two countries were not investigated.

Using the number of documents published each year, we calculated the annual growth rate (AGR) for the year ( $N+1$ ) defined by

$$\text{AGR} (N + 1) = \frac{\text{Number for year } (N + 1) - \text{Number for year } N}{\text{Number for year } N}$$

By taking the average of this quantity from 2007 to 2015, we also calculated the average annual growth rate (AAGR) for each country. In addition, we calculated the compounded annual growth rate (CAGR), which was defined in the present

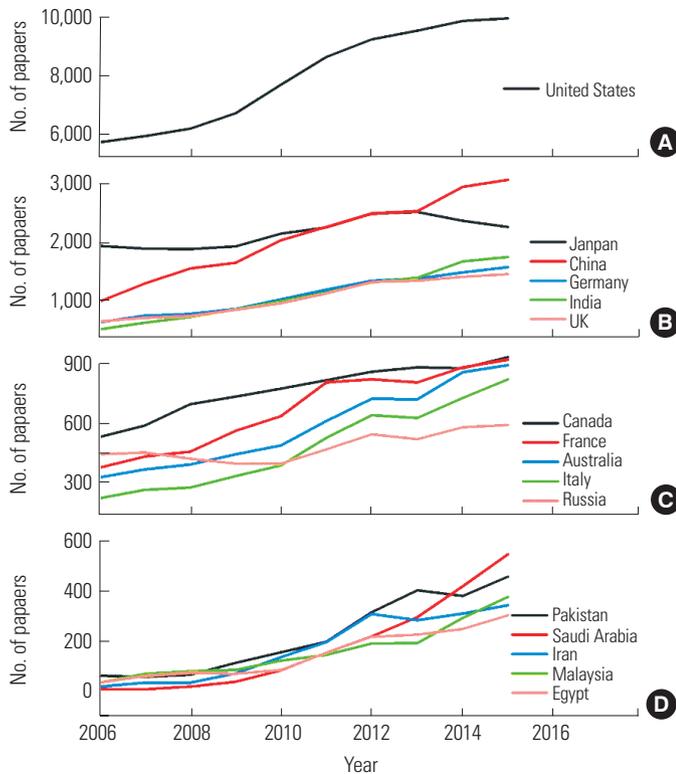
**Table 1.** The yearly number of documents coauthored by researchers in Korea and those in the country designated in the first column from 2006 to 2015

Country	No. of articles in each year											AGR (%)	CAGR (%)
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total		
United States	5,671	5,887	6,144	6,681	7,668	8,633	9,238	9,547	9,890	9,979	79,338	6.57	6.48
Japan	1,916	1,869	1,864	1,908	2,133	2,242	2,479	2,506	2,355	2,248	21,520	1.96	1.79
China	955	1,269	1,530	1,629	2,016	2,249	2,484	2,526	2,942	3,062	20,662	14.21	13.82
Germany	600	713	745	830	998	1,162	1,317	1,353	1,457	1,549	10,724	11.28	11.11
India	479	590	693	818	965	1,107	1,286	1,366	1,651	1,725	10,675	15.45	15.3
United Kingdom	615	670	703	807	924	1,095	1,292	1,313	1,386	1,431	10,236	10.01	9.84
Canada	540	600	710	750	790	833	878	899	896	953	7,849	6.63	6.52
France	382	440	465	573	647	822	839	823	900	939	6,830	10.88	10.51
Australia	332	374	398	452	497	622	738	735	876	912	5,936	12.14	11.88
Italy	224	267	280	339	394	536	652	639	742	837	4,910	16.22	15.77
Russian Federation	450	460	427	404	403	475	554	529	590	603	4,895	3.68	3.31
Taiwan	239	253	283	325	407	525	555	572	565	591	4,315	10.99	10.58
Switzerland	253	277	301	291	368	435	589	513	506	574	4,104	10.45	9.53
Spain	151	182	177	221	312	451	556	577	604	680	3,907	19.19	18.2
Netherlands	162	222	235	228	263	321	369	373	382	419	2,970	11.71	11.14
Singapore	122	101	155	193	279	329	371	408	467	515	2,940	18.97	17.35
Poland	165	192	158	180	209	242	315	312	341	347	2,460	9.42	8.61
Sweden	113	112	158	182	210	274	318	307	362	386	2,419	15.38	14.62
Viet Nam	108	87	136	149	191	234	266	357	365	436	2,329	18.52	16.77
Pakistan	59	53	63	111	154	196	315	405	382	461	2,199	28.35	25.66
Brazil	98	100	115	147	189	247	302	291	332	363	2,185	16.24	15.66
Belgium	110	144	112	158	204	222	272	264	321	352	2,157	15.39	13.8

AAGR, average annual growth rate; CAGR, compounded annual growth rate.

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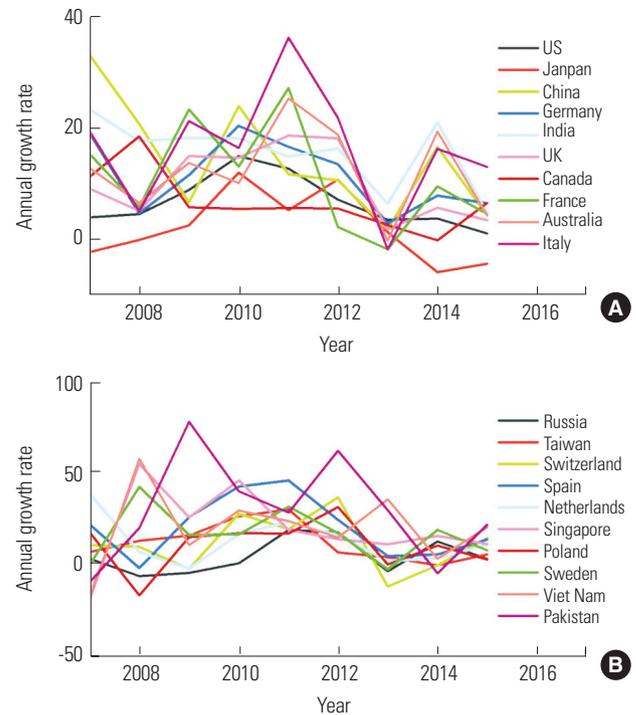
$$CAGR = \left( \frac{\text{Number in 2015}}{\text{Number in 2006}} \right)^{1/9} - 1.$$



**Fig. 1.** The number of papers coauthored by researchers in Korea and those in the country designated in the figure in each year from 2006 to 2015 plotted versus publication year. In (A), the United States and in (B), the countries which produced the 2nd to 6th largest number of papers are shown, while, in (C), those which produced the 7th to 11th largest number of papers are shown. In (D), the countries which had the top five average annual growth rate among all countries studied are shown.

## Results

Our main search results are summarized in Tables 1 and 2. In Table 1, we showed the yearly number of documents coauthored by researchers in Korea and those in the country designated in the first column from 2006 to 2015. We also showed the total number of documents during the ten-year period, the AAGR, and the CAGR. Twenty two countries



**Fig. 2.** Annual growth rate for (A) the top 10 and (B) the 11th to 20th countries which produced the largest number of documents in collaboration with Korea plotted versus year.

**Table 2.** The yearly number of documents coauthored by researchers in Korea and those in the country designated in the first column from 2006 to 2015

Country	No. of articles in each year										AAGR (%)	CAGR (%)	
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015			Total
Saudi Arabia	3	3	15	34	81	152	218	296	420	552	1,773	100.56	78.5
Iran	14	30	31	68	134	195	309	284	310	345	1,720	50.04	42.77
Thailand	53	59	94	108	122	150	171	247	307	342	1,653	23.95	23.02
Hong Kong	65	96	107	103	147	169	216	218	240	257	1,618	17.67	16.5
Malaysia	31	67	76	83	120	143	189	191	292	378	1,570	35.34	32.03
Mexico	89	89	146	146	183	243	266	218	238	267	1,887	14.99	12.98
Colombia	33	37	55	54	81	127	151	136	146	156	976	20.99	18.84
Egypt	30	58	72	66	82	152	216	225	248	304	1,452	33.09	29.35
South Africa	21	27	28	35	46	73	102	108	126	140	706	24.53	23.47

AAGR, average annual growth rate; CAGR, compounded annual growth rate.

which produced more than 2,000 documents in collaboration with Korea were United States, Japan, China, Germany, India, United Kingdom, Canada, France, Australia, Italy, Russian Federation, Taiwan, Switzerland, Spain, Netherlands, Singapore, Poland, Sweden, Viet Nam, Pakistan, Brazil, and Belgium in the decreasing order of the number of publications. Except for Japan, which showed a low AAGR of 1.96%, all countries showed a substantial growth in the number of pub-

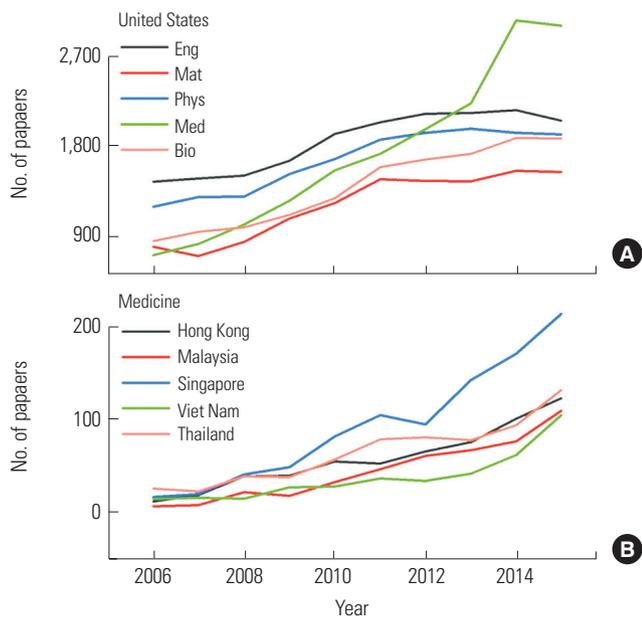
lications during the ten-year span. The average of the AAGR taken over the 22 countries listed was 12.9%. The CAGR is consistently a little smaller than the AAGR. The discrepancy between the AAGR and the CAGR is larger when the yearly fluctuation in the AGR is larger.

In Table 2, we showed the results obtained for 9 additional countries from Asia, North America, South America, and Africa, which include Saudi Arabia, Iran, Thailand, Hong Kong,

**Table 3.** Number of documents from 2006 to 2015 coauthored by researchers in Korea and those in the designated country in the top five fields

Country	1st field	2nd field	3rd field	4th field	5th field
United States	Eng (18,416)	Med (17,250)	Phys (16,490)	Bio (13,806)	Mat (11,986)
Japan	Phys (6,604)	Eng (4,370)	Mat (3,992)	Med (3,513)	Bio (3,387)
China	Phys (5,614)	Eng (4,720)	Mat (3,713)	Med (3,089)	Bio (2,912)
Germany	Phys (5,051)	Med (1,776)	Eng (1,683)	Mat (1,578)	Bio (1,333)
India	Phys (4,064)	Mat (2,815)	Chem (2,284)	Eng (2,201)	Chem Eng (1,306)
United Kingdom	Phys (3,806)	Med (2,063)	Eng (1,922)	Bio (1,369)	Mat (1,220)
Canada	Phys (1,918)	Med (1,740)	Eng (1,504)	Bio (1,218)	Comp (1,056)
France	Phys (3,327)	Eng (1,059)	Med (1,049)	Mat (815)	Bio (720)
Australia	Phys (1,478)	Med (1,434)	Eng (1,143)	Mat (834)	Bio (776)
Italy	Phys (2,443)	Med (1,160)	Bio (625)	Eng (618)	Earth (373)
Russian Federation	Phys (3,417)	Eng (667)	Mat (563)	Chem (317)	Earth (286)
Taiwan	Phys (1,967)	Med (1,025)	Eng (525)	Bio (414)	Comp (348)
Switzerland	Phys (2,330)	Med (712)	Eng (493)	Bio (401)	Mat (383)
Spain	Phys (2,027)	Med (773)	Eng (490)	Bio (462)	Earth (351)
Netherlands	Phys (1,303)	Med (748)	Bio (418)	Eng (332)	Earth (180)
Singapore	Med (937)	Eng (718)	Bio (581)	Comp (478)	Mat (411)
Poland	Phys (1,578)	Med (332)	Eng (236)	Bio (205)	Earth (187)
Sweden	Phys (1,108)	Med (544)	Bio (410)	Eng (282)	Chem (208)
Viet Nam	Eng (671)	Phys (535)	Mat (474)	Chem (420)	Med (381)
Pakistan	Phys (864)	Eng (367)	Comp (278)	Agri (264)	Math (256)
Brazil	Phys (1,394)	Med (426)	Eng (193)	Bio (176)	Earth (108)
Belgium	Phys (1,072)	Med (471)	Eng (321)	Bio (253)	Mat (192)
Saudi Arabia	Chem (451)	Mat (441)	Phys (426)	Eng (387)	Chem Eng (285)
Iran	Phys (713)	Math (354)	Eng (353)	Mat (250)	Med (176)
Thailand	Med (647)	Phys (366)	Bio (228)	Eng (213)	Agri (193)
Hong Kong	Med (586)	Eng (266)	Comp (236)	Bio (210)	Phys (189)
Malaysia	Med (450)	Eng (382)	Phys (337)	Comp (221)	Bio (184)
Mexico	Phys (1,333)	Med (237)	Eng (184)	Earth (131)	Mat (110)
Colombia	Phys (751)	Med (137)	Eng (68)	Math (59)	Bio (54)
Egypt	Phys (614)	Chem (289)	Eng (288)	Mat (252)	Med (179)
South Africa	Phys (287)	Med (176)	Eng (108)	Earth (106)	Bio (76)

Eng, engineering; Med, medicine; Phys, physics and astronomy; Bio, biochemistry, genetics and molecular biology; Mat, materials science; Chem, chemistry; Chem Eng, chemical engineering; Comp, computer science; Earth, earth and planetary sciences; Agri, agricultural and biological sciences; Math, mathematics.



**Fig. 3.** (A) The number of papers coauthored by researchers in Korea and those in the United States in each year from 2006 to 2015 in the top five academic fields which produced the largest number of papers plotted versus publication year. (B) The number of papers coauthored by researchers in Korea and those in the countries designated in the figure in each year from 2006 to 2015 in the field of medicine plotted versus publication year. Eng, engineering; Mat, materials science; Phys, physics and astronomy; Med, medicine; Bio, biochemistry, genetics and molecular biology.

Malaysia, Mexico, Colombia, Egypt, and South Africa. These countries produced the largest number of publications in collaboration with Korea in each continent, except for those already shown in Table 1. Their growth rates were, on the average, substantially larger than those listed in Table 1.

In Fig. 1, we showed the number of papers coauthored by researchers in Korea and those in some selected countries in each year from 2006 to 2015 versus publication year. In Fig. 1A, 1B, and 1C, the top 11 countries which produced the largest number of papers are shown, while, in Fig. 1D, the countries which showed the top five AAGRs are shown. Except for Japan and Russian Federation, the trend of rapid growth was clearly seen.

In Fig. 2, the AGR for the top 20 countries which produced the largest number of papers in collaboration with Korea is plotted versus year. We remind the reader that, for example, the AGR for 2007 is computed from the number of papers published in 2006 and that in 2007. The yearly fluctuation of the growth rate is observed to be rather large and sometimes the growth rate is negative. From the 20 curves shown in this figure, we notice that the growth rates for many countries dropped rather rapidly between 2012 and 2013 and also between 2007 and 2008. Similar behavior is observed for other

countries not shown in this figure.

We also examined the dependence of the growth of international collaboration on academic disciplines. In Table 3, the total number of documents from 2006 to 2015 coauthored by researchers in Korea and those in the country designated in the first column in the top five academic fields which produced the largest number of documents in each country. In many countries, physics and astronomy, medicine, engineering, materials science, and biochemistry, genetics and molecular biology are the dominant fields with the largest number of documents. Physics and astronomy is the most dominant field with the largest number of documents in 24 countries out of the total 31 countries. In five countries which include Colombia, Mexico, Russian Federation, Poland, and Brazil, the portion of the documents in physics and astronomy was more than 60%. Medicine is the second largest field with the largest number in 4 countries and the second largest number in 17 countries.

In Fig. 3A, we plotted the number of papers coauthored by researchers in Korea and those in the United States in each year from 2006 to 2015 in the top five academic fields which produced the largest number of papers versus publication year. We found that there was considerable growth in all five fields, with the growth in medicine being particularly rapid. In Fig. 3B, we showed the number of papers coauthored by researchers in Korea and those in the five Southeast Asian countries designated in the figure in each year from 2006 to 2015 in the field of medicine versus publication year. The rapid growth in all five countries is remarkable.

## Discussion

These results show that the rapid increase of international collaborations between Korean researchers and foreign researchers is a general trend, which applies to a very large number of countries in the world. That the United States is the top ranking collaborative country is not surprising because it has been the most favorite country for Korean students and young researchers to visit to study abroad and the number of visits has been outstanding. Out of the top five collaborative countries, India and China showed the 1st and 2nd largest growth rates. This is perhaps related to the large influx of graduate students and postdoctoral researchers from these countries into Korean universities and research institutes in the recent decade. The same reasoning may be applied to Pakistan, which showed the largest AAGR in Table 1. The extremely rapid growth rate for Saudi Arabia listed in Table 2 is especially remarkable. This seems to be due to the government policy drive to enhance research collaborations between the two countries.

In Table 3, we examined the dependence of the growth of

international collaboration on academic disciplines. The case of Colombia, where physics and astronomy documents take up 77% of the total, is particularly interesting. We found that there were 10 countries other than Korea and Colombia, each of which was affiliated with more than 70% of the total 976 documents produced by collaborations between Korea and Colombia. This implies that a great majority of documents were produced through international collaborations among many countries. We suspect that a very large number of documents are in the area of experimental high energy physics, in which multinational collaborations are quite common. On the other hand, it is quite interesting to notice that the four countries with the largest number of documents in medicine are all Southeast Asian countries, namely, Singapore, Thailand, Hong Kong, and Malaysia. Saudi Arabia is unique in that the field with the largest number of documents is chemistry, in contrast to all other countries. This supports our suspicion that the collaboration between Korea and Saudi Arabia has been driven by external policies to enhance research collaborations mainly in the fields related to petrochemical industry.

In Fig. 2, we mentioned that the growth rates for many countries dropped between 2012 and 2013 and between 2007 and 2008. We think this may be due to the global economic recession which occurred during the same period and a corresponding decrease in research funding in many countries.

In conclusion, the rapid growth of international research

collaboration was clearly seen in almost all cases studied here. The overall increase might be attributed to the movement of globalization, the development in communication and transportation technologies, and the development of the internet. Though research collaboration was most active in the field of physics and astronomy in most countries, it was found that, in many countries in Southeast Asia, the growth of collaboration in medicine was most remarkable. It may be originated from the intimate relationship between Korea and Southeast Asia and the leadership of Korean physicians in that region.

### Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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