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DEPARTMENT OF MANAGERIAL ECONOMICS, STRATEGY AND INNOVATION (MSI)

MSI 0710

# 'TRIAD' OR 'TETRAD'? ON GLOBAL CHANGES IN A DYNAMIC WORLD*

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## Abstract

The US-EU race for world leadership in science and technology has become the favourite subject of recent studies. Studies issued by the European Commission reported the increase of the European share in the world's scientific production and announced world leadership of the EU in scientific output at the end of the last century. In order to be able to monitor those types of global changes, the present study is based on the 15-year period 1991-2005. A set of bibliometric and technometric indicators is used to analyse activity and impact patterns in science and technology output. This set comprises publication output indicators such as (1) the share in the world total, (2) subject-based publication profiles, (3) citation-based indicators like journal- and subject-normalised mean citation rates, (4) international co-publications and their impact as well as (5) patent indicators and publication-patent citation links (both directions). The evolution of national bibliometric profiles, 'scientific weight' and science-technology linkage patterns are discussed as well.

The authors show, using the mirror of science and technology indicators, that the triad model does no longer hold in the 21st century. China is challenging the leading sciento-economic powers and the time is approaching when this country will represent the world's second largest potential in science and technology. China and other emerging scientific nations like South Korea, Taiwan, Brazil and Turkey are already changing the balance of power as measured by scientific production, as they are at least in part responsible for the relative decline of the former triad.

## Introduction

In some recent papers the impact and the competitiveness of national science systems have been analysed (*May*, 1997, *King*, 2004). Although their all-fields-combined approach provides a somewhat undifferentiated picture, the dominance of the USA, Japan and the large European countries is obvious. Above all, the US-EU race for world leadership in science and technology has become a favourite topic in both the EU (e.g., *REIST*-2, 1997, *REIST*-3, 2003, *Dosi* et al., 2005) and the US (e.g., *Shelton* and *Holdridge*, 2004). In Europe, more generally, the competition as well as the collaboration among the three world leaders in science and technology, namely among USA, EU and Japan, has come into the focus of interest. Following the tradition of political economy (*Ohmae*, 1985), the European Commission used the term 'triad' for this constellation. More recent studies (*Glänzel* et al., 2006, Hicks, 2005, *Leydesdorff* and *Wagner*, 2006, *Leydesdorff* and *Zhou*, 2005, *Zhou* and *Leydesdorff*, 2006, *Kostoff*, 2004), however, show that this model is becoming obsolete. According to the

* An extended version of this paper is presented at the *9th International Conference on Science and Technology Indicators*, Leuven (Belgium), 7-9 September 2006.

publication output indexed in the *Web of Science*, China has already overtaken France and is now challenging the position of Germany. China has an incredible average annual growth rate of its share in the database of almost 14%. This clearly parallels China's economic development. China has probably also overtaken France as the world's fifth largest economy last year (*ChinaDaily*, 2006). Thus, the question arises whether we might not better replace the old triad model by a 'tetrad'.

The objective of this paper is twofold, namely, to analyse the scientific and technological competitiveness of the four components of this tetrad, on the one hand, and to map the spectacular growth of other rising science systems in the world, on the other hand. Competition and collaboration among the leading and emerging scientific powers is shown to become the driving force of scientific and technological development in the era of globalisation.

## Data sources and methods

The paper is based on publication and patent data indexed in the *Science Citation Index Expanded* (SCIE) of the *Web of Science* and *Derwent Innovations Index* (DII) (both Thomson – ISI, Philadelphia, PA, USA). In order to be able to monitor the aforementioned global changes, the period 1991-2005 is studied. All papers recorded in the annual volumes of the Science Citation Index Expanded (SCIE) of the Institute for Scientific Information (ISI) as article, letter, note or review were taken into consideration. These papers were assigned to countries based on the institutional address given in the by-line of the publication. In addition to the USA, Japan and PR China and the set of selected dynamic countries, the supra-national region EU has been selected. In order to guarantee a fair approach and to obtain consistent results the EU15 has been used for the full period. Intra-EU co-publications have been de-duplicated to avoid double counting. Furthermore, intra-European co-publications among the member countries have not been taken into account when international collaboration of the EU15 was considered. Therefore, internationally co-authored publications of the EU always mean extra-European collaboration in this study.

A set of bibliometric and technometric indicators is used to analyse activity and impact profiles in science and technology. This set comprises publication output indicators such as the publication share in the world total, subject-based publication profiles; citation-based indicators like journal- and subject-normalised mean citation rates. In particular, we have used the following measures.

1. The *Mean Observed Citation Rate* (MOCR) is defined as the ratio of citation count to publication count. In this study a three-year citation window is applied.
2. The *Relative Citation Rate* (RCR) is the ratio of the previous indicator to the Expected Citation Rate per Publication which, in turn, is calculated on the basis of the three-year citation impact of the journals where the papers have been published (*Schubert* et al., 1983). This indicator measures whether the publications of a country or region attract more or less citations than expected on the basis of the journal impact measures. Since the citation rates of the papers are gauged against the standards set by the specific journals, this indicator is largely insensitive to the big differences between the citation practices of the different science fields and subfields.
3. The *Normalised Mean Citation Rate* (NMCR) is defined analogously to the RCR as the ratio of the Mean Observed Citation Rate to the weighted average of the mean

citation rates of the subfields to which the papers belong (*Braun* and *Glänzel*, 1990). This indicator is a second expected citation rate. In contrast to the RCR, the NMCR gauges the citation rates of the papers against the standards set by the specific subfields. The ratio of the two relative indicators uncovers national publication patterns, in particular, whether the entity under study is publishing in high or rather lower impact journals on an average. It should be stressed that in this study, a 3-year citation window to one source year is used for the calculation of both the enumerator and denominator of these relative indicators.

4. The *Activity Index* (AI), originally introduced in bibliometrics by *Frame* (1977), is used to analyse publication profiles. AI gauges the share of a country's or region's publication activity in a given field in its total publication output against the corresponding world standard. Both exact definition and interpretation of the Activity Index can be found in *Glänzel* (2000). As a consequence, a detailed description of this indicator will be omitted here. Since twelve major science fields* according to *Glänzel* and *Schubert* (2003) are used, this indicator can best be presented in a clockwork diagram.

The neutral value of all relative indicators used in this study is 1.0. Values greater (less) than 1.0 express a higher (lower) national standard then expected. In addition, indicators measuring the publication-patent citation links (both directions) are used to analyse science-technology linkage patterns and their impact on research.

**The 'Tetrad' model. Scientific productivity and research profiles.**

The two most recent European reports on Science and Technology Indicators (*REIST*-2, 1997, *REIST*-3, 2003) have announced that scientific productivity in the European Union has overtaken the North American Free Trade Agreement (NAFTA) consisting of the United States, Canada and Mexico. NAFTA had been the world's largest producer of scientific knowledge for decades, while the EU15 and Japan ranked second and third, respectively. The three economic, scientific and technologic super-powers USA, EU and Japan are often referred to as the 'triad'. This term was originally coined by *Kenichi Ohmae* (1985) for a large single market with common needs, the so-called 'triad market'. Ohmae argued that these three economies are the critical ones from a viewpoint of innovation, trade and investment. The term 'triad' has been adopted by science policy ever since to bring the three primary geopolitical entities in science and technology together under one umbrella. The triad's importance in science and technology is paramount. Table 1 presents the most active countries in the world's scientific publication output according to the SCIE in 1991, 1998 and 2005. The share of the EU15 publications in the world total – not shown in the table – amounted to 31.9% in 1991, 36.6% in 1998 and 34.6% in 2005. These data confirm the leading role of the triad in scientific production during the last 15 years.

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* **A**: Agriculture & Environment, **Z**: Biology (Organismic & Supraorganismic Level), **B**: Biosciences (General, Cellular & Subcellular Biology; Genetics), **R**: Biomedical Research, **I**: Clinical and Experimental Medicine I (General & Internal Medicine), **M**: Clinical and Experimental Medicine II (Non-Internal Medicine Specialties), **N**: Neuroscience & Behavior, **C**: Chemistry, **P**: Physics, **G**: Geosciences & Space Sciences, **E**: Engineering, **M** Mathematics

Table 1: The world's ten most active countries in scientific publications

| Rank | Country | 1991 | Country | 1998 | Country | 2005 |
|---|---|---|---|---|---|---|
| 1 | USA | 35.6% | USA | 32.3% | USA | 30.5% |
| 2 | *GBR* | 8.6% | JPN | 9.2% | JPN | 8.3% |
| 3 | JPN | 7.6% | *GBR* | 9.2% | *GBR* | 8.2% |
| 4 | *DEU* | 7.3% | *DEU* | 8.7% | *DEU* | 8.1% |
| 5 | SOV | 5.6% | *FRA* | 6.3% | CHN | 7.5% |
| 6 | *FRA* | 5.5% | CAN | 4.2% | *FRA* | 5.7% |
| 7 | CAN | 4.7% | *ITA* | 4.0% | CAN | 4.5% |
| 8 | *ITA* | 3.1% | RUS | 3.5% | *ITA* | 4.4% |
| 9 | IND | 2.4% | *ESP* | 2.8% | *ESP* | 3.3% |
| 10 | AUS | 2.2% | AUS | 2.7% | AUS | 2.9% |

About half the countries among the top ten producers are members of the European Union. Besides the EU15 members, the US and Japan are ranking at the top. Canada and Australia hold quite stable positions (rank 7 and 10, respectively), whereas India and the Soviet Union/Russia disappeared from the list in the 1990s. By contrast, China suddenly appeared among the ten most active countries right after 1998. According to its publication output, China presently ranks fifth in world behind the USA, the UK, Japan and Germany, and is now challenging Germany, the UK and Japan. If this trend continues, China will soon become the world's second largest producer of scientific knowledge behind the USA.

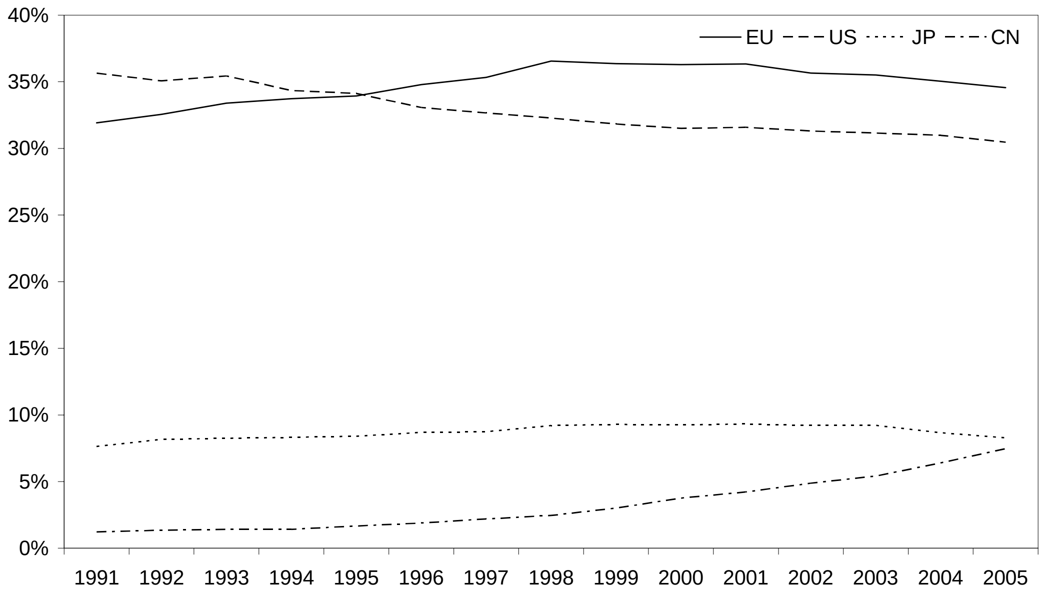


*Figure 1 Evolution of the share of publications of the triad members and China in the world total (1991-2005; all fields combined)*

Figure 2 shows the annual change of the shares of publication output of the EU, the USA, Japan and China in the world total during the last fifteen years. While still accounting for the largest part of ISI publications, the increase of the European share in the world's total publication output, resulting in overtaking the USA in 1995, has come to a standstill by the end of the last century. Recently, it has started to decrease, mirroring the falling US and Japanese shares. This already indicates that the world system of science is challenged by forces outside the triad. Even if we assume that the journal coverage and the constitution of the underlying bibliographic database has changed in favour of non-US and non-European journals, this fact alone might reflect that the balance of power has become different and the centre of gravity of the world system of science might be changing. This conclusion is in line with earlier findings by *Leydesdorff* and *Zhou* (2005).

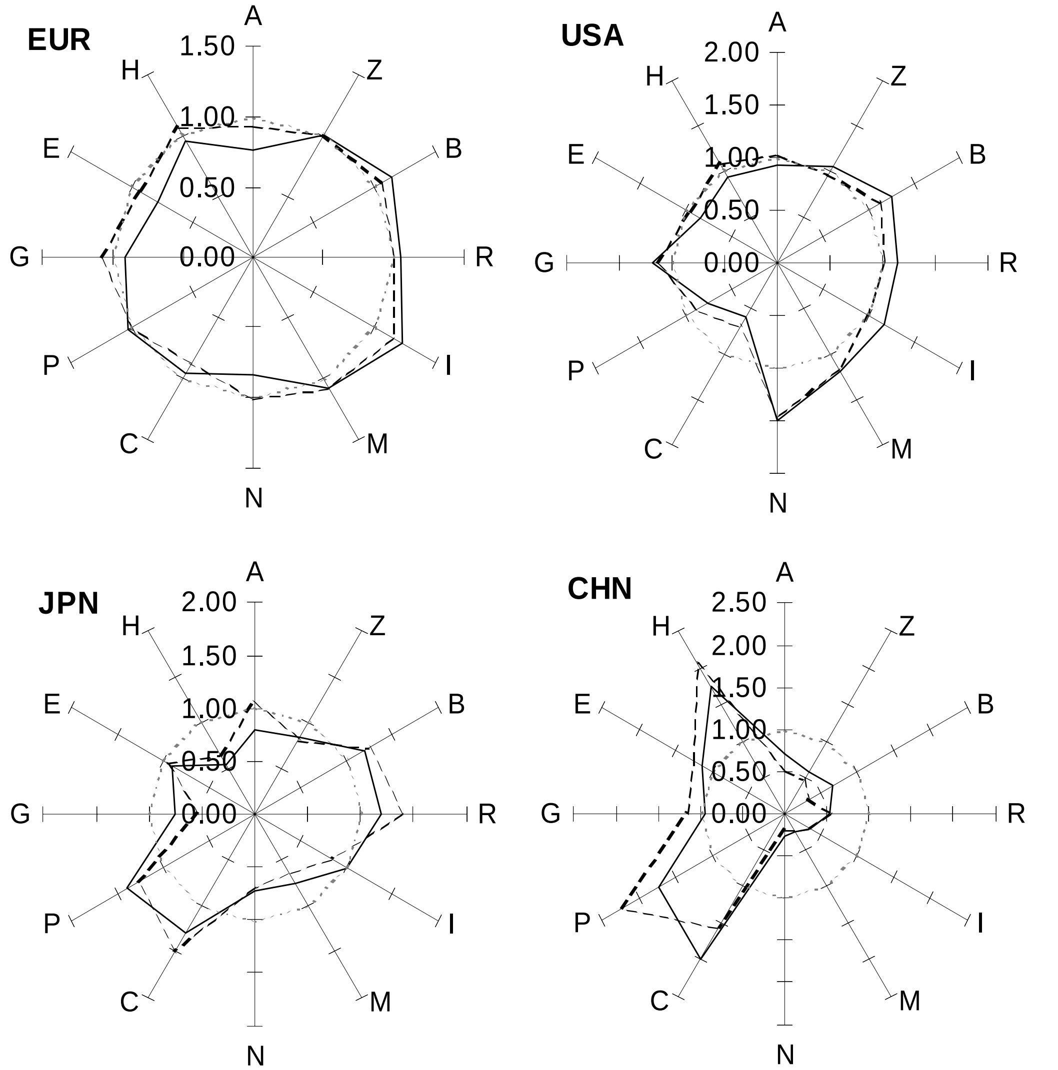


*Figure 2 Change of publication profiles of EU15, USA, Japan and China based on the Activity Index (dashed line = 1991, solid line = 2004, dotted line = world standard)*

However, China’s strong position in publication activity is not yet reflected in the citation impact of Chinese papers in most fields and subfields in the sciences. Trends in the citation impact of selected countries and the European Union will be discussed in detail in the following section.

The publication profile of China still considerably differs from that of the triad members, although a certain change towards the “standard” profile can be observed. This can, among others, be considered an effect of globalisation and intensifying collaboration. The most important partners can be found within the triad: USA, EU (above all Germany and UK) and Japan. Figure 2 presents the profiles of the triad members and China.

In principle, four basic paradigmatic patterns in publication profiles can be distinguished (cf. *REIST*-2, 1997), namely,

(1) the “western model”, i.e., the characteristic pattern of the developed Western countries with clinical medicine and biomedical research as dominant fields,
(2) the characteristic pattern of the former socialist countries, the present economies in transition and China with pronounced activity in chemistry and physics and less acitivity in the life sciences,
(3) the “bioenvironmetal model”, i.e., the pattern most typical for developing and more “natural” countries with biology and earth and space sciences in the main focus,
(4) the “Japanese model”, now also typical of the developed Asian economies with engineering and chemistry being predominant.

The EU and the USA clearly correspond to the western model (type 1) as they are very close to the world standard, which is practically set by the two most productive entities. The relatively low activity of the USA in chemistry and physics is known, and has been discussed, for instance, in *REIST*-2 (1997). Japan and China represent their own models (type 4 and 2, respectively), though a certain shift towards the world standard during the last fifteen years can be observed. This again substantiates the insight that the evolutionary process of macro-infrastructural changes is rather slow (cf. *Schlemmer* et al., 2004). By contrast, a recent meso-level study has shown that patterns of growth dynamics of Chinese universities publication output do not differ significantly from those found in the case of western countries (*Liang* et al., 2006).

## Towards a Patent Tetrad?

*Patent filings*

Patent data indicates that the Triad countries have been losing ground in the 1990’s even though they clearly remain the dominant force in world patenting accounting for more than 85% of global activity, irrespective of whether this is measured in terms of US or European patent data.

Nevertheless, an analysis of available data from the REIST-3 (2003) report on patent shares and growth rates suggest that a process of change is underway even though less pronounced as in terms of scientific publications. Figure 3 illustrates the rise in share of non-Triad patenting from around 7% at the beginning of the 1990’s to around 11% in both US and European patenting systems.

Looking at the period 1992-1999, the Asian economies have the most pronounced growth rates with an average annual growth of near, if not clearly above 20%, which outpaces the fastest growing European countries by almost three times (see Tab. 2 for details).[1]

More recently, there have been reports in the press (e.g. *Williams*, 2006) or by international organizations (*WIPO*, 2006) that suggest China’s patent filings have overtaken Germany’s. It is important to view these reports in context. While the data does reveal a substantial number and a seven-fold increase (over a decade) of filings with the national Chinese patent office, China compares to Sweden and Italy in terms of international patent applications (see Appendix 1). While China has demonstrated considerable growth

[1] Interestingly, China belongs only to the fastest growing countries in terms of European but not US patenting. Countries with fewer than 50 patents in 1999 have been excluded from the tables to avoid high growth rates associated with marginal patenting activity.

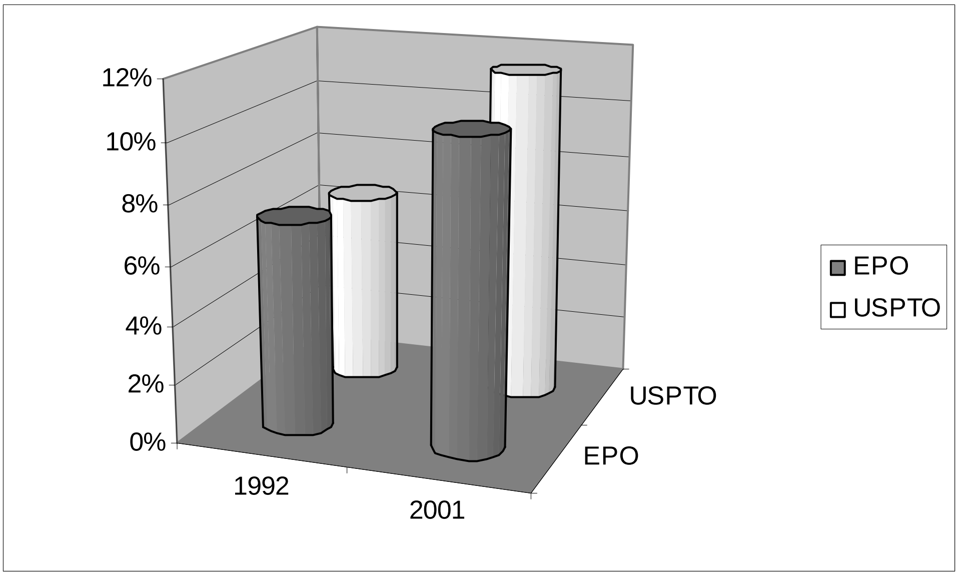


*Figure 3 Rise in non-Triad patenting 1992-2001(as observed through European and US patents).*

*Source: Authors' calculations based on data published in REIST-3 (2003)*

Table 2: Countries with fastest growth in patenting (based on average annual growth in patent share, 1992-1999)*

| Rank | European patents | Share Growth % | US patents | Share Growth% |
|---|---|---|---|---|
| **1** | China | 24.4 | Korea | 26.0 |
| **2** | Korea | 23.5 | Singapore | 22.9 |
| **3** | Singapore | 21.2 | Malaysia | 15.9 |
| **4** | New Zealand | 18.4 | Taiwan | 12.7 |
| **5** | Mexico | 15.7 | India | 11.3 |
| **6** | Israel | 12.6 | Argentina | 8.5 |
| **7** | Brazil | 11.7 | Hong Kong | 8.0 |
| **8** | Finland | 7.8 | New Zealand | 7.3 |
| **9** | India | 7.6 | Denmark | 6.8 |
| **10** | Ireland | 7.6 | Israel | 6.1 |

* Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.
*Source: Adopted from Tab. 6.1.2, REIST-3 (2003)*

*Linkage between science and technology*

Analogously to the macro patterns of research profiles, we still see a clear discrepancy concerning China if we compare how patents are cited by literature to how scientific papers are cited in patents. While US, Japanese and European papers are most cited in patents over the 10-year period 1991-2001, a still relatively small number of Chinese publications is cited in patents. Countries presented in Table 3 are ranked by the share of scientific publications with out-links and in-links to patents. The observation that papers cited by patents, thus highly technology relevant papers, are on average cited roughly four times as frequently as other papers is worth mentioning in this context. This ratio denoted by $q_{MOCR}$ has not changed much during one decade. The $q_{MOCR}$ values of most countries in Table 2 are in line with this rule of thumb. China's value of 8.0 is striking even if we take into account that citation impact is also influenced by peculiarities of national research profiles (see Figure 2). In any case, technology relevance considerably increases visibility and impact of Chinese publications. The other side of the coin, the number of papers with references to patents indicates that China has already caught up with the triad members. Combined with the strong growth in Chinese foreign patenting, this might point to a considerable build-up not only of substantial scientific and technological absorptive capacities but also of a proprietary technology base.

Table 3: The fifteen leading countries according to science-technology links based on patent citations based on the SCIE and DII databases ranked by country shares in world total ($q_{MOCR}$ denotes the ratio of the mean citation of papers cited by patents to that of all papers)

| Rank | Patent references* | | | | Patent citations** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | | 2001 | | 1991 | | | 2001 | | |
| | Ctry | Share | Ctry | Share | Ctry | Share | $q_{MOCR}$ | Ctry | Share | $q_{MOCR}$ |
| 1 | USA | 30.6% | USA | 26.3% | USA | 53.3% | 3.17 | USA | 46.0% | 3.63 |
| 2 | DEU | 9.3% | DEU | 9.2% | JPN | 10.2% | 2.72 | JPN | 12.0% | 4.30 |
| 3 | JPN | 7.6% | CHN | 7.9% | GBR | 8.3% | 3.66 | DEU | 10.0% | 4.05 |
| 4 | FRA | 7.1% | FRA | 6.8% | DEU | 6.8% | 3.35 | GBR | 9.1% | 4.08 |
| 5 | GBR | 6.5% | JPN | 6.8% | FRA | 5.2% | 3.50 | FRA | 5.8% | 4.92 |
| 6 | CAN | 3.6% | GBR | 6.3% | CAN | 4.6% | 3.25 | CAN | 4.3% | 3.98 |
| 7 | ITA | 3.2% | RUS | 6.1% | ITA | 2.4% | 3.26 | ITA | 3.4% | 3.17 |
| 8 | IND | 2.2% | IND | 3.8% | NLD | 2.3% | 2.92 | CHE | 2.8% | 3.18 |
| 9 | CHE | 1.8% | ITA | 3.8% | CHE | 2.1% | 2.95 | NLD | 2.7% | 3.18 |
| 10 | NLD | 1.7% | KOR | 3.4% | SWE | 2.0% | 2.84 | SWE | 2.7% | 3.33 |
| 11 | POL | 1.6% | CAN | 3.4% | AUS | 1.8% | 3.23 | AUS | 2.4% | 5.09 |
| 12 | ESP | 1.4% | ESP | 3.2% | BEL | 1.2% | 3.09 | ESP | 2.0% | 7.21 |
| 13 | RUS | 1.4% | NLD | 2.4% | ISR | 1.1% | 3.62 | KOR | 2.0% | 2.58 |
| 14 | BLG | 1.1% | CHE | 2.1% | ESP | 0.9% | 3.09 | CHN | 2.0% | 8.02 |
| 15 | CHN | 1.0% | POL | 1.9% | DNK | 0.9% | 2.85 | BEL | 1.6% | 4.10 |

* Patents cited by scientific literature
** Scientific literature cited in patents

## The new dynamic beyond the Tetrad. A bibliometric approach to global changes in a dynamic world.

Nonetheless, the tetrad in science and technology is already challenged by other nations. Based on the trends in national publication output and its relative growth, we have found four countries outside the EU with an *average relative annual growth* rate (ARAG) of more than 5% *and* a share in the world total publication output of 1% or more in 2004. These countries are Turkey and Korea (ARAG~16%–17%) and Brazil and Taiwan (ARAG~8%–9%). While their publication output is still not exceeding that of the medium-sized European countries, Canada, Australia or India, their publication growth is impressive. Among the four emerging nations, South Korea has, beyond any doubt, the greatest scientific weight. Table 4 presents the ranks that the five most dynamic countries held in the list of scientifically most productive nations during the last fifteen years. The changes indicate a spectacular increase of the publication output for China, Korea and Turkey. While Korea will be among the top ten countries soon, Brazil, Taiwan and Turkey form at present a cluster around position 18.

Table 4: Evolution of the ranks of the five most dynamic countries in the list of the world's most publishing countries

| Country | 1991 | 1998 | 2005 |
|---|---|---|---|
| **CHN** | 15 | 11 | 5 |
| **KOR** | 33 | 16 | 11 |
| **BRA** | 22 | 20 | 17 |
| **TWN** | 25 | 19 | 18 |
| **TRK** | 38 | 26 | 19 |

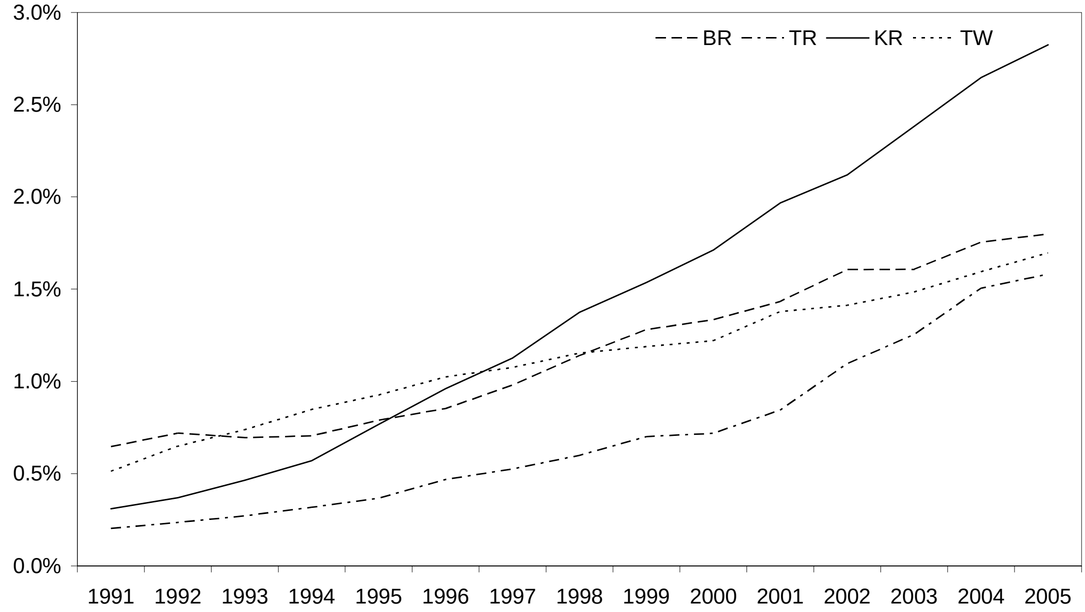


*Figure 4 Evolution of the share of publications of four dynamic countries in the world total (1991-2005; all fields combined)*

Figure 4 shows the growth of these four countries' relative publication activity with respect to the world total. While the strong increase of Korea's and Turkey's productivity is striking, that of Brazil and Taiwan is more moderate but decidedly continuous. In order to analyse in how far international collaboration might have contributed to this sharp raise, we have calculated the share of internationally co-authored paper in the corresponding national total for both the tetrad and the four emerging scientific powers Korea, Taiwan, Brazil and Turkey (see Table 5). The evolution of the share of internationally co-authored papers in all EU publications clearly parallels that of the US and Japan, and is in line with what we could consider the standard of the global development (cf. *Schubert* and *Braun*, 1990, *Glänzel*, 2001). Above all, Japan's collaboration with scientists abroad has considerably intensified.

The other selected countries, however, do not follow this trend. The evolution of the Chinese, Brazilian, Taiwanese and Korean collaboration shares are not unambiguous; the Turkish one is even regressive. The conclusion is rather striking. The dynamic growth cannot be explained by intensifying collaboration (cf. Turkey, China and Korea) whereas the relative decline of the triad is accompanied by increasing share of international co-publications.

Table 5: Evolution of the share of internationally co-authored papers of the Tetrad and four dynamic countries

| Country | 1991 | 1998 | 2005 |
|---|---|---|---|
| **EU15** | 13.5% | 21.5% | 27.7% |
| **USA** | 12.1% | 20.7% | 26.8% |
| **JPN** | 9.8% | 16.6% | 22.4% |
| **CHN** | 24.5% | 26.2% | 21.9% |
| **KOR** | 28.3% | 24.4% | 25.7% |
| **TWN** | 16.5% | 16.3% | 19.1% |
| **BRA** | 29.0% | 35.0% | 30.7% |
| **TRK** | 20.7% | 18.1% | 16.0% |

International scientific collaboration is assumed to increase citation impact, but several studies have also shown that collaboration does not always pay off (e.g., *Glänzel*, 2001). In the case of the tetrad and the four dynamic countries, the first statement holds, on an average, for collaboration with all international partners and in all fields combined. Again, the triad is characterised by stagnation, partially even by a certain regression (see Table 6). By contrast, the RCR values of the dynamic set (both of all papers and of international co-publications) reflect a powerful growth. Except for China and Korea, they do not reach the level of the triad as yet. The influence of international collaboration has become pronouncedly strong; while the RCR values of China's, Korea's, Taiwan's and Turkey's international co-publications still was rather moderate in 1991, indicator values of these countries evolved to distinctly higher-than-expectation in 2003. However, this does not tell anything about the countries' publication strategy so far. In order to gain deeper insight in national publication patterns and their effect on citation impact, we will have a closer look at the evolution of different relative citation-based measures as presented in Figure 5.

Table 6: Evolution of the Relative Citation Rate of internationally co-authored papers of the Tetrad and four dynamic countries

| Country | 1991 | | 1997 | | 2003 | |
|---|---|---|---|---|---|---|
| | All papers | Int. col. | All papers | Int. col. | All papers | Int. col. |
| **EU15** | 1.04 | 1.21 | 1.05 | 1.22 | 1.04 | 1.18 |
| **USA** | 1.07 | 1.22 | 1.09 | 1.24 | 1.10 | 1.21 |
| **JPN** | 0.97 | 1.19 | 0.97 | 1.20 | 0.94 | 1.10 |
| **CHN** | 0.67 | 0.85 | 0.79 | 0.95 | 1.02 | 1.11 |
| **KOR** | 0.72 | 0.91 | 0.88 | 1.06 | 0.94 | 1.10 |
| **TWN** | 0.75 | 0.89 | 0.78 | 0.94 | 0.87 | 1.12 |
| **BRA** | 0.75 | 1.00 | 0.76 | 0.90 | 0.86 | 1.05 |
| **TRK** | 0.62 | 0.85 | 0.70 | 1.03 | 0.90 | 1.17 |

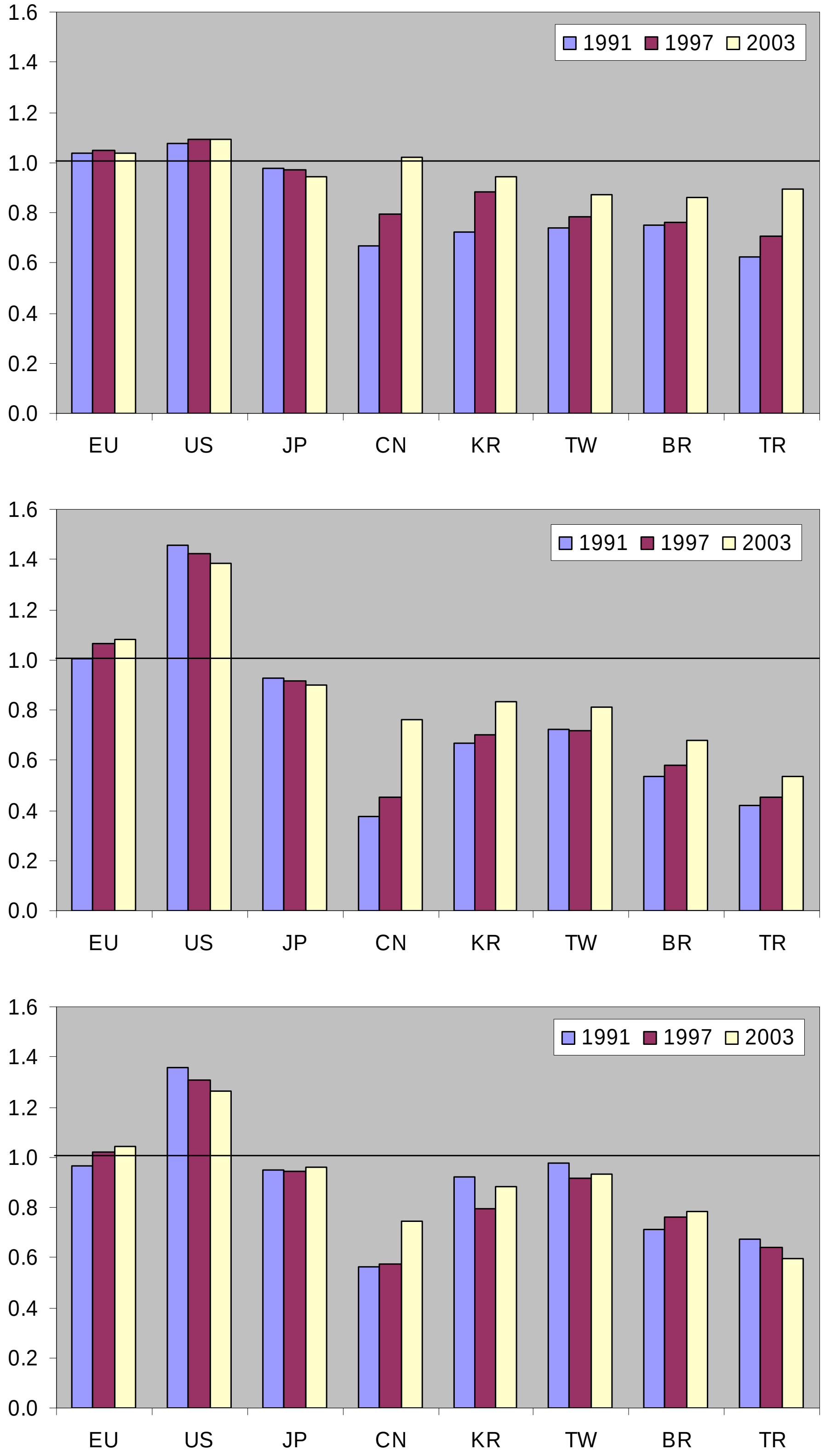


*Figure 5 Evolution of the citation impact of the Tetrad, Korea, Taiwan, Brazil and Turkey (top: RCR, middle: NMCR, bottom: NMCR/RCR)*

The diagram at the top of Figure 5 is the graphical presentation of the first columns in Table 6. Again, the triad's stagnation is contrasted by the powerful increase of RCR in China, Korea and Turkey. By contrast, the second diagram shows a slightly different picture. As mentioned at the outset, unlike the RCR indicator, the second relative citation indicator (NMCR) gauges observed citations against the respective subject standard. The European Union is the only member of the triad the NMCR of which still increases. China's normalised citation rate considerably grew, whereas the increase of the other dynamic countries is less pronounced. The subject-normalised impact of the five dynamic countries lies still distinctly below the neutral value of 1.0. The third diagram at the bottom reveals interesting details about national publication strategies. US scientists publish on average in journal with citation impact much higher than the world standard. Nonetheless, there is a pronounced trend towards decreasing journal impact. European, Japanese and Taiwanese authors select journals that are close to the world standard. Chinese, Brazilian and Turkish scientists still publish in lower-than-average journals but with opposite trends. Since there is apparently no clear correlation between international collaboration and journal impact at the macro level (cf. trends in Table 6 and Figure 5), the possible assumption whether Turkey's decreasing international co-publishing activity has at least partially contributed to this Turkish 'journal-impact decline' remains merely hypothetic.

The last question to be answered is whether these striking developments are accompanied by corresponding structural changes in publication profiles as well. At a first sight, the changes in the publication profile of the four dynamic countries outside the tetrad (see Figure 6) look more spectacular than within the tetrad (cf. Figure 2). It should be mentioned here that one important reason for this effect is merely the lower publication output of these four countries in 1991.

Both Brazil and Turkey rather correspond to the western model (type 1) while Korea and Taiwan are clearly representatives of the Japanese model (type 4). However, a certain shift of the latter two countries towards the western model can be perceived (see Figure 6). Brazil and Turkey have undergone remarkable changes. The striking changes in the Brazilian publication profiles have already been reported by *Leta* et al. (2006). Besides the predominance of physics and research in medicine, the strong increase of activity in chemistry and engineering accompanied by a decline of relative activity in biology and geosciences & space sciences, was one of the most remarkable features of the development in the last fifteen years in Brazil. This trend, which could be observed also at the institutional level, has to be interpreted in the context of new funds that have recently been created to improve the link between industry and academia. This is also an interesting case where changes in the macro-structure are mirroring meso-structural developments, that is, the national profile shift is not the results of the establishment of new institutions but rather it coincides with changes in the orientation of existing universities (cf. *Leta* et al, 2006).
The Turkish profile shows a similar spectacular shift, however, in the opposite direction. A pronounced decrease in relative publication activity in the natural and technical sciences coincides with the growing focus on life sciences and, above all, on agriculture & environment. Analogously to the Brazilian case, these changes can be considered an evolution towards a more 'western' profile. Although a certain shift from chemistry towards the life sciences can be observed in Korea and Taiwan as well, these countries remain typical representatives of the 'Japanese model'.

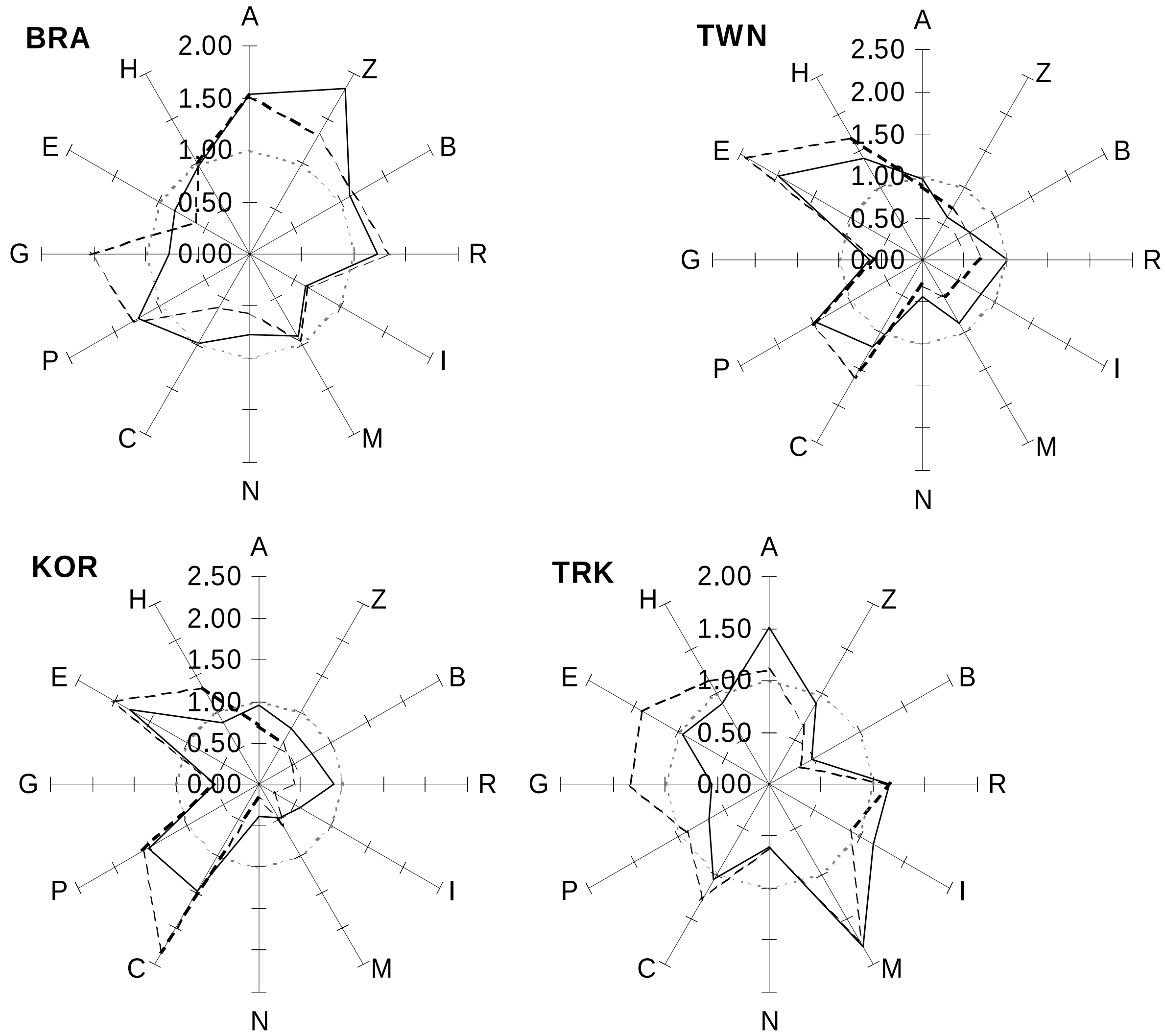


*Figure 6 Change of publication profiles of Brazil, Taiwan, Korea and Turkey based on the Activity Index (dashed line = 1991, solid line = 2004, dotted line = world standard)*

## Conclusions

The world system of science is currently undergoing dramatic changes. Although, Europe has become the largest scientific producer and source of potential in the world, the race between the USA and the EU for world leadership in science and technology has already been overshadowed by a new dynamic of a group of emerging nations. A fourth member has now joined the triad formed by the USA, EU and Japan. China has transformed this group into a tetrad; and other countries already started to compete for a position among the leading nations in science and technology. China and other emerging scientific nations like South Korea, Taiwan, Brazil and Turkey are already changing the balance of power, thus contributing to the relative decline of the former triad. Although the emerging countries have not yet reached the citation standard set and maintained by the former triad, the catch-up process is already in progress. In addition, their research profiles seem to converge to either the ‘western’ or the ‘Japanese’ paradigmatic structure.

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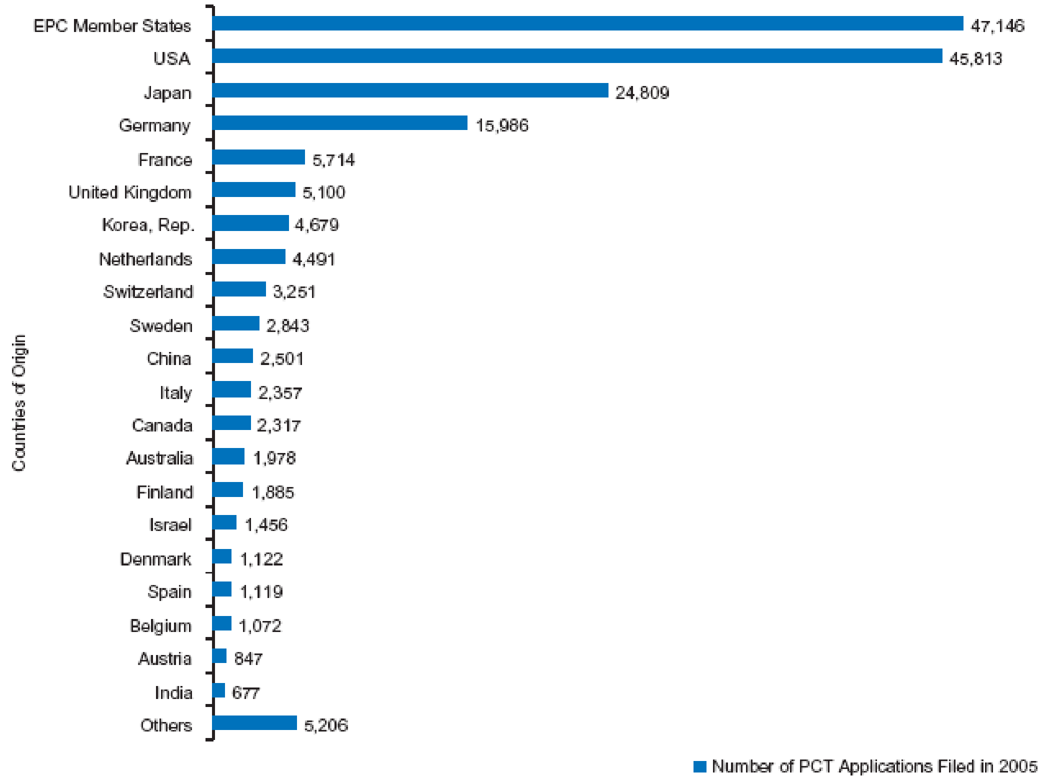
Appendix 1: *Country of Origin of PCT International Applications*




Source: WIPO (2006), Table E.3