

# Mapping international collaboration in science in Asia through coauthorship analysis\*

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Using data from *SCI* 1998, we have analysed international collaboration in science in 11 Asian countries. Papers resulting from collaboration among these countries and with G7, European Union, OECD and selected Latin American and African countries were classified under subject categories to characterize each country's total and collaborated scientific literature output. Japan (16.4% of internationally collaborated papers), India (17.6%) and Taiwan (16.3%) recorded an internationalization index less than 30 whereas China (28.5%), South Korea (24.6%) and Hong Kong (36.2%) recorded an internationalization index greater than 40. India, China and South Korea have collaborated more in physics, whereas the other eight countries have collaborated more in life sciences. In almost all fields and for virtually all Asian countries, USA is the most preferred collaborating partner. All G7 countries collaborate more with China, which is emerging as a leader in regional collaboration, than with India.

## Introduction

SCIENCE is becoming increasingly global as reflected by the rapid growth in international collaboration<sup>1-3</sup>. The past decade witnessed a vigorous increase in international collaboration, as indicated by internationally coauthored scientific and technical articles. From 1986-88 to 1995-97, the total number of articles in the ISI databases increased by 12%; multi-institutionally coauthored papers by 46% (from an annual average of 177,100 to 258,500); and internationally coauthored articles increased by almost 115% (from 35,700 to 76,200)<sup>4</sup>. In 1997, half of the papers in a set of about 5000 journals indexed in *Science Citation Index* since 1985 had authors from more than one institution and 30% of these coauthored articles involved international collaboration, compared to 23% a decade earlier<sup>4</sup>. The growing international nature of science is further underscored by the increase in the share of cross-national citations; in 1997, about 59% of all citations were to non-domestic papers, as against 53% in the early nineties<sup>4</sup>. Traditionally, most of these international

collaborations have been taking place in the advanced (G7, EU and OECD) countries, many of which also publish large numbers of research papers<sup>5,6</sup>. But in recent years, Asian countries are fast increasing their share of worldwide international collaboration in science. It is this that we have attempted to map in this paper.

This paper is an extension of an earlier paper by Arunachalam where he has used international coauthorship data taken from *SCI* 1998 to map international collaboration involving India, China, Japan and Israel<sup>7</sup>. A few years ago Arunachalam *et al.*<sup>8</sup> had mapped international collaboration involving India, China and Japan using data from *SCI* 1991. Using similar methodology, Arunachalam and Jinandra Doss<sup>9</sup> have mapped international collaboration in new biology research in Israel using data from three years of *Biochemistry and Biophysics Citation Index* (1992, 1995 and 1998).

## Methodology

We downloaded, in comma delimited form, all papers indexed in the CD-ROM version of *SCI* 1998 with an address in anyone of the following countries: India (IN), China (CN), Japan (JP), South Korea (KR), Taiwan (TW), Hong Kong (HK), Singapore (SG), Thailand (TH), Malaysia (MY), Indonesia (ID) and Philippines (PH). Only (full-length research) articles, reviews and notes, were taken into account, as these tend to report substantive research results. We used a custom format covering the following fields: Name(s) of author(s), author address(es), source (journal title, volume, year, and page), document type, ISSN, and language. For each journal title, we added the impact factor value from *Journal Citation Reports* 1997 (CD-ROM edition), and the standard subject category from information obtained from the Research Group of the Institute for Scientific Information. ISI has categorized all journals into about 25 standard subject categories and more than 100 deluxe categories. We have classified journals (and papers published in them) into the standard subject categories and also grouped them into seven larger groups. We used FoxPro and Visual Basic for analysing the data.

We identified papers having more than one country in the address field and calculated for each country its inter-

\*Dedicated to Dr Eugene Garfield, scientometricist *par excellence*, on his 75th birthday.

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nationalization index, based on the number of international linkages, as suggested by Davidson Frame and Carpenter<sup>10</sup>:

$$\text{Internationalization Index} = 100 \times \frac{\text{number of international links}}{\text{total number of papers from the country}}$$

We calculated the (international) cooperation index and affinity index from papers resulting from collaboration between each one of the 11 countries with many selected countries, following the procedure described earlier<sup>7</sup>. We have also classified internationally coauthored papers into major subject categories, based on journal titles, and calculated average expected impact factors for each subject category as well as for the entire collaborated output.

## Results and discussion

In Table 1 we give the total number of papers from these 11 countries, the number of papers resulting from international collaboration, the total number of international linkages and the number of papers involving different number of collaborating countries. Japan, with over 60,000 papers, is second only to the USA in the number of papers published. China (11th), India (14th) and South Korea (15th) are the only three other Asian countries to figure in the top 15 producers of scientific papers. Whereas about 17% of papers from India, Japan and Taiwan have resulted from international collaboration, close to one-fourth of Korean papers, over 28% of Chinese papers and over 30% of papers of Singapore have resulted from international collaboration. Countries with very small publication output, such as Philippines (67%) and Indonesia

(88%) have recorded a very high percentage of internationalization.

For all countries, international collaboration involving one other country accounts for bulk of the collaboration. That is followed by collaboration involving three countries. Multinational collaboration involving more than three countries is relatively rare, except in the case of Japan. Following Miquel<sup>11</sup>, we have made a distinction between the number of collaborative papers and total number of collaborative links. More the number of countries in the byline of papers from a country, the greater will be the number of links<sup>7</sup>.

Table 2 lists the number of papers in which the eleven Asian countries have collaborated with about 50 countries, including the G7 countries, the European Union countries, OECD countries, the newly emerging economies of Asia, the Tigers, Israel and selected African and Latin American countries. In some of these papers there may be collaborators from more than the two countries listed. Except for Malaysia, for every country considered, the United States is the preferred partner for collaborative research. Worldwide, 44% of all internationally coauthored papers published in 1995–97 had at least one US coauthor<sup>4</sup>. With a few exceptions, from 25 to 33% of European countries' internationally coauthored papers involved collaboration with the United States. For major science-producing Asian nations, coauthorship with US researchers ranked higher. Japan and India – both nations with relatively low overall rates of international collaboration – shared 46 and 40%, respectively of their internationally coauthored articles with United States researchers. For other Asian nations, collaboration rates with the United States ranged from 70% for Taiwan to 31% for Singapore [ref. 4, pp. 6–49].

**Table 1.** Distribution of papers from 11 Asian countries by number of nations in the byline

No. of nations in the byline	IN	CN	JP	KR	TW	HK	SG	TH	MY	ID	PH
1	9422	9923	50714	6211	5950	2046	1316	314	294	32	88
2	1601	3349	8075	1626	931	971	489	319	202	167	122
3	258	417	1337	223	133	161	69	84	31	49	34
4	57	59	312	56	32	19	9	12	5	8	7
5	14	28	82	8	9	3	5	5	2	3	5
6	3	14	39	11	6	2	1	3	1	3	6
7	3	9	53	1	24	1	2	–	1	2	1
8	7	3	25	4	3	2	–	4	1	1	1
9	9	3	43	5	1	1	–	1	–	–	1
10	17	3	8	16	–	–	–	–	–	–	–
11	6	7	7	2	–	2	–	1	–	–	–
12	3	29	17	41	1	2	–	–	1	–	–
≥ 13	37	34	9	30	23	–	1	1	–	1	1
Total no. of papers	11437	13878	60721	8234	7113	3210	1892	774	538	266	266
Total no. of collaborative papers	2015	3955	10007	2023	1163	1164	576	460	224	234	178
Total no. of links	3300	5569	13497	3475	1908	1442	706	649	316	347	297
Internationalization index	28.85	40.13	22.23	42.20	26.82	44.92	37.32	83.85	58.74	130.45	111.65

In general, the 11 Asian countries collaborate often with G7 countries and to some extent with Australia. China has collaborated with Australia in 171 papers, with the Netherlands in 107 papers, with Spain in 98 papers and with Sweden in 81 papers. India has collaborated with Australia in 80 papers, with Switzerland in 76 papers, with Spain in 73 papers and with the Netherlands in 59 papers. Indonesia has collaborated with Australia in 40

papers and with the Netherlands in 26 papers, and Singapore has collaborated with Australia in 63 papers. South Korea has collaborated with Spain in 80 papers, with Switzerland in 69 papers and with Poland in 46 papers. The Asian countries hardly collaborate with countries in Latin America and Africa.

Table 3 lists the cooperation index and affinity index for collaboration between the Asian countries on the one

**Table 2.** Number of papers coauthored by authors from Asian countries with authors from different countries. (Data from *SCI* 1998)

Collaborating countries		IN	CN	JP	KR	TW	HK	SG	TH	MY	ID	PH
A	Canada (26094)	88	195	555	92	67	83	24	13	8	17	11
	Japan (60721)	195	627		416	155	38	43	89	25	39	42
	USA (199980)	809	1216	4494	1216	725	344	161	166	28	63	58
B	France (40594)	219	244	575	125	58	16	10	17	7	18	11
	Germany (54676)	300	485	1094	167	98	50	12	28	4	30	11
	Italy (26081)	132	184	405	109	54	12	4	6	8	4	0
	United Kingdom (57349)	232	368	980	117	76	123	81	79	69	16	16
C	Austria (5687)	9	67	90	34	5	2	1	9	1	1	0
	Belgium (8131)	32	50	113	11	10	6	12	5	3	5	6
	Denmark (6780)	21	59	115	37	7	6	4	13	3	0	4
	Finland (5676)	44	43	117	27	25	5	4	5	3	1	2
	Greece (3468)	5	41	32	30	0	0	1	0	0	0	0
	Ireland (1984)	2	9	24	3	1	0	3	0	1	1	0
	The Netherlands (15761)	59	107	292	55	37	14	4	15	5	26	9
	Portugal (1984)	8	19	16	0	3	1	0	1	0	1	0
	Spain (17521)	73	98	154	80	30	7	4	5	0	0	6
	Sweden (12658)	48	81	287	21	12	12	13	6	5	4	1
D	Australia (16467)	80	171	397	48	43	76	63	32	26	40	15
	Czech Republic (3222)	12	10	97	3	2	7	0	1	3	0	1
	Hungary (3134)	45	40	139	28	25	3	1	3	0	0	2
	Iceland (267)	0	0	9	0	1	0	0	0	0	0	0
	Mexico (3377)	39	17	46	22	1	3	0	5	1	2	4
	New Zealand (3493)	10	22	72	5	4	11	9	3	1	3	1
	Norway (3918)	12	19	71	4	2	1	5	5	1	3	1
	Poland (6705)	42	24	180	46	3	4	0	1	1	2	1
	Switzerland (11677)	76	97	293	69	52	12	5	18	0	5	2
	Turkey (3404)	6	3	29	4	1	0	0	0	1	0	0
E	Indonesia (266)	3	9	39	3	3	2	0	10	5		5
	Malaysia (538)	27	15	25	4	2	8	22	13		5	2
	Philippines (266)	4	17	42	8	7	4	4	6	2	5	
	Thailand (774)	8	5	89	7	5	7	3		13	10	6
F	Singapore (1892)	10	105	43	3	27	30		3	22	0	4
G	Hong Kong (3210)	17	415	38	0	45		30	7	8	2	4
	South Korea (8234)	68	142	416		52	0	3	7	4	3	8
	Taiwan (7113)	38	101	155	52		45	27	5	2	3	7
H	Bangladesh (201)	16	1	20	0	0	0	0	0	1	2	1
	China (13878)	71		627	142	101	415	105	5	15	9	17
	India (11437)		71	195	68	38	17	10	8	27	3	4
	Pakistan (379)	2	2	12	2	1	3	2	2	0	1	1
	Sri Lanka (110)	2	0	4	0	0	1	0	2	0	1	2
I	Kenya (421)	6	3	12	0	0	0	0	1	0	2	1
	Nigeria (470)	5	3	1	1	0	0	0	0	0	1	0
	South Africa (2777)	15	5	39	2	2	6	4	1	1	1	0
J	Argentina (3229)	23	8	25	22	0	1	1	5	1	0	2
	Brazil (6597)	52	37	94	26	2	3	1	4	1	2	1
	Chile (1369)	7	9	9	4	1	3	1	3	0	1	4
	Cuba (350)	2	3	2	0	1	1	1	8	0	1	1
	Peru (155)	1	0	1	1	0	0	0	1	0	2	3
	Venezuela (702)	3	3	4	0	0	0	0	1	0	0	2
K	Israel (7523)	18	16	148	31	13	8	5	4	1	0	0

A + B = G7,

E + F + G + H = Asia,

B + C = EU,

I = Africa,

A + B + C + D = OECD,

J = Latin America,

E + F = ASEAN,

K = Israel.

F + G = Tigers,

hand and their major collaborating partner countries. China has a much higher cooperation index with G7 countries, South Korea, Taiwan, Hong Kong and Singapore than India. Japan has a higher cooperation index with other G7 countries than China. Malaysia, which has published only 538 papers, has a cooperation index of over 20 with both Singapore and Thailand, over 14 with the UK and over 10 with India. With the exception of Malaysia, all the countries have a high affinity towards the USA. Malaysia has a higher affinity to the UK.

Although, compared to collaboration among the countries of the European Union<sup>7</sup>, the level of intra-Asian research collaboration is rather low, it has increased considerably in recent years (Table 4). The main trend in Asia appears to be the development of regional collaborative patterns involving China and the newly industrialized economies. Overall, intraregional collaboration increased from 15% of all Asian foreign collaboration in the late 1980s to 24% a decade later<sup>4</sup>. For China, intraregional collaboration rose from 15.8 to 35% of its internationally coauthored papers; and for Singapore from 19.5% to 37%. However, regional collaboration remained relatively low for Japan and India, at about 15% of their internationally coauthored articles in 1995–97 (ref. 4, pp. 6–50).

An interesting observation is that virtually every country considered here collaborates with a larger number of countries now than a few years ago. In 1986–88, India had collaborated with 87 countries, and the number rose to 109 in 1995–97 (ref. 4). Corresponding figures for other Asian countries are given in Table 5 (ref. 4).

In Table 6 we provide data on the per cent of papers resulting from international collaboration and the average expected impact factor of internationally coauthored papers from the 11 countries in journals in seven major fields, viz. physics, chemistry, life sciences, mathematics, engineering, geosciences and multidisciplinary journals. For every country, the average expected impact factor of collaborated papers is higher than the average expected impact factor of all papers as well as the average impact factor of non-collaborated papers (Figure 1). Whereas India, China, and South Korea have collaborated more often in physics, the other eight countries have predominantly collaborated in life sciences. Indeed, life sciences account for more than half of the collaborated papers of Thailand, Malaysia, Indonesia and Philippines (Table 6). Incidentally, the United States collaborates largely in the area of clinical medicine, a part of life sciences. India and Korea have roughly the same number of internationally coauthored papers, but there is considerable difference in the distribution of collaborated papers by subject. Whereas India has collaborated with other countries more often than South Korea in physics, chemistry and geosciences, South Korea has collaborated more often than India in life sciences, mathematics and engineering.

Table 7 provides some statistics on the extent and distribution of internationally coauthored papers of South Korea, as well as data on the expected impact of these papers based on impact factors of journals in which the papers were published. Also given in Table 7 are the cooperation index and affinity index for papers resulting

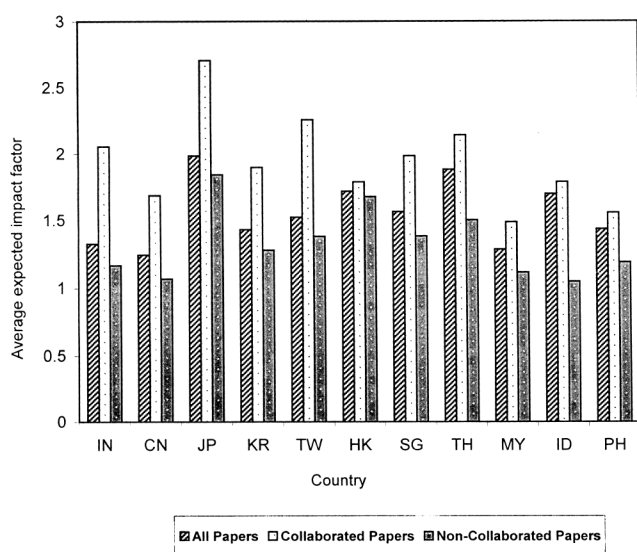
**Table 3.** Cooperation index and affinity index values for Asian countries with selected cooperating countries

	US	DE	GB	FR	JP	IT	CA	AU	CN	KR	TW	IN
Cooperation index												
India	16.92	12.00	9.06	10.16	7.40	7.64	5.09	5.83	5.64	7.01	4.21	
China	23.08	17.61	13.04	10.28	21.60	9.67	10.25	11.31		13.28	7.15	5.64
Japan	40.78	18.99	16.61	11.58		10.18	13.94	12.55	21.60	18.60	7.46	7.40
South Korea	29.94	7.87	6.21	6.84	18.60	7.44	6.28	4.12	13.28		6.79	7.01
Taiwan	19.22	4.97	3.86	3.41	7.46	3.96	4.92	3.97	10.17	6.79		4.21
Hong-Kong	13.58	3.77	9.36	1.40	2.72	1.31	9.07	10.45	62.18	0.00	9.42	2.81
Malaysia	2.60	0.74	14.42	1.50	4.37	2.14	2.14	8.74	5.49	1.90	1.02	10.88
Thailand	12.70	4.30	12.01	3.03	12.98	1.34	2.89	8.96	1.53	2.77	2.13	2.69
Singapore	8.28	1.18	7.78	1.14	4.01	0.57	3.42	11.29	20.49	0.76	7.36	2.15
Indonesia	8.35	7.85	4.10	5.47	9.69	1.52	6.44	19.08	4.68	2.03	2.18	1.72
Philippines	7.95	2.88	4.10	3.35	10.45	0.00	4.18	7.17	8.85	5.41	5.09	2.29
Affinity index												
India	24.54	9.09	7.03	6.63	5.91	4.00	2.67	2.42				
China	21.84	8.71	6.61	4.38	11.26	3.30	3.50	3.07				
Japan	33.30	8.11	7.26	4.26		3.00	4.11		4.65	3.08		
South Korea	34.96	4.81	3.88	3.60	11.97	3.14	2.65		4.09			
Taiwan	37.98	5.13	4.09	3.04	8.12	2.83	3.51		5.29			
Hong-Kong	23.86	3.47	8.81	1.11	2.64	0.83	5.76	5.27	28.78		3.12	
Malaysia	8.54	1.27	21.84	2.22	7.91	2.53	2.53	8.23	4.75			8.54
Thailand	24.35	4.31	12.33	2.62	13.71	0.92	2.00	4.93				
Singapore	22.80	1.70	11.47	1.42	6.09	0.57	3.40	8.92	14.87		3.82	
Indonesia	17.58	8.65	4.61	5.19	11.24	1.15	4.90	11.53				
Philippines	19.53	3.70	5.39	3.70	14.14		3.70	5.05	5.72			

**Table 4.** Intra-Asian research collaboration – coauthorships among Asian countries: 1986–88 and 1995–97

	Number of articles			Internationally coauthored			Intra-Asia coauthored		
	1986–88	1995–97	% increase	1986–88	1995–97	% increase	1986–88	1995–97	% increase
Japan	101,553	142,548	40.4	8,259	21,608	161.6	1,009	3,308	227.8
China	11,480	27,706	141.3	2,626	7,982	204.0	415	2,808	576.6
Hong-Kong	1,518	6,741	344.1	333	2,694	709.0	83	1,253	1,409.6
South Korea	2,338	14,091	502.7	686	3,892	467.3	191	1,139	496.3
India	29,492	28,520	-3.3	2,791	4,473	60.3	244	684	180.3
Taiwan	3,807	15,874	317.0	754	2,813	273.1	157	599	281.5
Singapore	1,344	3,874	188.2	318	1,147	260.7	62	423	582.3
Thailand	1,019	1,552	52.3	493	976	98.0	134	381	184.3
Indonesia	328	732	123.2	215	631	193.5	57	277	386.0
Malaysia	722	1,292	78.9	249	554	122.5	70	270	285.7
Philippines	542	695	28.2	247	454	83.8	96	219	128.1

Based on ref. 4, Text table 6–7, pp. 6–50.



**Figure 1.** Average expected impact factor of internationally collaborated papers and indigenous papers of the 11 Asian countries.

from South Korea's collaboration with eight major partner countries. USA dominates international collaboration with South Korea; indeed the number of papers resulting from US–Korea collaboration exceeds the number resulting from Korea's collaboration with the next seven leading collaborating countries! The affinity index for South Korea → USA is close to 35 and the cooperation index is close to 30. Apart from the G7 countries, China is an important collaborator of South Korea. Invariably, the average expected impact factor of internationally co-authored papers is considerably higher than the average expected impact factor of all South Korean papers. Whereas over 48% of all papers from South Korea have appeared in journals of impact factor less than unity, among internationally coauthored papers only a smaller fraction has appeared in such low-impact journals. Again, of all papers from South Korea less than 12% have

**Table 5.**

Country	No. of collaborating countries	
	1986–88	1995–97
China	54	107
Japan	80	127
South Korea	33	83
Taiwan	34	67
Hong Kong	35	82
Singapore	42	65
Thailand	49	94
Malaysia	32	76
Indonesia	39	84
Philippines	44	75

appeared in journals of impact factor greater than 3.0, but a much higher share of internationally collaborated papers have appeared in such higher-impact journals. In particular, more than 55% of papers resulting from collaboration between Korean authors on the one hand and Italian or French authors on the other have appeared in journals of impact factor greater than 3.0.

Table 8 gives similar data for internationally collaborated papers of Taiwan. For Taiwan also, China is a leading collaborating nation apart from the G7 nations. International collaboration in Taiwan is also dominated by the USA, which has collaborated with Taiwan in more papers than the next seven leading collaborating countries put together. The affinity index for Taiwan → USA is close to 38 and the cooperation index is over 19. As with South Korea, here again, the expected average impact factor of internationally coauthored papers is much higher than that of all papers from Taiwan. In particular, the expected average impact of papers written in collaboration with the People's Republic of China is twice that of all papers from Taiwan. Whereas over 45% of all papers from Taiwan have appeared in journals of impact factor less than unity, a much smaller proportion of internationally collaborated papers—as low as 14% in the case of French–Taiwanese collaboration—has appeared in such

low-impact journals. Less than 11.5% of all Taiwanese papers have appeared in journals of impact factor greater than 3.0, but a much higher percentage of internationally collaborated papers have appeared in such higher-impact journals. The figures vary from 22.2% for papers with

Japan and 24.8% for papers with USA to 83.3% for papers with Italy and 56.9% for papers with France.

For India and China also USA is the number one collaborator, but USA is not as dominating as in the case of South Korea and Taiwan. Also, a very high per cent of

**Table 6.** Average expected impact factor of internationally collaborated and non-collaborated papers

	IN	CN	JP	KR	TW	HK	SG	TH	MY	ID	PH
No. of papers	11437	13878	60721	8234	7112	3210	1892	774	538	266	266
No. of collaborated papers	2015	3955	10007	2023	1163	1164	576	460	244	234	178
% of collaborated papers	17.62	28.5	16.48	24.57	16.34	36.26	30.44	59.43	45.35	87.97	66.92
Collaborated papers in											
Physics journals	703	1311	2563	663	295	305	124	26	19	22	7
Life sciences journals	563	1082	4606	631	463	340	193	339	122	155	142
Chemistry journals	374	573	1108	280	109	166	88	39	76	18	10
Engineering journals	138	402	743	210	134	193	103	28	13	11	3
Mathematics journals	67	200	177	96	76	92	46	2	3	1	3
Geosciences journals	59	170	251	40	33	27	5	7	3	16	6
Multidisciplinary journals	56	97	219	22	20	21	6	5	7	4	3
Average expected impact factor of collaborated papers in											
Physics*	2.242	1.735	1.948	2.008	2.246	1.788	1.503	1.071	1.182	1.680	1.607
Life sciences <sup>#</sup>	2.312	2.161	3.469	2.502	2.799	2.515	3.288	2.420	1.579	1.543	1.408
Chemistry	1.598	1.563	1.925	1.570	1.942	1.825	1.640	1.152	1.023	1.496	1.528
Engineering	0.763	0.785	0.862	0.767	0.698	0.743	0.742	0.740	0.613	1.114	0.836
Mathematics <sup>§</sup>	0.595	0.489	0.582	0.497	0.601	0.594	0.632	0.654	0.992	0.273	0.180
Geosciences	1.493	1.255	1.718	1.453	1.863	1.299	0.763	1.423	1.133	1.036	1.043
Multidisciplinary	6.840	4.707	11.713	8.327	11.407	5.965	9.862	10.851	7.880	20.642	11.753
Average expected impact factor of all papers	1.323	1.243	1.986	1.430	1.522	1.717	1.564	1.882	1.283	1.697	1.434
Average expected impact factor of collaborated papers	2.055	1.685	2.707	1.898	2.257	1.787	1.984	2.142	1.486	1.786	1.556
Average expected impact factor of non-collaborated papers	1.166	1.067	1.843	1.277	1.379	1.677	1.381	1.502	1.114	1.047	1.188

\*Includes Materials Science and Astrophysics.

<sup>#</sup>Includes Agricultural Sciences, Biology & Biochemistry, Clinical Medicine, Ecology/Environment, Immunology, Molecular Biology & Genetics, Microbiology, Neuroscience, Plant & Animal Science, Pharmacology & Psychology/Psychiatry.

<sup>§</sup>Includes Computer Science.

**Table 7.** Some statistics on internationally collaborated papers of South Korea

Characteristics	South Korea	In collaboration with							
		US	JP	DE	CN	GB	FR	IT	CA
No. of papers	8234	1215	416	167	142	135	125	109	92
No. of journals used	1367	569	268	74	67	84	50	34	58
No. of papers per journal	6.023	2.135	1.552	2.257	2.119	1.607	2.500	3.206	1.586
Average impact factor of journals used* ( <i>JCR</i> 1997)	1.538	1.939	1.808	2.269	1.319	1.994	2.593	2.258	2.255
Average expected impact factor of the papers**	1.430	2.178	1.812	2.313	1.844	1.973	2.956	2.518	2.583
% of papers appearing in journals in the impact factor range									
0 < 1	48.31	35.31	38.46	35.93	45.77	38.52	20.00	30.28	31.52
1 < 2	30.79	26.17	32.45	14.37	11.27	25.93	17.60	7.34	22.83
2 < 3	9.83	12.84	10.82	5.39	9.15	8.15	7.20	5.50	4.35
3 < 4	7.48	15.06	11.54	40.72	32.39	19.26	42.40	51.38	27.17
≥ 4	3.59	10.62	6.73	3.59	1.41	8.15	12.80	5.50	14.13
Cooperation index		29.94	18.60	7.87	13.28	6.21	6.84	7.44	6.28
Affinity index		34.96	11.97	4.81	4.09	3.88	3.60	3.14	2.65

\*Based on the number of journals used, not taking into account the number of papers published in each journal.

\*\*Based on the number of papers in each journal used.

papers from these two countries, over 55% for India and over 53% for China, have appeared in journals of impact factor less than unity. A very low per cent of papers have appeared in journals of impact factor higher than 3.0 – about 7.5% for India and about 6.8% for China. Here again, a much higher per cent of internationally collaborated papers have appeared in high-impact journals<sup>7</sup>. In the case of Japan the distribution of international collaboration is somewhat less even, with the US share among the top eight collaborators being 49.1% as against less than 40% for India and less than 35% for China.

Table 9 gives data on the distribution of internationally collaborated papers of South Korea by subject and collaborating country. South Korea collaborates often in physics (27.4% papers are internationally collaborated) and chemistry (16.5%) and to a lesser extent in engineering (20.1%) and clinical medicine (23.8%). Among countries its preferred partners are USA (more than 60% of collaborations are with the USA) and Japan (20.6%). The numbers in the top two rows – physics and chemistry – under all countries and most numbers under USA and Japan are larger than the rest of the numbers in the matrix.

**Table 8.** Some statistics on internationally collaborated papers of Taiwan

Characteristics	Taiwan	In collaboration with							
		US	JP	CN	DE	GB	CA	FR	IT
No. of papers	7113	725	155	101	98	78	67	58	54
No. of journals used	1434	423	103	63	48	66	42	35	13
No. of papers per journal	4.960	1.714	1.505	1.603	2.042	1.182	1.595	1.657	4.154
Average impact factor of journals used* ( <i>JCR</i> 1997)	1.659	2.164	1.734	2.840	2.621	2.998	1.946	2.419	2.312
Average expected impact factor of the papers**	1.522	2.362	2.126	3.047	3.301	2.822	2.936	2.898	3.817
% of papers appearing in journals in the impact factor range									
0 < 1	45.57	36.14	30.32	30.69	17.35	32.05	22.39	13.79	3.70
1 < 2	31.95	24.55	32.26	14.85	9.18	30.77	17.91	13.79	7.41
2 < 3	11.04	14.48	14.19	15.84	17.35	11.54	10.45	15.52	5.56
3 < 4	7.14	13.24	10.32	32.67	35.71	10.26	23.88	50.00	59.26
≥ 4	4.32	11.59	12.90	5.94	20.41	15.38	25.37	6.90	24.07
Cooperation index		19.22	7.46	10.17	4.97	3.86	4.92	3.41	3.96
Affinity index		37.98	8.12	5.29	5.13	4.09	3.51	3.04	2.83

\*Based on the number of journals used, not taking into account the number of papers published in each journal.

\*\*Based on the number of papers in each journal used.

**Table 9.** Distribution of internationally collaborated papers of South-Korea by subject and collaborating country

Subject	No. of journals	No. of papers	No. of collaborated papers	In collaboration with							
				US	JP	DE	CN	GB	FR	IT	CA
Physics	100	1789	491	304	90	85	74	51	71	65	29
Chemistry	154	1693	280	145	59	15	12	11	9	3	15
Engineering	175	1045	210	148	33	3	2	6	3	3	7
Clinical Medicine	290	858	204	156	37	6	6	5	2	2	4
Materials Science	71	712	144	60	32	8	13	10	4	–	–
Biology & Biochemistry	100	588	138	85	36	6	4	5	7	2	5
Plant & Animal Science	84	156	67	20	24	2	1	4	3	3	8
Pharmacology	33	156	30	18	10	–	–	–	–	–	–
Computer Science	27	140	39	27	1	1	1	1	–	–	1
Mathematics	39	130	57	31	4	2	6	1	–	5	3
Neuroscience	37	115	30	20	6	2	–	–	–	1	–
Agricultural Sciences	29	103	36	16	11	1	–	1	1	–	2
Ecology/Environment	36	102	42	20	9	2	–	3	3	–	1
Molecular Biology & Genetics	39	90	38	25	10	3	–	3	1	1	1
Microbiology	21	79	25	10	6	1	1	4	1	–	3
Geosciences	44	77	40	31	5	1	2	2	1	1	2
Immunology	20	60	21	17	5	1	–	1	1	–	–
Multidisciplinary	14	53	22	12	5	1	1	–	1	1	–
Astrophysics	13	42	28	18	7	1	–	3	–	–	1
Economics & Business	2	9	2	2	–	–	–	–	–	–	–
Blank category	1	1	–	–	–	–	–	–	–	–	–
Social Sciences, General	1	1	1	1	–	–	–	–	–	–	–
Not classified journals	37	235	78	49	26	26	19	24	17	22	10
Total	1367	8234	2023	1215	416	167	142	135	125	109	92

**Table 10.** Distribution of internationally collaborated papers of Singapore by subject and collaborating country

Subject	No. of journals	No. of papers	No. of collaborated papers	In collaboration with										
				US	CN	GB	AU	JP	HK	TW	CA	DE	FR	IT
Engineering	127	438	103	31	22	10	12	10	9	3	2	3	1	–
Clinical Medicine	161	304	68	30	3	15	6	5	7	2	3	2	4	–
Chemistry	77	275	88	18	20	7	10	6	2	9	6	1	–	–
Physics	66	241	89	17	33	13	9	10	1	–	1	1	1	3
Materials Science	46	150	35	7	12	4	4	1	1	1	1	1	–	1
Biology & Biochemistry	38	83	34	16	2	3	4	–	1	1	1	–	1	–
Plant & Animal Science	40	68	17	2	3	2	1	2	1	4	1	–	–	–
Mathematics	33	61	29	9	3	4	2	2	1	2	2	–	–	–
Computer Science	19	45	17	8	1	1	4	–	1	2	1	–	–	–
Molecular Biology & Genetics	25	39	25	6	–	8	2	1	–	–	2	2	2	–
Pharmacology	15	34	10	1	2	–	1	2	–	1	1	–	–	–
Microbiology	11	34	9	2	–	3	1	1	–	–	–	2	–	–
Ecology/Environment	15	27	11	1	3	1	2	–	4	–	–	–	–	–
Neuroscience	11	22	7	4	–	4	–	–	–	–	–	–	–	–
Multidisciplinary	11	17	6	2	–	2	1	1	–	–	–	–	–	–
Agricultural Sciences	8	13	8	1	–	1	–	1	1	–	2	–	–	–
Geosciences	9	10	5	1	–	2	–	–	1	–	–	–	–	–
Immunology	7	8	4	2	–	–	1	–	–	1	–	–	–	–
Astrophysics	1	1	–	–	–	–	–	–	–	–	–	–	–	–
Economics & Business	1	2	1	–	–	–	1	–	–	–	–	–	–	–
Not classified journals	13	20	10	3	1	1	2	1	–	1	1	–	1	–
Total	734	1892	576	161	105	81	63	43	30	27	24	12	10	4

Singapore collaborates most often with the USA (28% of all collaborated papers) and China (18.2%). About 37% of papers in physics, 32% of papers in chemistry, over 23.3% of papers in materials science, 23.5% of papers in engineering, and 22.4% of papers in clinical medicine from Singapore have come out of international collaboration (Table 10). Most of the numbers in the top left hand corner – the first four rows – engineering, clinical medicine, chemistry and physics under USA, China, UK, Australia and Japan – are considerably larger than the rest of the numbers.

Similar data are available with us for other Asian countries. Arunachalam has already published such data for India and China<sup>7</sup>.

## Conclusion

As pointed out by Katz and Hicks, at the macro level (involving all fields and all countries) international collaboration has been increasing at a constant rate since the mid-1960s in both the USA and UK<sup>1,12</sup>. The trend has been the same in other advanced countries. By and large the growth in international scientific collaboration, as reflected by jointly authored papers, paralleled the growth in the number of airline passengers and the number of international telephone calls in these countries. As it happens, in all walks of life there is a time lag before the less advanced countries catch up with such trends. Based on data from *SCI* 1991, Arunachalam *et al.*<sup>8</sup> pointed out that South–South collaboration was meagre. By 1998 the situation has improved considerably for collaboration

involving the three Asian giants and other Asian countries. In particular, China, South Korea, Taiwan and Singapore have become much more international. China, in particular, seems to be emerging as a regional focal point.

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