Reasons for and Developments in International Scientific Collaboration: Does an Asia-Pacific Research Area Exist from a Bibliometric Point of View?

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Abstract

This paper describes the different forms of and tries to give reasons for international scientific collaboration in general. It focuses on eleven countries in the Asia-Pacific region by evaluating their national research output with the help of bibliometric indicators in particular. Over two million journal articles published by these countries between 1998 and 2007 in ISI-listed periodicals are analyzed. Discipline-specific publication and citation profiles reveal national strengths and weaknesses in the different research domains. The exponential increase in publication output by China over the last few years is astonishing, but in terms of visibility, i.e. citation rates, China cannot keep up with leading science nations, remaining below the world average. A discipline-specific analysis shows that Chinese authors took an active part in more than a quarter of all articles and reviews published in the field of materials science in 2007, while their contribution to medical research is very low. Co-publication networks among the eleven countries are generated to observe the development of cooperation bonds in the region. Applying Salton's measure of *international collaboration strength*, an above-average strengthening of scientific collaboration in the Asia-Pacific region can be observed.

Introduction

This paper focuses on the analysis of the scientific output and collaboration of eleven countries in the Asia-Pacific region and addresses the different aspects of international collaboration in science in general. The underlying analysis was conducted on behalf of the International Bureau of the German Federal Ministry of Education and Research (BMBF) in 2008 (Haustein, Mittermaier & Tunger, 2008; Heinrichs, Baelz, Haustein & Tunger, to be published). The International Bureau was interested in the publication behavior of and among countries in the Asia-Pacific region, which were regarded as current or upcoming research nations: Australia, China, Indonesia, Japan, Malaysia, New Zealand, Singapore, South Korea, Taiwan, Thailand and Vietnam[1]. A comparison with Germany should help us gain more information on science and research in these countries, possibly find partners for future cooperation, adjust funding decisions, and derive concepts for future collaboration in science and technology. The study is based on data from Thomson Reuters' SCI-Expanded, SSCI and A&HCI, which were accessed through the Web of Science (WoS) in July 2008. The publication output on the country level was examined for the period of 1992 to 2007, whereas the detailed analysis focuses on the ten years from 1998 to 2007. Additionally, data analysis for this paper was conducted in April 2009. In 2002, Moed expressed the need on the part of science managers for output studies on R&D activities as follows:

> Science and technology are the driving forces of our contemporary society. Analyses of these forces are indispensable in any national science policy or research management strategy. In view of this there is a need for valid and user-oriented analyses of scientific and technological developments.

Furthermore, the importance of research evaluation was emphasized as follows:

> The ability to judge a nation's scientific standing is vital for the governments, business and trusts that must decide scientific priorities and funding. (King, 2004)

This paper aims to outline the different approaches for analyzing research output on a national level and to explain the different forms of and give reasons for international collaboration. The theoretical approach shall be supported by examples from the study of the eleven countries in the Asia-Pacific region. Since a "greater intra-regional collaboration" (Kim, 2005) has been attested to Asia before, this paper will focus on the question as to whether patterns of collaboration indicate the existence of an Asia-Pacific research area from a bibliometric point of view.

Country studies

Studies concerning the scientific output of countries may focus on the research output of a nation as a whole, analyze a country's publication or science activity profile, the impact of its research in different areas or highlight the major institutions or authors involved (Gómez & Méndez 1992; Gupta, Munshi & Mishra, 2004; Tunger, 2009). Time analyses will also reveal the development of different areas of research or show the changes in a country's publication profile over the last few years (Okubo, Dore, Ojasoo & Miquel, 1998). Considering indicators such as a country's expenditure on R&D, the number of researchers or population size and gross domestic product (GDP), relates the scientific output of a country to its input and allows comparisons between countries of different sizes (Kim, 2005; King, 2004).

Figure 1a Number of Publications of Australia, China, Japan, South Korea and Taiwan in Journals covered by ISI from 1992 to 2007.

Figure 1b Number of Publications of Indonesia, Malaysia, New Zealand, Singapore, Thailand and Vietnam in Journals covered by ISI from 1992 to 2007.

Similar to the worldwide trend in publications, an increase in publication output was also observed for the countries in the Asia-Pacific region in the period of 1992 to 2007. The annual number of publications of each of the eleven countries is shown in figures 1a and 1b. The huge differences in annual publication output required the splitting of the diagram. These differences have to be taken into consideration when interpreting the results of the study. The majority of these countries produce a level of publications that currently ranges between a few hundred to around 10,000 per annum. Five countries in this group distinguish themselves from the others in that they partially exhibit significantly higher outputs. These include Taiwan, South Korea, Australia, Japan, and China (see figure 1a). The increase in publications by China is particularly striking and has been observed elsewhere (Glanzel, Debackere & Meyer, 2008; Martinez & Moore, 2008). Its growth is exponential ($y=4E\text{-}143e^{0.1692x}$ with $R^2=0.99$) and leaves all of the other research nations, even established scientific powerhouses like Japan and Australia, trailing behind.

> If this trend continues, China will soon become the world's second largest producer of scientific knowledge behind the USA. (Glanzel, Debackere & Meyer, 2008)

In the 1970s, China was still practically non-existent in terms of publication output in international journals (Frame, Narin & Carpenter, 1977). It started off with around 9,300 publications in 1992, which was far less than Australia. In 2007, however, China boasted almost 100,000 publications, which saw it pass out established research nations such as Japan, which can be compared to Germany in terms of publication output during the years analyzed. Even though China's growth rates are astonishing, it is still far from drawing level with the USA or EU-27, which published approximately 450,000 and 502,000 papers, respectively, in ISI-listed journals in 2007. In addition to China, South Korea also increased its output from 2,600 to 33,800 between 1992 and 2007. With an almost six-fold increase in scientific output, Thailand and Singapore also produced very high growth rates. Of course, this is due to the above-mentioned difference in volume: only a fairly low number of publications at the outset in 1992 allow for these astonishing growth rates.

To create country-specific publication profiles, the output in this study has not only been analyzed on a country level, but a country's publications also have been assigned to different research areas. Due to the differences in publication and citation behavior in specific fields of science, citation and publication rates cannot be compared between different research areas (King, 2004). Thus, publications were allocated to one of thirteen different disciplines by an intellectual topic classification according to the ISI subject category of the journal they were published in. Due to multiple classification of journals, articles were counted more than once if they belonged to subject categories that were assigned to more than one of the thirteen disciplines. The thirteen disciplines are agricultural science, biology and biotechnology, chemistry, energy, engineering, geosciences, information and computer science, materials science, mathematics, medicine, multidisciplinary journals, nanotechnology, and physics. The database share of articles and reviews published in these thirteen disciplines for 2007 is shown in figure 2. Since the disciplines are not represented equally in the database and due to different publication and citation behavior, the publication profiles of the countries (figures

Figure 2 Share of Articles and Reviews published in 2007 in SCI EXPANDED, SSCI and A&HCI according to thirteen scientific Disciplines. Papers may have been assigned to more than one Discipline.

3a and 3b) are normalized with respect to the total output in each field in 2007. Figure 3a clearly shows China's domination among the Asia-Pacific countries in terms of output. In 2007, Chinese researchers produced over a quarter of worldwide publications in materials science and a fifth of the output in chemistry and nanotechnology. In medicine, the dominant research field in the database, however, China trails behind.

Figure 3a Publication Profiles for Australia, China, Japan, South Korea and Taiwan (Research and Review Articles only). Country Output is relativized with respect to the total Output in the specific Research Discipline.

Figure 3b Publication Profiles for Indonesia, Malaysia, New Zealand, Singapore, Thailand and Vietnam (Research and Review Articles only). Country Output is relativized with respect to the total Output in the specific Research Discipline.

The publication profiles reveal the strengths and weaknesses of each country in terms of output. Whereas Japan has a rather balanced profile – which is quite typical for well-developed countries – and is thus active in all of the thirteen research areas, the other Asia-Pacific countries tend to specialize in certain fields: Taiwan is strong in information and computer science and in engineering; Singapore in nanotechnology and information and computer science. Australia and New Zealand both focus on agricultural and geosciences. Together with their common cultural background, this might explain the strong co-publication ties between both nations. Among the Asia-Pacific countries, Australia is New Zealand's first collaboration partner, and New Zealand is Australia's second most important co-publication partner (see table 2 and figures 6 and 7).

A large number of articles only describe the basis of visibility not the actual perception, which can be measured by the number of citations. As has been shown in previous studies (Guan & Ma, 2007; Moed, 2002), the present analysis confirms that Chinese citation rates lie well below expectations. A good example is China's publication and citation rate in materials science in 2007: with 14,389 articles and reviews, China published 27% of the worldwide output in this field as covered by the WoS databases (see figure 3a), while its citation rate lies about 23% below the world average (see figure 4a). Due to differing citation behavior, specific citation rates have been derived for research and review articles from each of the 13 disciplines. In 2007, the average citation rates range from 1.6 for mathematical papers to 15.5 for articles from the subject category of multidisciplinary sciences (table 1).

Table 1 Average global Citation Rates per Discipline for Articles and Reviews from 2007.

Figure 4a Field-normalized Citation Rates for Research and Review Articles published in 2007 by Australia, China, Japan, South Korea and Taiwan (World Average = 100%).

Figures 4a and 4b show the extent to which the countries' field-normalized citation rates lie above or below the world average (100%). Since the study was conducted on behalf of a German government organization, the countries' citation rates in the study were compared to that of the benchmark Germany in individual disciplines (Haustein, Mittermaier & Tunger, 2008). While in the present analysis, the average global citation rates are based on articles and reviews from the year 2007 only, the study for BMBF included citation data on all types of publications from 1998 to 2007. With mathematics and nanotechnology as the only disciplines below the world average, Australia performed as the best Asia-Pacific country in terms of visibility. Singapore followed with nine out of thirteen field-specific citation rates above average. Indonesia was the least visible country among the Asia-Pacific countries: it only met the world standard in medicine. In multidisciplinary journals, South Korean articles and reviews were cited twice as often as the average, but the country trailed behind in all of the other disciplines. In terms of visibility, Singapore was by far the most successful country in the Asia-Pacific region: in agricultural science, biology and biotechnology, chemistry, energy, engineering, materials science, mathematics, medicine and multidisciplinary journals, it had higher citation rates than any other country in the research area. It was only beaten in physics and in information and computer science by Australia, in the geosciences by Vietnam, and in nanotechnology by New Zealand. Singapore's high citation rates might be explained by its good knowledge infrastructure, for which the foundations were laid at the beginning of the 90s (Evers, Gerke & Schweißhelm, 2004).

Figure 4b Field-normalized Citation Rates for Research and Review Articles published in 2007 by Indonesia, Malaysia, New Zealand, Singapore, Thailand and Vietnam (World Average = 100%).

International collaboration

In addition to focusing on scientific output on a national level, studies on research output also analyze collaboration between countries. The motives and reasons for scientists to collaborate can be subdivided into direct and indirect benefits. Among the direct advantages of working with scientists from other countries is the access to complementary knowledge or skills, unique sites and facilities (Birnholtz, 2007). One of the major reasons behind collaboration is to share costs and possible risks (Kim, 2005). International collaboration becomes inevitable when transnational or global problems need to be solved or when standards are to be established. Indirect benefits are also associated with international scientific collaboration. For example, science can function as an initial facilitator for future economic or political bonds (Georghiou, 1997). International collaboration is influenced by cognitive, social and cultural factors as geographic proximity, common language and by historical developments or the national education system (Inonu, 2003; Kim, 2005; Luukkonen, Persson & Sivertsen, 1992; Wagner, Brahmakulam, Jackson, Wong & Yoda, 2001). Political and economic changes influence science as well. Kim (2005) has shown that the economic change in South Korea had an impact on international collaboration. Price (1963) emphasized the importance of economic instead of intellectual dependency for collaborating in science.

The nature of scientific collaboration can either be formal or informal. Both "may lead to joint production of outputs" (Georghiou, 1997). Working together scientifically on an informal level includes communicating directly via telephone or e-mail or exchanging ideas, materials, and research results in face-to-face meetings. Informal cooperation is often characterized by the absence of a contract between the participants. Since informal collaboration is hard to measure, most science studies concentrate on the formal aspect of international collaboration. This can occur in the form of funded programs, conferences, patents, formal collaboration agreements or publications authored by researchers from different countries (Georghiou, 1997; Gupta, Munshi & Mishra, 2004). As journals function as the main publication channel for research results in science, our analysis focuses on international collaboration in journal articles. An article is usually referred to as internationally co-authored, if the addresses of the authors' affiliations include more than one country (Luukkonen, Persson & Sivertsen, 1992; Moed, 2002). Table 2 shows the square matrix of the absolute number of co-publications between the Asia-Pacific countries[2] in 1998 and 2007.

Table 2 Number of Co-publications between the eleven Asia-Pacific Countries for 1998 and 2007. The Diagonal indicates the total Number of Publications for each Country for the particular Year.

Since a jointly published article does not indicate the direction or choice of cooperation in terms of who took the initiative, the matrix is symmetrical (Luukkonen, Persson & Sivertsen, 1992). The diagonal indicates the total output of the respective country for the particular year and not the number of co-publications within a country. In table 2, the general increase in total publications from 1998 to 2007 can be observed. The number of co-publications within the analyzed area has risen as well. Over the past two decades, a general increase in scientific co-publication has been ascertained in many places (Georghiou, 1997; Luukkonen, Persson & Sivertsen, 1992; Wagner, Brahmakulam, Jackson, Wong & Yoda, 2001; Wagner, Yezril & Hassell, 2001).

> International scientific collaboration – where scientists work with their counterparts in other countries towards a common research goal – is growing as a percentage of all scientific activity. (Wagner, Brahmakulam, Jackson, Wong & Yoda, 2001)

Figure 5 Percentage of Articles and Reviews that a Country published together with at least one international Partner from 1998 to 2007.

Figure 5 shows this percentage for each country in Asia-Pacific, where international scientific collaboration is defined as the share of articles and reviews published together with at least one author from another country worldwide. In general, the Asian-Pacific countries with a very high yearly output – i.e. China, Japan, South Korea and Taiwan – co-publish only a small percentage (up to 28%) on an international basis, whereas countries with a smaller output generate almost half up to 90% of their scientific papers in collaboration with other nations. Indonesia and Vietnam, the two countries analyzed with the least scientific output, have by far the highest percentage. The coherence between country size in terms of output and the share of internationally co-authored papers has been ascertained by others in the past (Luukkonen, Persson & Sivertsen, 1992).

> At the national level, the share of international collaboration in large countries is necessarily lower than that of medium-sized or even small countries. (Schubert & Braun, 1990)

Wagner, Brahmakulam, Jackson, Wong and Yoda (2001) differentiate between scientifically advanced, proficient, developing and lagging countries and assume a positive coherence of R&D investments and economic growth. Since a co-publication does not reveal which partner was the driving force behind the collaboration, we do not know if a high share of international collaboration indicates that the respective country chose or was chosen to cooperate. Therefore, a high degree of international collaboration could either stand for dependence or expertise, and a low level may be evidence of independence or isolation. Glänzel and Schubert (2007) have outlined that international collaboration in general has positive aspects but they also pointed out the problems linked to it. It may be assumed that countries like Thailand and Vietnam benefit from collaborating with other research nations (Luukkonen, Persson & Sivertsen, 1992).

With a fairly high publication output and over 40% of its total publications in 2007 being internationally co-authored, Australia is an exception to the rule. It is also one of the countries with the strongest increase in international collaboration over the ten years analyzed. Only New Zealand (from 38% to 52%) and Singapore (from 32% to 48%) show higher growth rates between 1998 and 2007. Thailand, China and Vietnam are the only Asia-Pacific countries where the share of internationally co-authored articles and reviews decreased over the ten years analyzed. The mean value of internationally co-authored papers for all Asia-Pacific countries was 41% in 1998 and 46% in 2007, allowing a general tendency towards formal international collaboration to be assumed for the countries analyzed.

Since a general increase in international co-publication has been ascertained on a global scale, we shall now examine the extent to which scientific collaboration between the countries in the Asia-Pacific region has developed according to the worldwide trend and evaluate whether they experienced an above-average increase. The question is raised as to whether bibliometric measures indicated the existence or development of an Asia-Pacific research area. Figure 6 depicts the number of publications for each country in 1998 in contrast to their share of a country's scientific output published within the research area. The latter is defined as the number of articles a country has co-published with at least one other of the eleven countries analyzed. Thus, the percentage share indicates the level of cooperation within the Asia-Pacific network. The results for cooperation within the network are similar to the findings for the share of worldwide co-publications of the Asia-Pacific countries in figure 5: Countries with a low output generate a large share of their research results within the defined region. On the contrary, countries with a high scientific output, contribute a rather low share of articles to the region proportionally (Luukkonen, Persson & Sivertsen, 1992).

Figure 6 Comparison of Publication Output and the Share of Articles published within the Asia-Pacific Region for each Country in 1998.

Figure 7 Comparison of Publication Output and the Share of Articles published within the Asia-Pacific Region for each Country in 2007.

Indonesia is the country with the highest share of research output jointly published with at least one of the other members of the region: almost a third of its publications were generated within Asia-Pacific in 1998. At this point, the differences between small and large countries must be considered: even though Indonesia co-publishes almost a third of its output within the network, it contributes only about 130 papers to the regional output, whereas Japan publishes around 2,360 papers together with at least one other Asia-Pacific country. Indonesia's most important partners in Asia-Pacific are Japan, Australia and Thailand. The USA remains the most important ally on a global scale. Germany is forth in terms of Indonesian research collaboration. With 399 publications, Indonesia published the second lowest number of journal articles in 1998 within the analyzed region, behind Vietnam, which published 253. Japan, on the other hand, was well ahead of all the other members of the Asia-Pacific region with 78,504 publications, but it only contributed 3% of its annual output to the research area. The most important partners for Japanese scientists come from the USA, Germany and the UK. China features as the first cooperation partner from the analyzed network in forth place. South Korea and Australia follow in seventh and eighth place. Regardless of its low relative share, Japan still produces the most articles in 1998. Half of the Asian-Pacific output is authored by Japanese researchers. Australia and Chinese researchers follow with 17% and 13%, respectively. Nine years later, the situation has changed (see figure 9): due to its exponential growth, China has become the most important country in the network in terms of the number of publication. With 34%, it accounts for a third of all publications in the area. Japan, New Zealand and Australia lost ground to the other contributors. Comparing figures 6 and 7, an increase in annual publications can be observed as can growth in the share of collaboration within the network of the eleven countries. All of the countries analyzed do not only publish more in absolute numbers, but they also show an above-average increase in the number of articles they produce together with at least one other Asia-Pacific country. The two variables of publication number and percentage collaboration share still correlate highly negatively, and thus confirm general findings on size in terms of output and collaboration in terms of internationally co-authored papers (Luukkonen, Persson & Sivertsen, 1992). Since the overall share of output published within the research area has grown, the network integration has increased. Indonesia remained the smallest country in terms of output and published almost half of its scientific results in cooperation with other countries in the Asia-Pacific region in 2007.

Table 3 Internationally collaborating Countries for the largest and smallest of the Asia-Pacific Countries in 1998 (Japan and Indonesia) and 2007 (China and Indonesia). Partners within the Asia-Pacific Region are highlighted.

As can be seen in table 3, the number of Asia-Pacific countries in the top 10 international collaborators has increased for Indonesia as well, and Japan has replaced the USA as the most important co-publishing partner. The extremely high share of co-published articles by countries in the Asia-Pacific region with a low annual output suggests a high dependency on the larger and more developed countries.

> "[T]o avoid isolation, scientists from smaller countries have to look for partners from scientifically more central ones. The increasing specialization in science makes research areas more narrowly focused and scientists from scientifically peripheral countries are likely to find only a few, if any, colleagues in their own country. Another reason for their high rate of international collaboration might be their greater need for cost sharing." (Luukkonen, Persson & Sivertsen, 1992)

Since the cooperation values also for increase Japan and Australia, however, we can speak of increasing collaboration within the network and not only a center-periphery relationship between the large and small countries in the Asia-Pacific region (Luukkonen, Tijssen, Persson & Sivertsen, 1993).

A strengthening of the cooperation bonds between the countries can be observed in the network diagrams in figure 8 and 9. The lines indicate the number of co-authored journal articles in 1998 and 2007 within the eleven countries analyzed, which are represented by the vertices. The thicker the lines, the more the two respective countries collaborated. The number of joint publications has been normalized with respect to the total output of the two countries by applying Salton's measure of *international collaboration strength* (S) (Glänzel & Schubert, 2007; Salton & McGill, 1986). It measures the strength of the bond between two countries x and y by dividing their co-authored papers C_{xy} by the square root of the product of the total output of the two countries C_x and C_y:

$$S_{xy} = \frac{C_{xy}}{\sqrt{C_x \cdot C_y}}$$

Thus, Salton's measure considers differences in the sizes of output of the two collaborating countries. Since the co-publications are normalized with respect to the countries' output, the strengthening of the network cannot be explained by the overall increase in scientific output. The members of the research area have rather increased their collaboration above expectations. An analysis of the co-publication network of ten selected[3] countries[4] (further referred to as *sample countries*) did not show such an intensification of cooperation (compare figures 10 and 11). A slight increase in international collaboration for these countries can indeed be seen, but this is not comparable to the strengthening of the Asia-Pacific network. In fact, strong bonds in the network of sample countries can be observed, especially between countries in the same geographic or cultural area, e.g. France and Germany, Russia and Ukraine, Japan and South Korea, as well as Argentina and Brazil, respectively (see figures 10 and 11). This indicates the influence of cultural backgrounds on scientific cooperation as mentioned above. Only the growth in the relative co-operation of Russia with France and Germany, respectively, cannot be explained by such reasons (see figure 11). In this case, the decrease in the absolute number of Russian publications from 1998 to 2007 could play a decisive role.

Figure 8 Co-publications between the Asia-Pacific Countries in 1998 normalized with Salton's *International Collaboration Strength*.

Figure 9 Co-publications between Asia-Pacific Countries in 2007 normalized with Salton's *International Collaboration Strength*.

Figure 10 Co-publications between ten Sample Countries[5] in 1998 normalized with Salton's *International Collaboration Strength*.

Figure 11 Co-publications between ten Sample Countries[5] in 2007 normalized with Salton's *International Collaboration Strength*.

Concluding Remarks

As Glänzel and Schubert have stated, international collaboration "is accepted as a basically *positive phenomenon*" (Glänzel & Schubert, 2007). This paper has shown this and has explained why researchers collaborate with colleagues from other nations. By analyzing author affiliation addresses in scientific journal articles, the most common method of international scientific cooperation was examined for eleven countries from the Asia-Pacific region. Findings on the general increase in publication output and international cooperation in science were validated. Discipline-specific publication profiles revealed the strengths and weaknesses of countries in different scientific fields. Normalized citation rates have shown that a high output does not necessarily lead to great visibility, which has especially proven true for China.

With different approaches and indicators, the publication behavior of and among the eleven Asia-Pacific countries was analyzed. The results allow the conclusion that international cooperation between the countries in the Asia-Pacific region has intensified between 1998 and 2007, and that an Asia-Pacific research area does exist from a bibliometric perspective. Comparing the co-publication network of the Asia-Pacific countries to a network for a set of sample countries, it was confirmed that inner-Asian scientific collaboration has developed more than the global average. To be able to speak about the emergence of an Asia-Pacific research area in general, an evaluation of the scientific, political, socioeconomic, historic and cultural frameworks in and relations between the Asia-Pacific countries is required.

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[1] The analyzed countries will be further referred to as *Asia-Pacific countries*.

[2] AUS=Australia, CHN=China, IDN=Indonesia, JPN=Japan, MYS=Malaysia, NZL=New Zealand, SGP=Singapore, KOR=South Korea, TWN=Taiwan, THA=Thailand, VNM=Vietnam.

[3] The countries were chosen to represent a mixed sample set in terms of output and location.

[4] Argentina, Brazil, France, Germany, Japan, Mexico, Russia, South Africa, South Korea and Ukraine.

[5] ARG=Argentina, BRA=Brazil, FRA=France, GER=Germany, JAP=Japan, KOR=South Korea, MEX=Mexico, RSA=South Africa, RUS=Russia, UKR=Ukraine.

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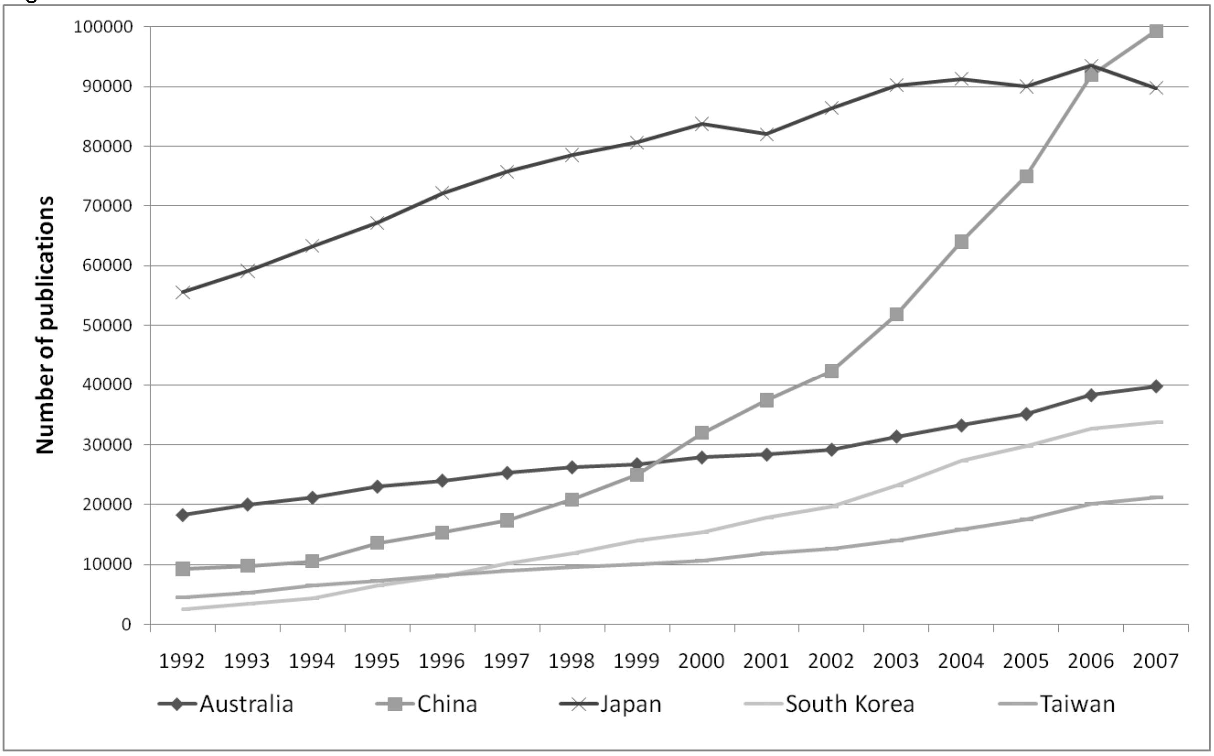
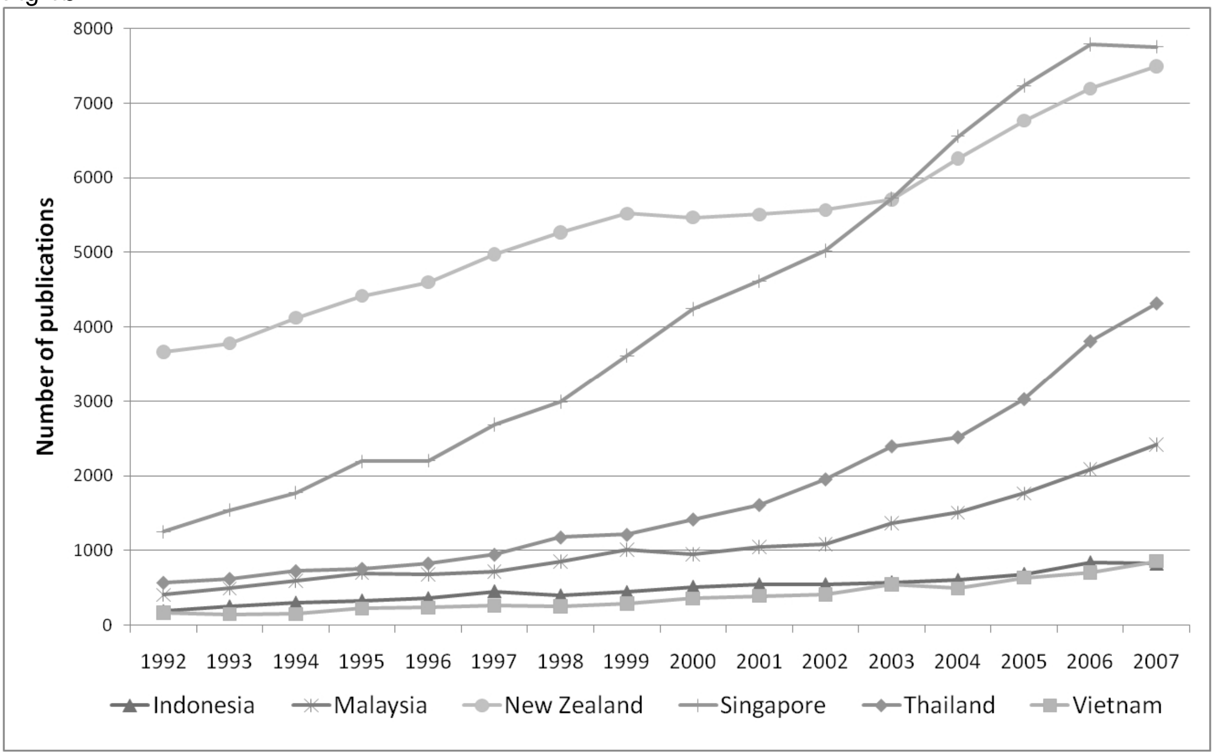
Fig 1a



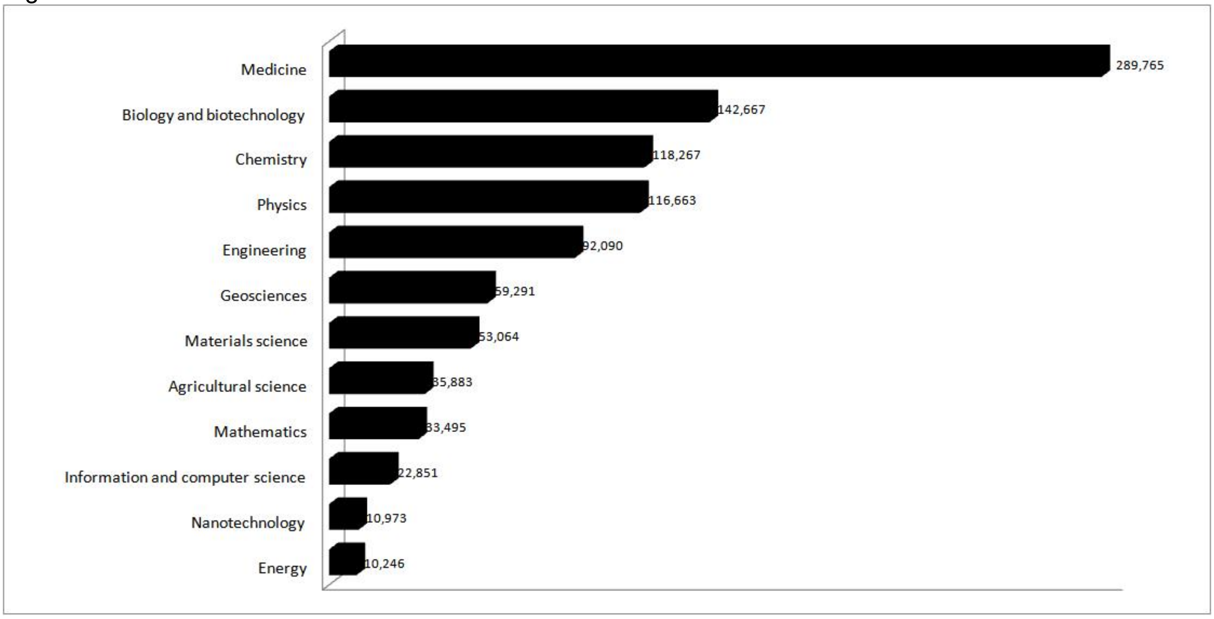
Number of publications
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Australia
China
Japan
South Korea
Taiwan

Fig 1b



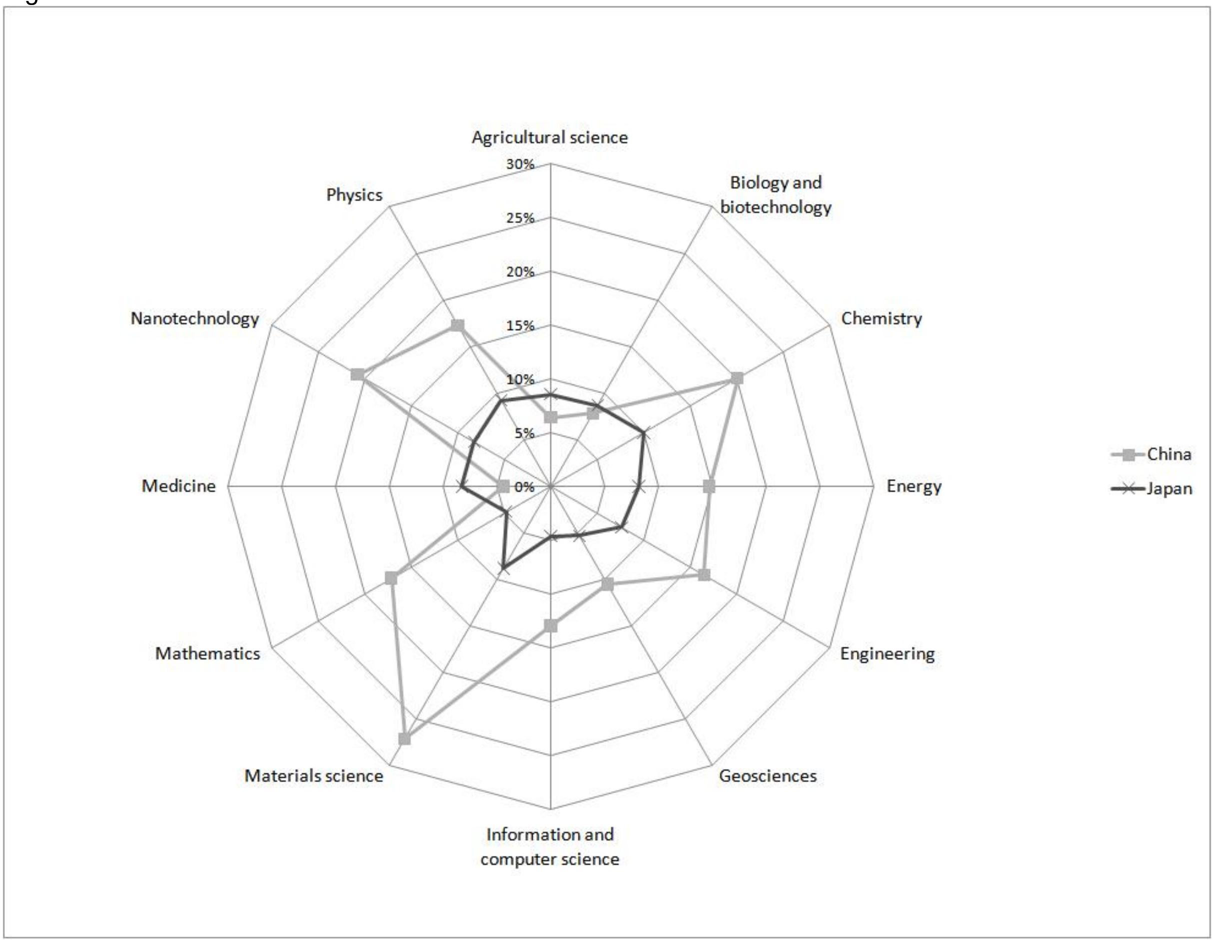
Number of publications
8000
7000
6000
5000
4000
3000
2000
1000
0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Indonesia
Malaysia
New Zealand
Singapore
Thailand
Vietnam

Fig 2



Medicine
Biology and biotechnology
Chemistry
Physics
Engineering
Geosciences
Materials science
Agricultural science
Mathematics
Information and computer science
Nanotechnology
Energy
289,765
142,667
118,267
116,663
92,090
59,291
53,064
35,883
33,495
22,851
10,973
10,246

Fig 3a



Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
30%
25%
20%
15%
10%
5%
0%
China
Japan

Fig 3b

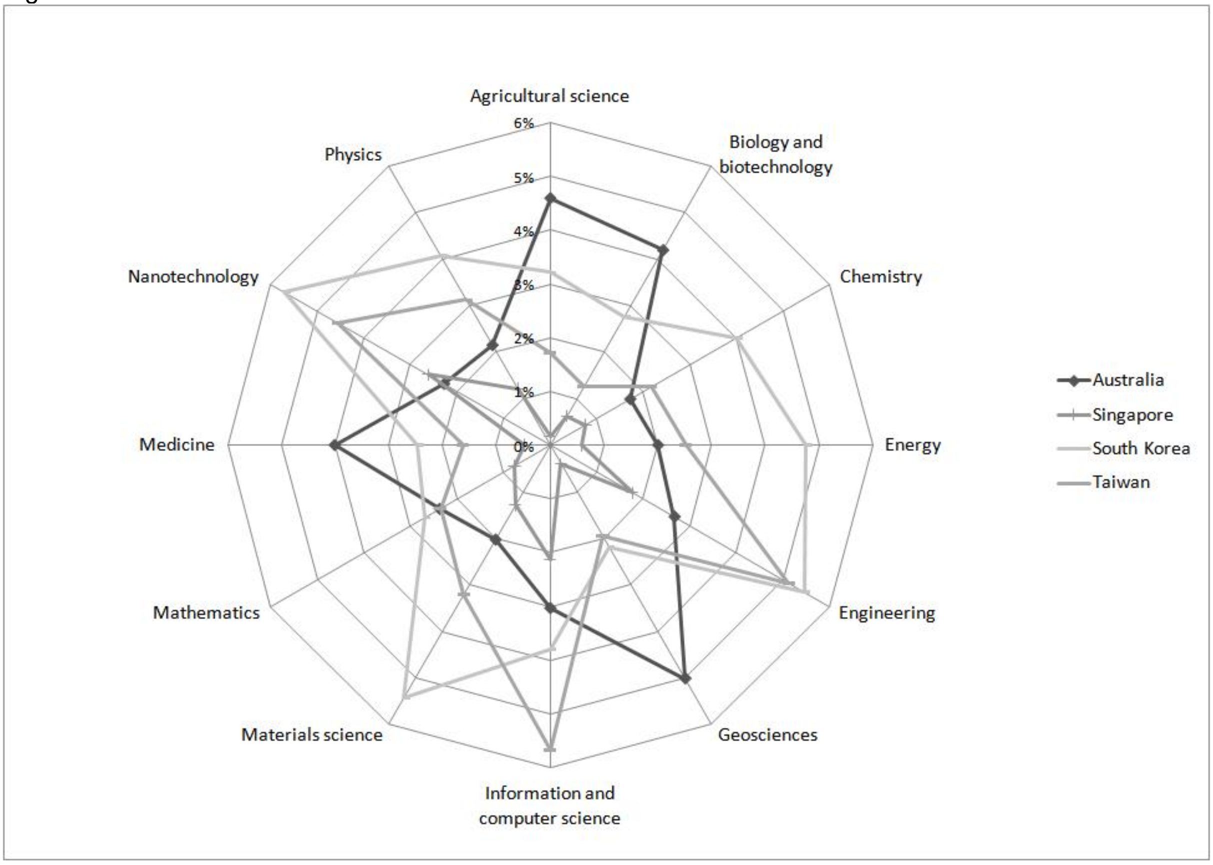

Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
0%
1%
2%
3%
4%
5%
6%
Australia
Singapore
South Korea
Taiwan

Fig 3c

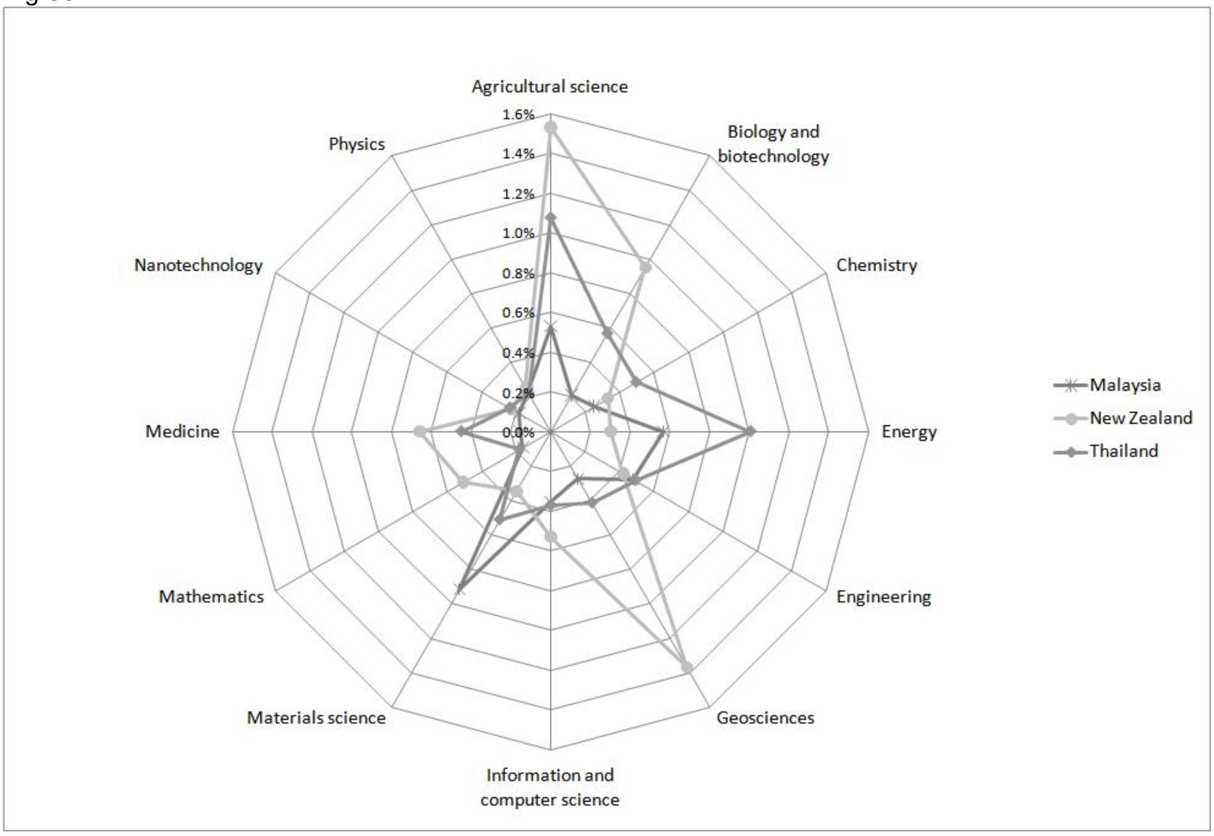
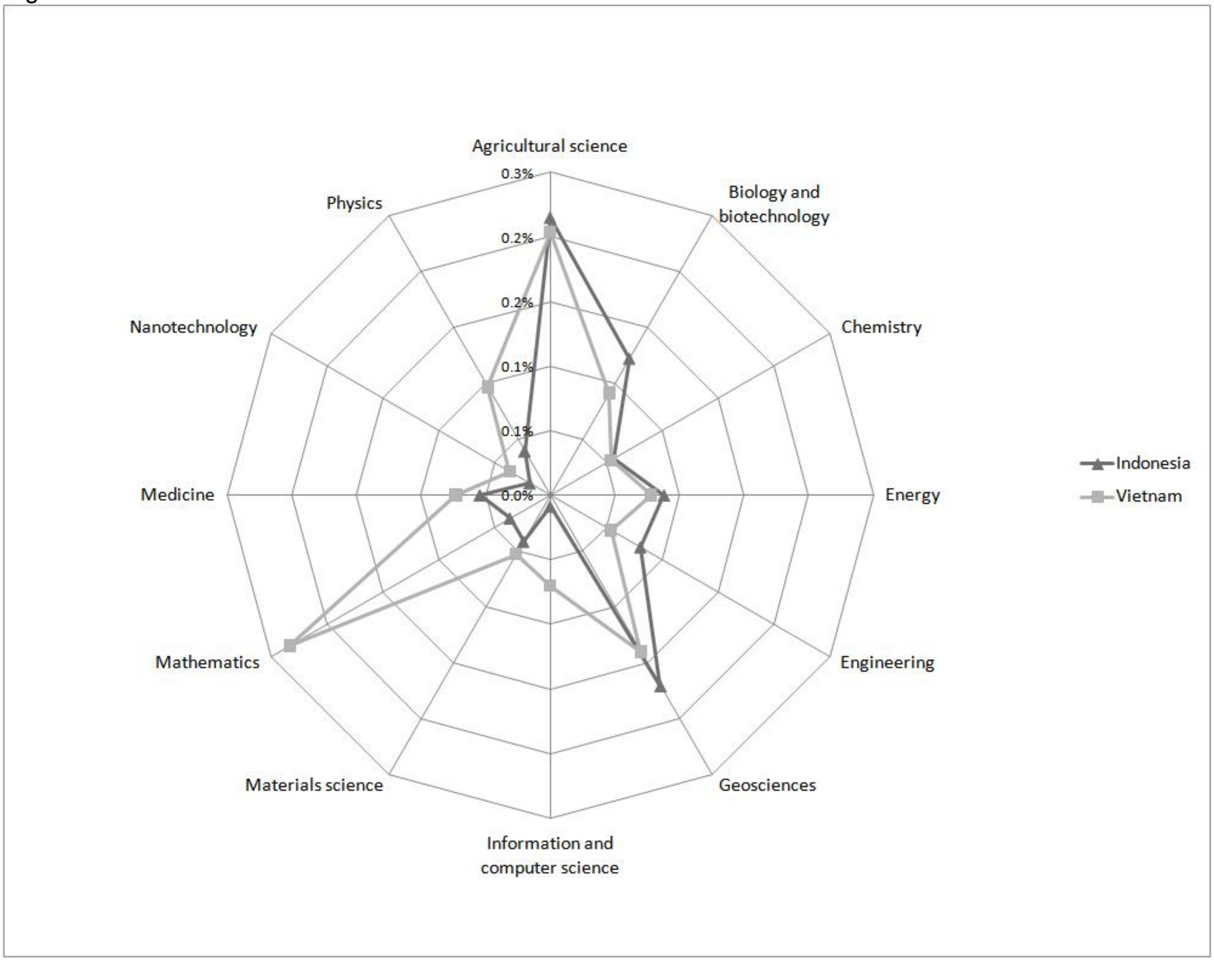
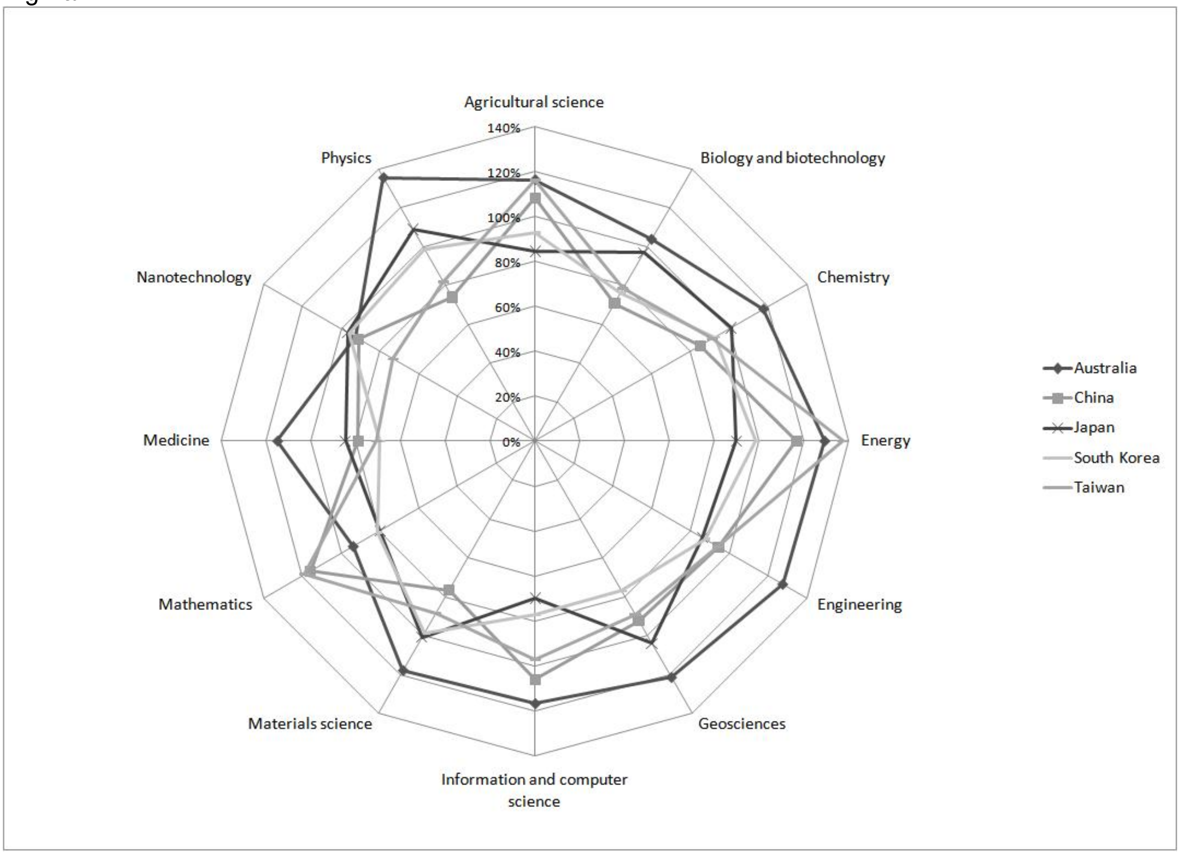

Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
0.0%
0.2%
0.4%
0.6%
0.8%
1.0%
1.2%
1.4%
1.6%
Malaysia
New Zealand
Thailand

Fig 3d



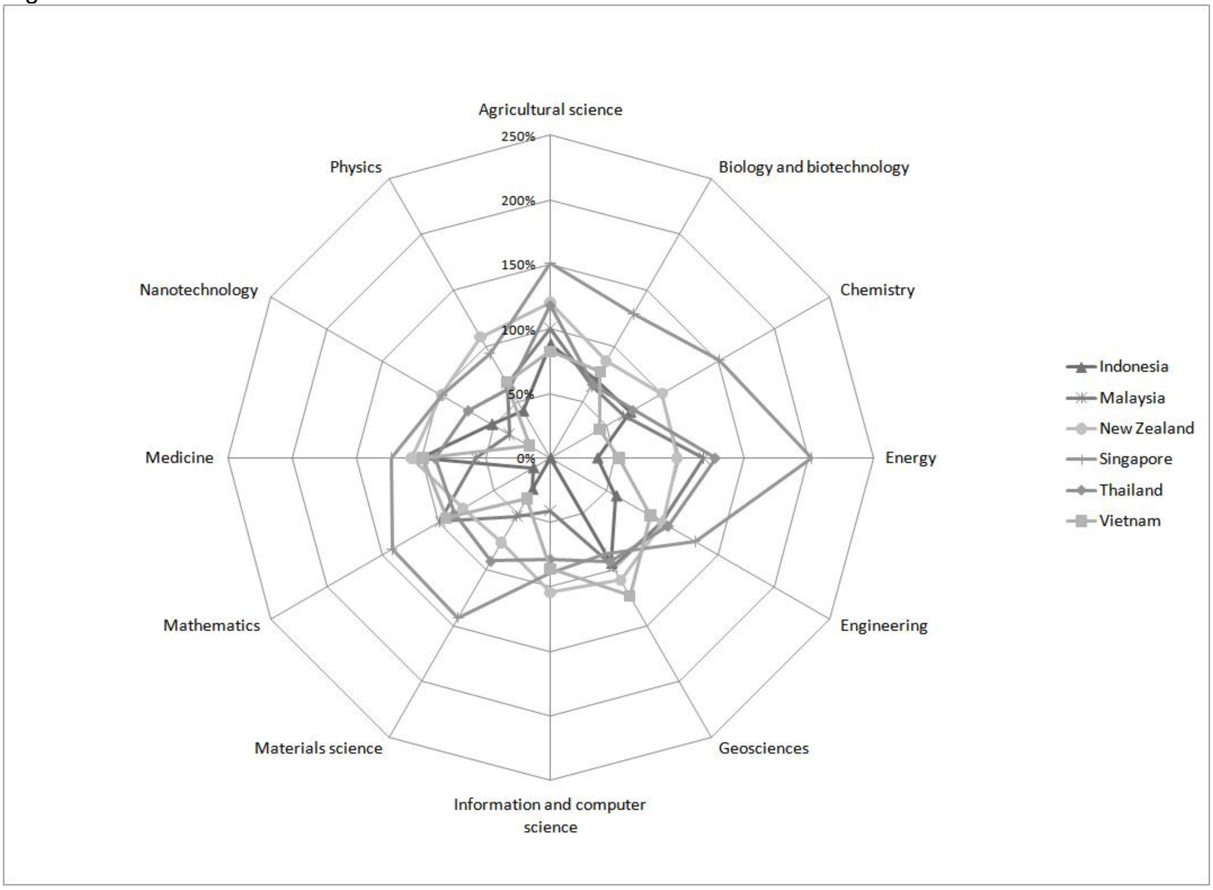
Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
0.3%
0.2%
0.2%
0.1%
0.1%
0.0%
Indonesia
Vietnam

Fig 4a



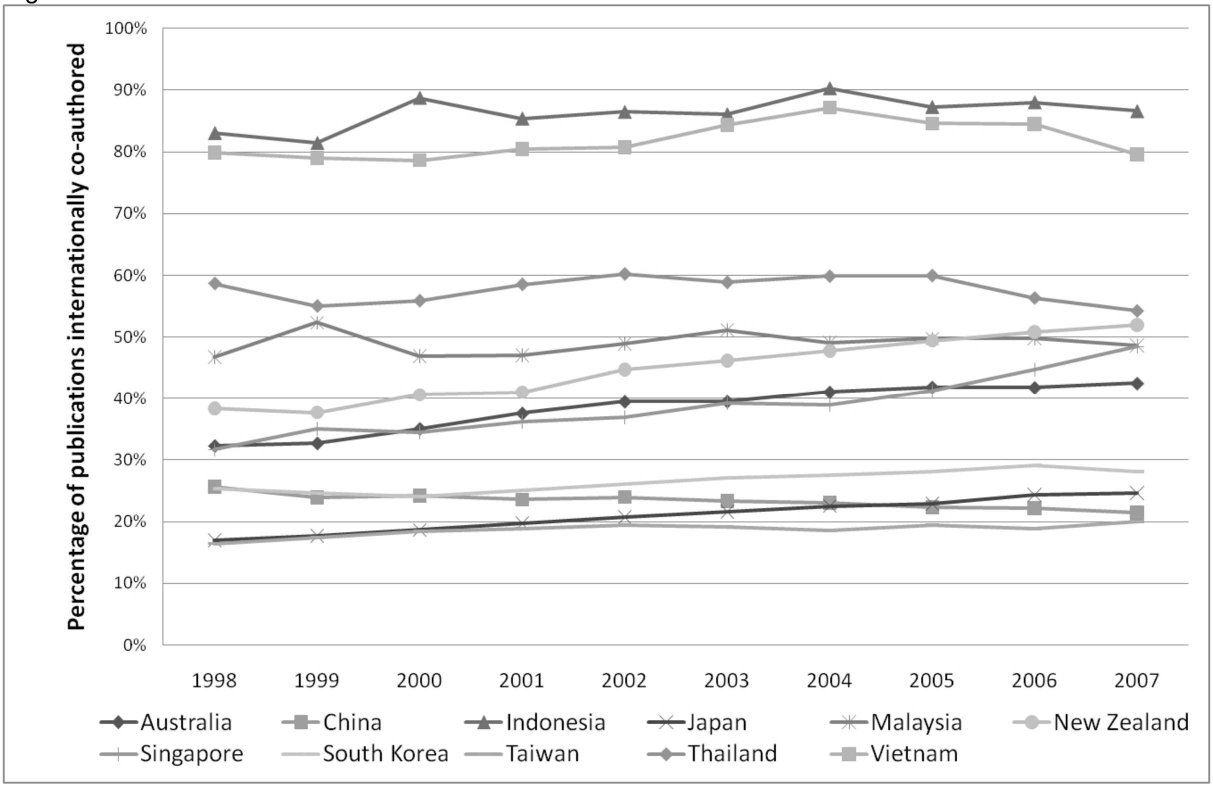
Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
140%
120%
100%
80%
60%
40%
20%
0%
Australia
China
Japan
South Korea
Taiwan

Fig 4b



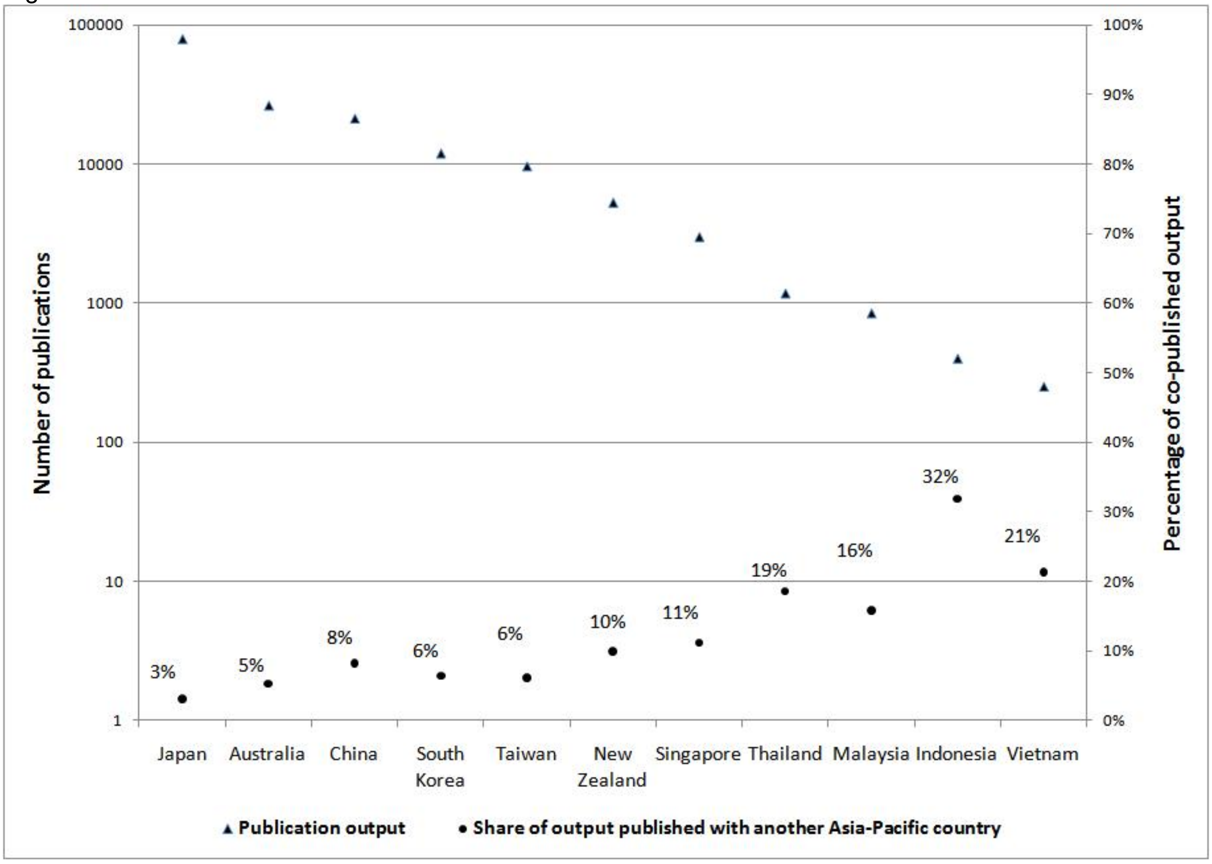
Agricultural science
Biology and biotechnology
Chemistry
Energy
Engineering
Geosciences
Information and computer science
Materials science
Mathematics
Medicine
Nanotechnology
Physics
250%
200%
150%
100%
50%
0%
Indonesia
Malaysia
New Zealand
Singapore
Thailand
Vietnam

Fig 5



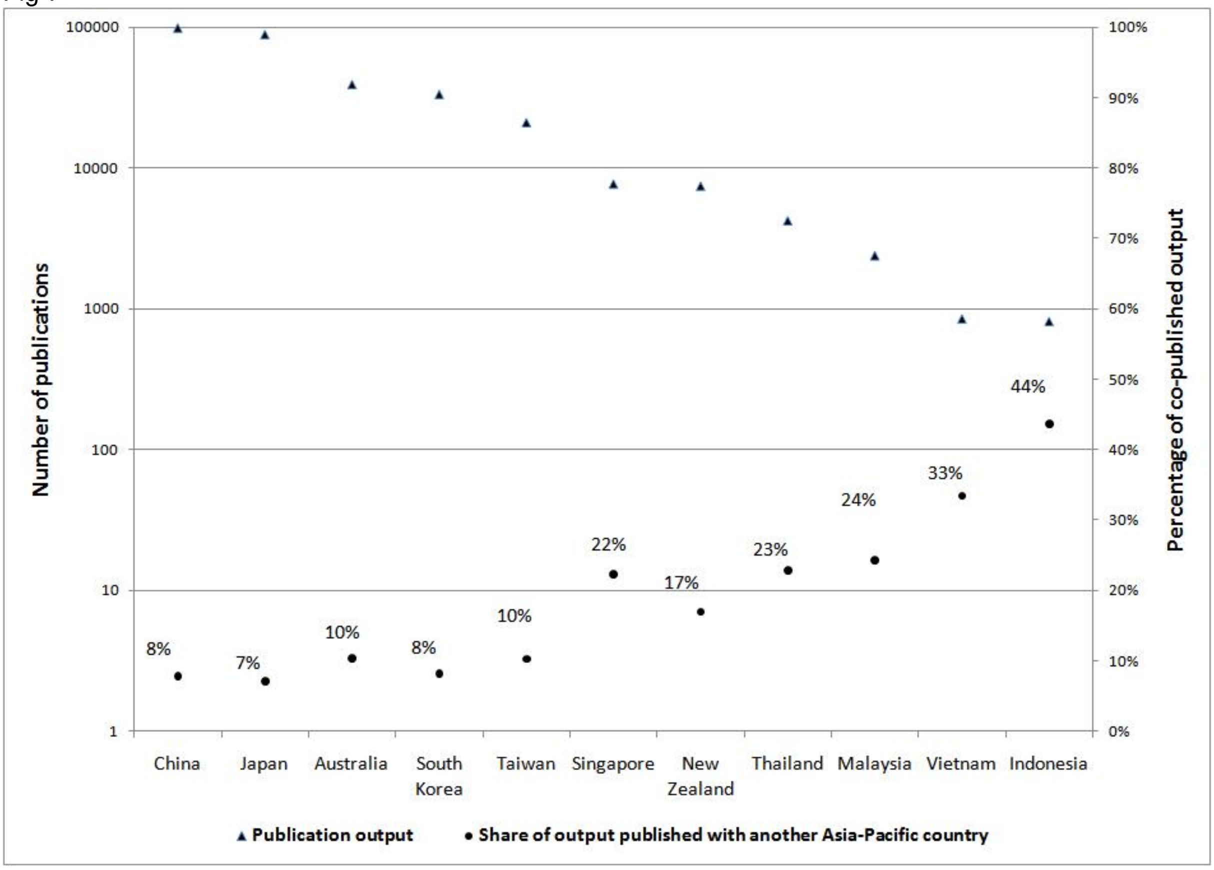
Percentage of publications internationally co-authored
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Australia
China
Indonesia
Japan
Malaysia
New Zealand
Singapore
South Korea
Taiwan
Thailand
Vietnam

Fig 6



Number of publications
Percentage of co-published output
100000
10000
1000
100
10
1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3%
5%
8%
6%
6%
10%
11%
19%
16%
32%
21%
Japan
Australia
China
South Korea
Taiwan
New Zealand
Singapore
Thailand
Malaysia
Indonesia
Vietnam
Publication output
Share of output published with another Asia-Pacific country

Fig 7



Number of publications
Percentage of co-published output
100000
10000
1000
100
10
1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
8%
7%
10%
8%
10%
22%
17%
23%
24%
33%
44%
China
Japan
Australia
South Korea
Taiwan
Singapore
New Zealand
Thailand
Malaysia
Vietnam
Indonesia
Publication output
Share of output published with another Asia-Pacific country

Fig 8

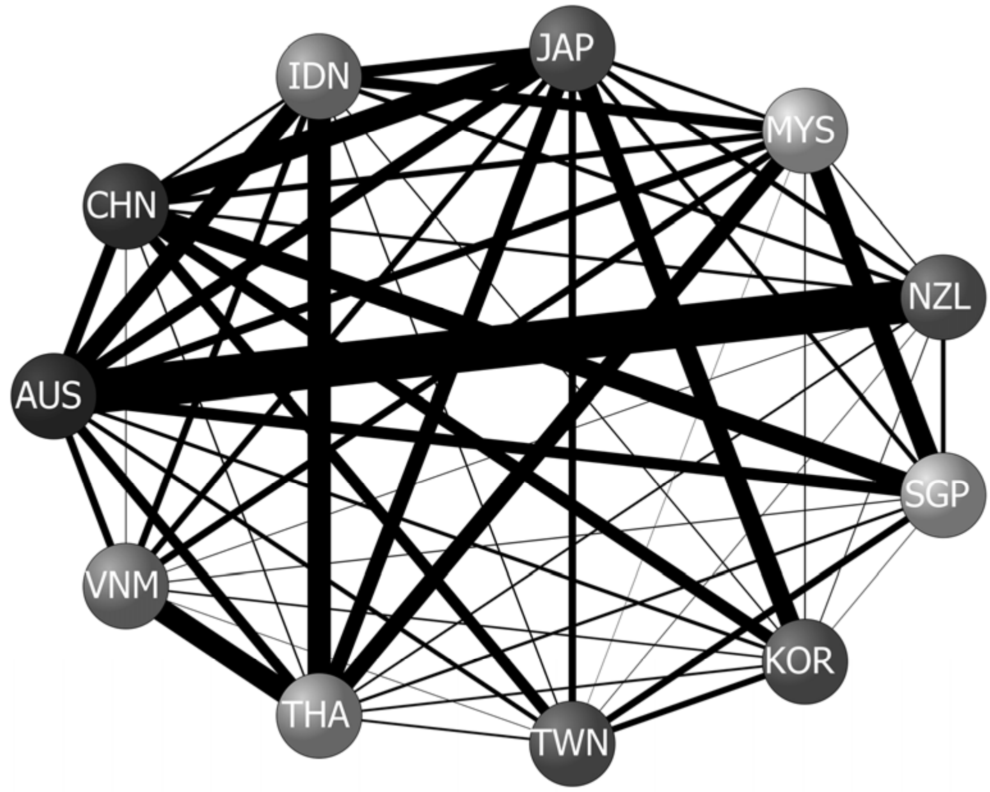

IDN
JAP
MYS
CHN
NZL
AUS
SGP
VNM
KOR
THA
TWN

Fig 9

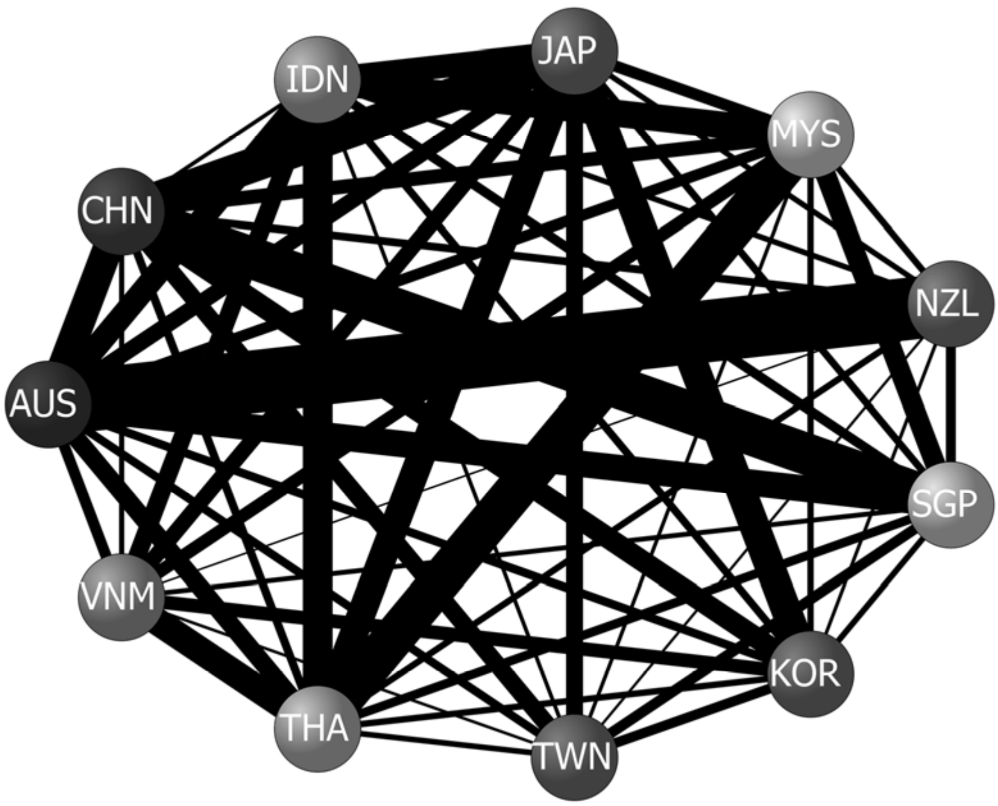

IDN
JAP
MYS
CHN
NZL
AUS
SGP
VNM
KOR
THA
TWN

Fig 10

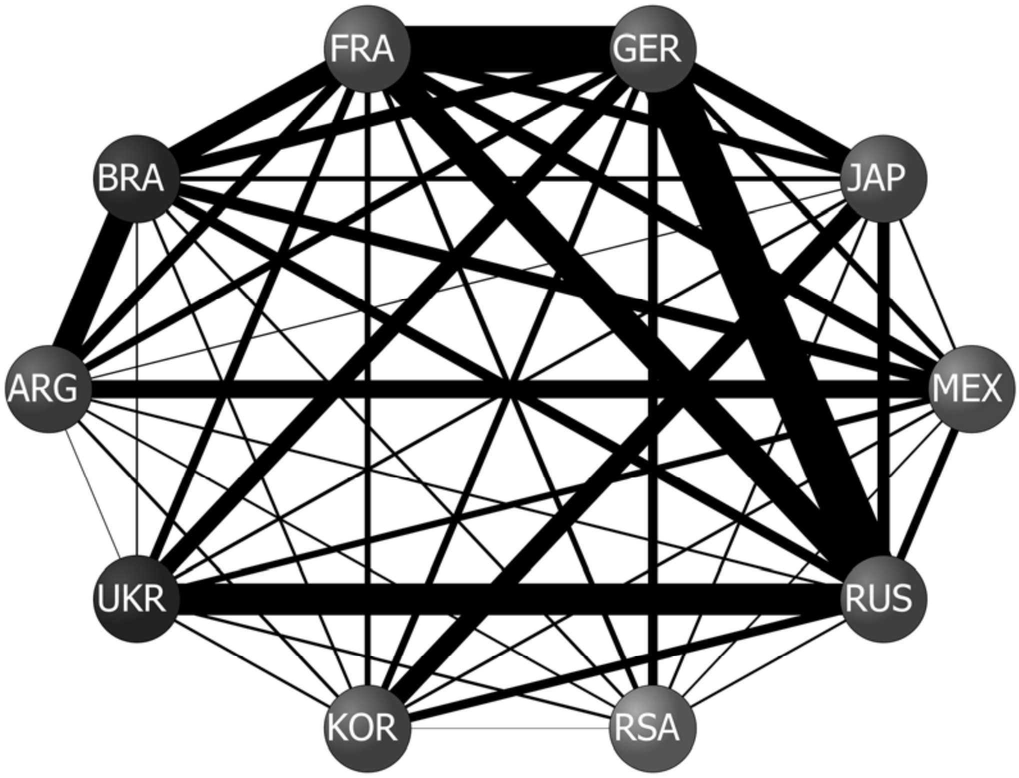
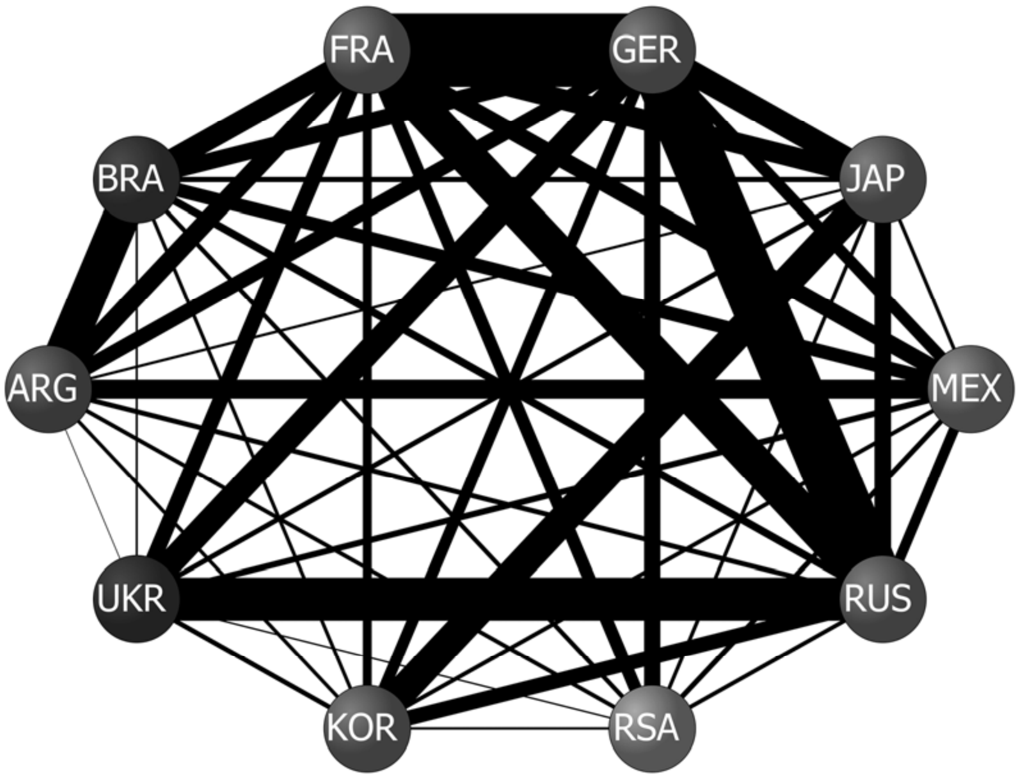

FRA
GER
BRA
JAP
ARG
MEX
UKR
RUS
KOR
RSA

Fig 11


FRA
GER
BRA
JAP
ARG
MEX
UKR
RUS
KOR
RSA

Tab 1

	Median of annual increase in publications
China	20%
Thailand	17%
Malaysia	15%
Vietnam	15%
South Korea	11%
Taiwan	11%
Singapore	10%
Indonesia	6%
Australia	4%
New Zealand	4%
Germany	3%
Japan	3%

Tab 2

Discipline specific citation rates for articles and reviews published in 2007	
Discipline	**Average citation rate**
Agricultural science	2.4
Biology and biotechnology	5.2
Chemistry	4.8
Energy	3.1
Engineering	2.4
Geosciences	3.0
Information and computer sciences	2.3
Materials science	3.4
Mathematics	1.6
Medicine	4.9
Nanotechnology	6.7
Physics	4.3

Tab 3

1998	AUS	CHN	IDN	JPN	MYS	NZL	SGP	KOR	TWN	THA	VNM
AUS	26233	251	54	506	36	447	93	58	63	51	17
CHN	251	20818	9	820	24	31	132	180	142	8	2
IDN	54	9	399	59	6	6	0	3	3	14	2
JPN	506	821	59	78504	31	100	64	529	179	129	25
MYS	36	24	6	31	849	3	29	4	1	15	3
NZL	447	31	6	100	3	5272	16	8	5	5	1
SGP	93	132	0	64	29	16	2991	4	34	5	1
KOR	58	180	3	529	4	8	4	11893	60	8	3
TWN	63	142	3	180	1	5	34	60	9617	7	1
THA	51	8	14	129	15	5	5	8	7	1179	11
VNM	17	2	2	25	3	1	1	3	1	11	253

2007	AUS	CHN	IDN	JPN	MYS	NZL	SGP	KOR	TWN	THA	VNM
AUS	39571	1630	115	823	94	930	403	270	211	204	56
CHN	1630	98957	31	2821	189	185	1003	1062	694	146	41
IDN	115	31	817	174	33	12	21	35	14	48	13
JPN	823	2821	174	89643	147	125	166	1429	640	477	119
MYS	94	189	33	147	2402	24	76	49	23	114	16
NZL	930	185	12	125	24	7462	65	48	29	32	4
SGP	403	1003	21	166	76	65	7741	84	117	45	11
KOR	270	1062	35	1429	49	48	84	33701	232	67	64
TWN	211	694	14	640	23	29	117	232	21221	47	11
THA	204	146	48	477	114	32	45	67	47	4254	45
VNM	56	41	13	119	16	4	11	64	11	45	855

Tab 4

1998					
Rank	**JAPAN (largest output)**		*Rank*	**INDONESIA (smallest output)**	
-	*total output*	*78504*	-	*total output*	*399*
1	USA	6071	*1*	USA	87
2	GERMANY	1314	*2*	JAPAN	59
3	UK	1212	*3*	AUSTRALIA	54
4	CHINA	820	*4*	GERMANY	34
5	CANADA	722	*5*	NETHERLANDS	31
6	FRANCE	678	*6*	UK	29
7	SOUTH KOREA	529	*7*	FRANCE	22
8	AUSTRALIA	506	*8*	THAILAND	14
9	RUSSIA	504	*9*	CANADA	13
10	ITALY	474	*10*	SWITZERLAND	10

2007					
Rank	**CHINA (largest output)**		*Rank*	**INDONESIA (smallest output)**	
-	*total output*	*98957*	-	*total output*	*817*
1	USA	8971	*1*	JAPAN	174
2	JAPAN	2821	*2*	USA	148
3	UK	2147	*3*	AUSTRALIA	115
4	GERMANY	1822	*4*	NETHERLANDS	93
5	CANADA	1719	*5*	UK	62
6	AUSTRALIA	1630	*6*	GERMANY	48
7	FRANCE	1113	*7*	THAILAND	48
8	SOUTH KOREA	1062	*8*	ITALY	36
9	SINGAPORE	1003	*9*	SOUTH KOREA	35
10	TAIWAN	694	*10*	MALAYSIA	33