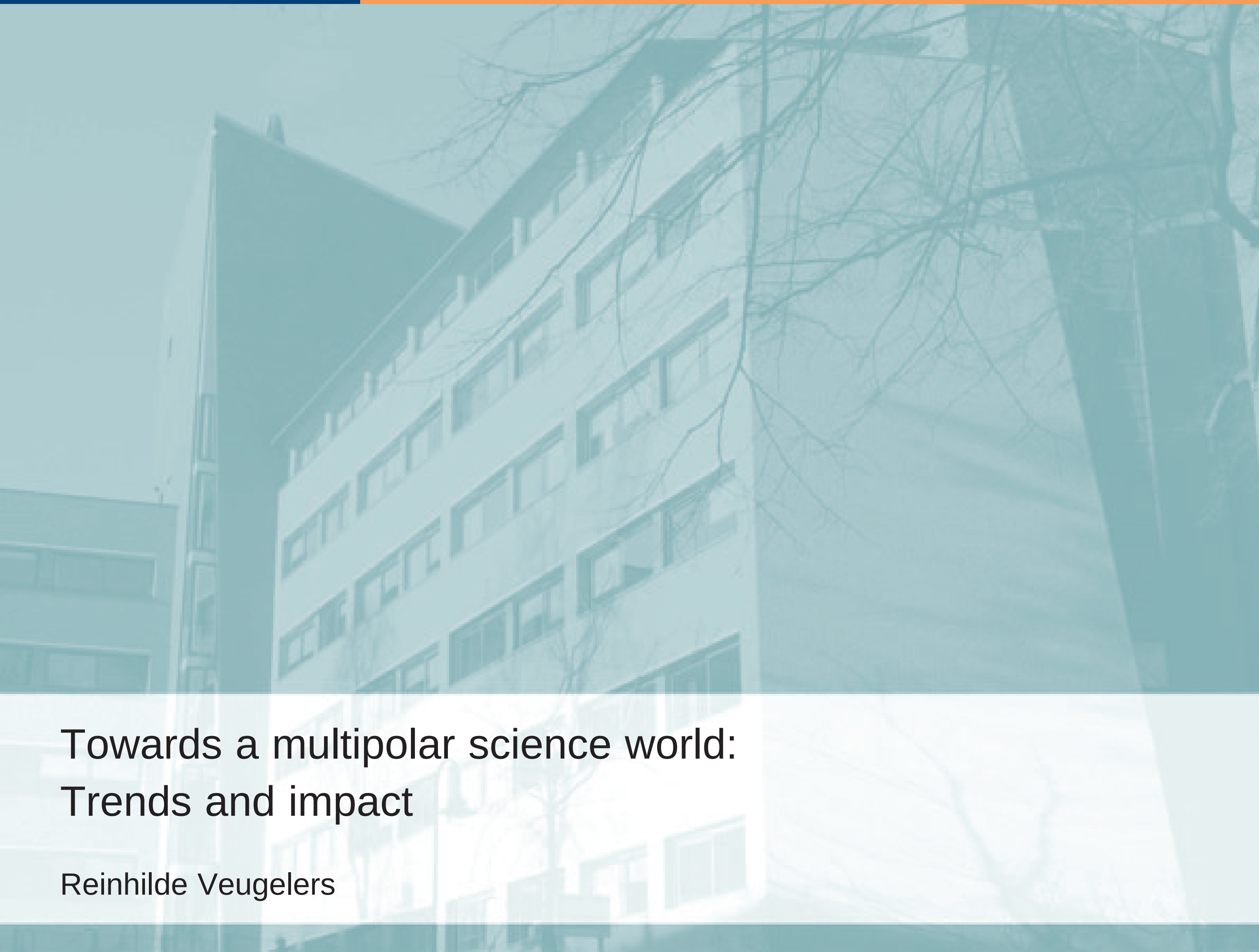
KATHOLIEKE UNIVERSITEIT
LEUVEN

Faculty of Business and Economics



Towards a multipolar science world: Trends and impact

Reinhilde Veugelers

DEPARTMENT OF MANAGERIAL ECONOMICS, STRATEGY AND INNOVATION (MSI)

OR 0808

TOWARDS A MULTIPOLAR SCIENCE WORLD:

TRENDS AND IMPACT

May 2008
Revised December 2008

Prof. Dr. Reinhilde Veugelers
University of Leuven (MSI & SOOS), Senior Fellow at Bruegel, and Research Fellow at CEPR [1]
Naamsestraat 69, B-3000 Leuven; reinhilde.veugelers@econ.kuleuven.be

Abstract

This paper brings together recent statistical evidence on international (co-)publications and (foreign) PhD-students and scholars to document shifts in geographic sources of scientific production and their impact. The evidence demonstrates that despite the continued dominance of the US and the increasing importance of the EU, the TRIAD is in relative decline. Other geographic sources of science outside the TRIAD are rising, both in quantity, but also, although still to a lesser extent, in quality. Especially China drives this non-TRIAD growth. This catch-up of non-TRIAD countries drives a slow but real process of global convergence. It nevertheless leaves a less equal non-TRIAD science community, as the growth of China, is not matched by other non-TRIAD countries.

Despite the rise of China's own scientific production, and the increasing return flows of overseas students and scholars, the outward flows of Asean talents have not diminished over time. The data suggest a high correlation between the patterns of international mobility of scientists and the patterns of international collaborations. The large and stable flow of Chinese human capital into the US forms the basis on which stable international US-Chinese networks are built. With the EU lacking this Chinese human capital circulation, it is more difficult to build up similar strong and stable networks.

[1] This paper was largely written when the author was at the EC-BEPA. It does not necessarily reflect the view of the EC. The author is grateful for the comments received from Paula Stephan, Peter Droell, Kurt Vandenberghe, Vitor Gaspar, Myriam Sochacki. Financial support from the Belgian federal government (PAI P6/09), KUL (OT/07/011) , FWO (G.0523.08) and EC-FP7 (Scifi-Glow) is gratefully acknowledged. All errors remain for the author.

1. Introduction

Science is becoming increasingly more globalised – with more countries now actively building their scientific capabilities and participating in world science and with scientific knowledge increasingly being created cross-borders.

Several factors drive the increasing globalisation of science. First there is the globalisation of the world economy. Firms are increasingly selling to and sourcing inputs from abroad. This also holds for their R&D activities, where firms are more and more looking for accessing scientific sources outside their local boundaries (e.g. Thursby & Thursby (2006)). This global science sourcing by multinational firms affects the institutions in research and higher education. Second, scientific talents are increasingly more internationally mobile, students as well as scholars. As a consequence, scientific institutions and firms are ever more competing for talents in a global market. Third, the cost of international scientific activities has drastically reduced. Particularly the ICT and Internet revolution has reduced the cost of international communication and boosted international exchanges in scientific work. Fourth, the research agenda is increasingly being made up of issues that have a global dimension, such as climate change, energy, safety, pandemics…Finally, policy makers are increasingly focusing attention on international S&T cooperation, funding programmes to stimulate internationalisation of higher education and research.

Nevertheless, also within science there are still forces counterbalancing the globalisation, such as the resilience of the national dimension in education, science and technology policy and public funding, proximity effects in the exchanges of tacit knowledge requiring face-to-face interactions; cultural and language barriers, and the inertia of personal and institutional networks.

Globalisation of science and its impact is very often talked about and with great animosity. Especially in the US, the decline of its dominant position in science, the rise of the Asian countries, and its dependence on (Asian) foreign scientists in the S&E workforce, raise deep concerns on the sustainability of US's capacity for scientific leadership, innovation and international competitiveness (e.g. NAS (2006), King (2004), Segal (2004), Freeman (2005)). But the debate also extends into the EU, evaluating its capacity to become the most knowledge based economy in a globalizing world. Most of the time, these debates are taking place without good empirical underpinning.

This paper takes stock of the recent evidence available to document (i) the geographic shifts in scientific production (section 2) and (ii) the impact this has on the global market for scientific talent (section 3.1) and partners for scientific collaboration (section 3.2). Section 4 concludes with some policy implications.

2. Trends in global sources of scientific production

To identify which countries are the major sources of scientific production, and more specifically to identify any major shifts in the geographic distribution of this production, we will look at both the output and the input side of the science process. On the **output** side, we will use the bibliometric information available on publications and citations (section 2.1)[2]. On the **input** side, we look at

[2] Standard bibliometric analysis relies on publications and citations as recorded by Thomson's ISI-Web of Science journals, which includes only journals that satisfy a number of quality criteria (internationally peer-reviewed). These journals carry some English-language bias as well as a disciplinary bias in favour of biomedicine and life sciences. Scientific output, i.e. increases in the stock of scientific knowledge, extend beyond what is measured in the standard publication databases. There are other forms such as books, working papers,

human capital for science, more particularly new PhD graduates (section 2.2)[3]. While sections 2.1 and 2.2 looks for the trends in global science production, section 2.3 investigates in more detail the process of convergence, i.e. whether there is a trend towards a more even distribution of geographic sources of scientific knowledge creation and a reduction in the inequality of the knowledge production process worldwide.

2.1. Global Science Trends: where are the publications being produced?

An important starting observation is that total number of world scientific publication has been increasing, at an average annual growth rate of 2% from 1995 to 2005. Although the size of the global cake has been growing, there are nevertheless important shifts in how the rising cake is being sliced.

The **US** had been and remains the single world's largest country in terms of scientific publications, although it has, since 1995, been outperformed by the EU, when taking as an integrated area.

Table 1: Share of the TRIAD and non-TRIAD in World scientific publications

	1995	**2000**	**2005**
USA	34%	31%	29%
EUROPEAN UNION	35%	35%	33%
JAPAN	8%	9%	8%
RoWEST*	9.3%	9.0%	9%
TRIAD	**86%**	**84%**	**79%**
ASIA (excl Japan)	5.3%	8.0%	12.8%
C/SAMERICA	1.7%	2.4%	2.9%
Other former USSR	4.1%	3.3%	2.5%
Near East/Africa	2.4%	2.4%	2.5%
NON_TRIAD	**14%**	**16%**	**21%**

Source: NSF, S&E Indicators 2008
S&E articles in all fields, ISI-publications
* RoWest= Canada, Oceania and other Western Europe; **RoWorld is the residual;

Nevertheless, the TRIAD as a group, has been losing share relative to **non-TRIAD countries**. This increase outside the TRIAD is mostly on account of the **Asian** continent (see also Hicks (2007)). In Asia, **China**'s scientific growth performance is the most impressive (see also Zhou & Leydesdorff (2006)).

Table 2: Share and growth (AAGR) of the BRICs in World scientific publications

	1995	**2000**	**2005**	**95-05** AAGR%
BRICs	7.2%	8.2%	11.4%	
CHINA	1.6%	2.9%	5.9%	16.5%
INDIA	1.7%	1.6%	2.1%	4.5%
RUSSIA	3.3%	2.7%	2.0%	-2.5%
BRAZIL	0.6%	1.0%	1.4%	11.1%

Source: NSF, S&E Indicators 2008
AAGR%=Average annual growth rate

With an average annual growth rate of 16.5%, **China** increased its position in world publications from almost non-exist to ranking fifth in 2005, behind the US, the UK, Japan and Germany. And n 2006 (not shown in NSF 2008), China became the world's second largest producer of scientific knowledge

[3] The formation and training of the scientific workforce, i.e. graduate and Phd students, can also be considered as an output dimension of the science system, creating the inputs for the future.

behind the US (Fraunhofer report, EC-Relex (2007)). China's increasing presence is particularly felt in specific scientific fields like Physics, Chemistry, and also Engineering, where China holds a comparative scientific advantage (Glänzel et al (2008)) [4].

China outperforms the other 3 **BRICs** countries with large economic growth (potential). While still being on par with **India** in 1995, China is in 2005 almost three times as large as India on publication output. The **USSR** still represented the 5th largest producer of scientific output in 1991. But after the split up of the country, its base has been steadily eroded (Wilson & Markusova (2004)). **Brazil**, although displaying an impressive growth performance, still is the smallest of the BRICs in absolute numbers of publications.

Beyond the spectacular rise of China, also other emerging scientific nations are changing the balance of power. **South Korea** and **Turkey** have an *average annual growth* rate of more than 10% *and* a share in the world total publication output of 1% or more in 2005, and thus represent, together with China and Brazil, the most dynamic sizeable countries in science production.

Most of the Asian increase can be found in the bottom end of the quality distribution of scientific (ISI) journals, mostly to the detriment of the US share there. But also in the TOP10 citation percentile journals, as well as in the TOP1, Asian countries are improving their position, but at a slower pace. Also the EU is catching up, particularly in the TOP1 segment. Nevertheless, none of these trends are yet able to challenge substantially the pervasive dominance of the US in the top end of the quality distribution, still representing more than half of the TOP1 articles.

Table 3: Trends in publications shares across the quality distribution

	Share in articles in TOP1 citation pc journals			Share in articles in TOP10 citation pc journals			Share in articles in BOTTOM50 citation pc journals		
	1995	2000	2005	1995	2000	2005	1995	2000	2005
USA	62	60	55	50	45	42	32	28	26
EU	25	26	29	32	35	34	33	35	34
ASIA10	5	6	7.5	7	9	12	14	17	21

Source: NSF, S&E Indicators 2008

Note: Top1: 99th percentile of citations received (>21); Top10: 90th percentile (>6); the Bottom50 contains the publications with 0 or 1 citations; 1995 are all 91-93 articles cited by 1995 articles; 2000 are all 96-98 articles cited by 2000 articles; 2005 are all 2001-2003 articles cited by 2005 articles.

2.2. Global Science Trends : where is the science workforce located?

Human capital is the most critical input factor in the science process. Unfortunately, there are no internationally and historically comparable data available on the science workforce[5]. This section presents the evidence there is on trends in the geographic distribution of new PhDs degree awarded[6] .

[4] Zhou & Leyderdorff (2006) illustrate how China has become a leading player in nanotechnology.

[5] Part of the problem is the wide diversity across countries on how to define the science community. There exists a wide heterogeneity across countries on the employing institutions (universities, public or private research institutes, public or private enterprises); on the qualifications (PhDs, masters, bachelors), on the professional activities included in science (S&E workforce);

[6] A number of remarks on the indicator being used: (i) not all PhDs end up in science and not all scientists have a PhD; (ii) the data only reflects the add-ons to the stock of already existing PhDs. To calculate stocks one would need a long time period of flow data and also information on exits, which are unfortunately not available; (iii) PhDs are allocated to countries on the basis of where they obtain their degree; but as

For the most recent year available, 2004, Table 4 provides the share of regions and selected individual countries in World number of PhD degrees awarded. The last column of Table 4 repeats the share in world publications, for comparison. Although the US is the Number 1 country for numbers of PhD degrees awarded, its top position is less dominant as in World publications. The US is the country with the highest ratio of publications per PhD degree awarded. The EU-27 delivers more than twice the number of US PhD degrees, and also the Asian region and the former USSR countries account for sizeable numbers of PhDs awarded. With the exception of Turkey, all BRICs and emerging science countries have a larger share in World number of PhD degrees awarded than their share in World publications.

Table 4: Doctoral degrees awarded (2004);
By regions awarding; By selected Triad/BRIC/Emerging Science countries awarding

COUNTRY	**Share in world PhD degrees awarded 2004**	**Share in world Publications 2005**
USA	14.7%	29%
Japan	5.9%	8%
UK	5.3%	6.4%
GER	9.1%	6.2%
Russia	10.4%	2.0%
China	8.2%	5.9%
India	4.8%	2.1%
Brazil	2.8%	1.4%
S. Korea	2.8%	2.3%
Turkey	0.9%	1.1%
REGION	**Share in world PhD degrees awarded 2004**	**Share in world Publications 2005**
EU-27	33.7%	33%
Asia	23.3%	21%
N America	16.1%	33%
Other former USSR	13%	2.5%
Near East/Africa	6.7%	2.5%
C/S America	3.9%	3%
RoWest	3.2%	5.4%

Source: own calculations on the basis of NSF, S&E Indicators 2008

Unfortunately, the data reported in Table 4 do not allow trend analysis. Only for a handful of countries, the number of PhD degrees awarded can be compared over time. The results in Table 5 are strikingly similar to the trends observed on the basis of scientific publications. The **US**, despite more or less maintaining the number of PhD degrees it awards, is seeing its market share decreasing, due to the catching up of others. The most impressive catching-up country is **China**. **India**, although it awarded twice as many PhDs than China in 1995, drops in the ranking because China and the UK rise faster. The quality of doctorate education in these catch-up countries surely is not yet comparable. But as the new doctoral programs develop in these countries, also this quality gap will diminish over time.

the following sections will demonstrate, international mobility of PhDs after graduation may shift these country allocations.

Table 5: Doctoral degrees awarded; by selection of countries awarding;

Rank		Number of doctoral degrees awarded 1995		Number of doctoral degrees awarded 2003*	AAGR 1995-2005**
1	USA	41747	USA	40740	0.4%
2	GER	22387	GER	23043	1.5%
3	JPN	12645	CHN	18806	18.7%
4	INDIA	9070	JAP	16314	2.9%
5	UK	7560	UK	14870	4.4%
6	S KOR	4462	INDIA	13733	4.2%
7	CHN	4364	S KOR	7172	5.8%

Source: own calculations on the basis of NSF, S&E Indicators 2008
Notes: All fields; No shares are calculated, because World total is not available and because data are not homogeneous enough across countries; * 2003 is selected because this is the most recent year comparable across all listed countries; **For India the latest year is 2003, for China & S Korea 2004;

2.3. Is there a process of convergence?

Do the trends documented in the previous sections imply a more general process of catching-up and convergence? Looking at several indicators to measure concentration/inequality (Table 6), we can see the real but nevertheless slow character of the process of convergence during the period 2000-2005. [7]

Table 6: Trends in convergence of scientific publications

Indicator for concentration/inequality	2000	2005
C1 Concentration ratio	0.31	0.29
C4 Concentration ratio	0.54	0.49
C10 Concentration ratio	0.74	0.71
C20 Concentration ratio	0.88	0.88
Herfindahl	0.12	0.11
GINI-coefficient	0.60	0.56
Relative Theil-coefficient	0.26	0.23

Source: Own calculations on the basis of NSF, S&E Indicators 2008
Note: on the basis of the 37 largest publishing countries only.
See Appendix for a discussion of the indicators;

The Theil coefficient, allows decomposing the total world inequality into subgroups, i.c. the Triad and the Non-Triad countries. This decomposition permits to analyse whether the trend in overall convergence is due to convergence between these two groups, which is the catching-up process of the Non-Triad countries, and/or because of convergence within each of these two groups.

Table 7: Decomposing the World's scientific inequality:
Triad versus Non-Triad (2000-2005)

[7] The results based on older bibliometric studies, before the rise of China, already validated a *real* but nevertheless *slow* process of convergence. Zitt & Bassecoulard (2004) report a drop in the Gini-index in the period from 1991 to 2000. But although they reported convergence, the inequality remained high, with the US maintaining a clear and dominant position. For citations, the inequality is even higher, but also shows a slight downward trend

	Rel T_{World} (1)	Rel T_{Triad} (2)	Rel $T_{Non\text{-}Triad}$ (3)	$Share_{Triad}$ (4)	Share of world inequality due	
					Between-group (5)	Within-group (6)
2000	0.26	0.26	0.14	0.84	23%	77%
2005	0.23	0.25	0.17	0.78	16%	84%

Source: Own calculations on the basis of NSF, S&E Indicators, 2008
Appendix contains a more detailed calculation of the Theil decomposition.

The *"between-group" inequality* only accounted for 23% of overall inequality. But this "between-group" component has decreased significantly over the period 2000-2005. This is clear evidence of the catching-up process of the non-Triad countries.

The *inequality within the non-Triad countries*, displayed in column (3) is markedly smaller than the inequality within the Triad countries (column (2)). But it has increased over the time period considered. This suggests that the catch-up process of the non-Triad countries has been very unequal. The dramatic rise of **China**, was not matched by other non-Triad countries. China has increased its share of non-Triad publications from 18% in 2000 to 27.5% in 2005. The *inequality within the Triad countries* has decreased somewhat. Most of the convergence intra-Triad is due to the EU catching up with the US.

To conclude, almost all of the reduction in world scientific inequality, is due to the Non-Triad countries catching-up. This catching-up is particularly a reflection of China's growth, which has at the same time been responsible for an increase in the inequality among the non-Triad countries.

3. The impact of the rise of new poles on world science

The previous section has demonstrated the rise of non-Triad countries, especially China, both in quantity and quality of scientific publications as well as in PhDs. This section examines the implications of this geographic shifts in scientific production on the global market for scientific talent (section 3.1) and partners for scientific collaboration (section 3.2).

3.1. International mobility of human capital

The spreading conviction that a highly educated workforce is key in successfully building growth economies, increased the global competition for scientific talents by science institutions, firms and countries (Freeman (2005)). Particularly in the human capacity constrained TRIAD countries, the rise of other science countries raises concerns of being able to attract foreign talents from these regions and concerns on reversing flows of talents returning home.

Before presenting the evidence on shift in shares of countries as destination or source of foreign talents, it is important to note that there is a remarkable lack of systematic cross-country and cross-time comparable data.

3.1.1. International mobility of tertiary students

A first important observation is that overall, the number of internationally moving students and scholars has increased. In 2005, there were 2.7 million foreign students enrolled in tertiary education outside their country of origin ((under)graduates and PhDs). This is a 50% increase as compared to 2000. (OECD, Education at a Glance 2007)).

The most important country of origin of these mobile students is not surprisingly **China**, followed by India. Korea (3.8%) and Japan (2.5%) further complement the Asian window. The other BRICs (Russia and Brazil) are less significant sources of foreign students. The most favoured destination for these foreign students was the **US.** There are however some marked differences for the BRICs in terms of countries of destination, with India's extreme focus on the US and Russia's strong favour for Germany and relative negligence of the UK and the US.

Table 8: Distribution of foreign tertiary students from BRICs to TRIAD destinations, 2005

		Country of destination			
Country of origin		**US**	**UK**	**GER**	**FRA**
China	**16%**	*23%*	*13%*	*7%*	*4%*
India	**5.5%**	*60%*	*12%*	*3%*	*0.4%*
Brazil	**0.7%**	*38%*	*6%*	*9%*	*9%*
Russia	**1.6%**	*12%*	*5%*	*28%*	*6%*
		27%	**17%**	**14%**	**6%**

Source: OECD, Education at a Glance (2007))

Note: Numbers in italics are the shares in row country's total number of students enrolled abroad. Shaded cells represent cases of "overrepresentation", i.e. where the share of the row country in the column country is larger than the total column country's share

3.1.2. International mobility of PhD students

As data for the US show, of all tertiary students, PhDs are the most internationally mobile (NSF, S&E Indicators (2008)). When zeroing in on PhD students only, the US is again the major recipient (OECD (2007)). [8] Despite the post-9/11 immigration troubles, the trend in number of foreign PhD students continues to increase. Non-citizens, primarily those with temporary visas, account for the bulk of the growth in S&E doctorates awarded by U.S. universities from 1985 through 2005. [9]

The overwhelming majority of foreign S&E PhD students in the US come from Asia, with **China** representing about 3 out of every 10 foreign S&E PhD, a share which does not seem to decline recently, on the contrary (Table 9). India's share of foreign PhDs in the US is more modest and has decreased steadily over time[10]. Chinese and Indian PhD students record the **highest stay rates** after graduation and this has only marginally decreased (Table 9) [11].

Hence, there are no signs as yet that the rising power of China's own indigenous scientific capability, as documented in section 2, has affected the mobility patterns of Chinese PhD students in the US significantly.

Table 9: Foreign recipients of US S&E Doctorates

[8] In absolute terms, the US ***enrolled*** about 79000 students in 2001 (no numbers reported for 2003), while the UK comes in second with 26000 in 2001, and 34500 in 2003.

[9] During this period, the number of S&E doctorates *earned* by U.S. citizens fluctuated from approximately 14,000 to about 17,000, while the number earned by temporary residents rose from 4,200 to a peak of 10,800 in 2005.

[10] India is a more important country of origin for foreign *graduate* students in the US, cf Veugelers (2008)

[11] Black & Stephan (2007) confirm with an econometric study, that the stay rates are larger for students from China and India, while lower for Brazil and Germany.

	NUMBER/SHARE OF FOREIGN S&E DOCTORAL RECIPIENTS			Plans to stay		
	94-97	98-01	02-05	94-97	98-01	02-05
TOTAL	**42490**	**37825**	**41071**	**71%**	**72%**	**74%**
CHINA	26.7%	26.3%	28.3%	96%	91%	92%
INDIA	11.8%	10.2%	8.7%	91%	88%	88%
S KOREA	9.5%	8.5%	9.9%	45%	63%	70%
BRAZIL	1.6%	1.6%	1.4%	32%	34%	43%
TURKEY	1.5%	2.5%	3.5%	58%	58%	60%
EUROPE	11.8%	16.3%	16.0%	68%	72%	75%

Source: NSF, Science and Engineering Indicators 2008

3.1.3. Foreign scholars in US science institutions

Foreign scholars are estimated to represent 30% to 40% of total university researchers in the United States. And this percentage has increased over time. In 2005/6, universities in the United States received almost 97000 **foreign scholars** (non-immigrant, non-student academics) against about 60000 in 1993/4 (NSF, S&E Indicators 2008)).

Expansion of the population of foreign scholars in the US has been driven by a massive and sustained influx of **Asian** academics. Although a large number of Asian academics already worked in US universities in the mid-1990s, the numbers from India and China have kept growing at average annual rates of 8% and 6%, respectively. As a consequence, **China** was in 2005/6 the leading country of origin, with around 20% of non-US scholars Chinese (OECD (2007)).

3.1.4. Return rates

Overall, with the large proportion of brains flowing into the US and the high stay rates, it is fair to say that US science and technology benefited substantially from the influx of scientific human capital. The dominant position which the US continues to enjoy in scientific rankings is increasingly being created by international human capital, especially from Asia. But this does not necessarily exclude benefits for the country of origin. Benefits can still flow to the country of origin, even when students are staying after their studies, and this through maintained links with their country of origin (section 3.2 will analyse links through co-publications) and/or when they return later in their research career.

Unfortunately, on return rates relatively little systematic evidence is available[12]. According to Statistics from the China Scholarship Council, between 1978 and 2004, 814884 Chinese students went abroad for studies. The number of students going abroad has particularly skyrocketed since the end of the 1990s. Despite the massive growth in number of outgoing students, the number of students returning to China grew even faster. According to the Chinese statistics, 197884 (i.e. almost 25%) have now returned. To increase the return rate of students, government institutions offer positions, funding and preferential tax treatment for overseas talent to come back and work in China[13]. The

[12] Table 9 only reflects (firm) plans to stay in the US for foreign students at PhD graduation.

[13] The Chinese National Natural Science Foundation offers research positions and funding for returning junior faculty members “Distinguished Young Scholars” . Also Chinese Science Academy’s “One Hundred Talent” Project, funds overseas talent to come back and work in China. Recipients are awarded research funds, receive housing, a laboratory, equipment, a research team.

Ministry of Education is setting up entire science parks and incubators where returned students and scholars are encouraged to set up shop under very favourable conditions.[14]

3.2. International co-production of scientific publications

Does the increasing rise of non-traditional science countries manifest itself in changing patterns of international scientific collaboration? In this section, we will look at trends in international collaboration, as measured through international co-publications[15].

3.2.1. Trends in international co-publications

A first important observation is an overall increase in international scientific collaborations. (Glänzel et al (2006)). However, for the fast emerging science countries, as their own science base grows, the share of international collaboration does not intensify over time, it even has declined in relative terms (see also Fraunhofer-EC-RELEX (2007) for similar results on China). But their shares were already historically higher than for other Triad countries (cf section 3.2.3 for more on the relationship between international collaboration and catch-up). The two BRICs countries which have no fast growth in scientific output, India and Russia, have a different trend in international collaborations: India scored historically very low in international collaborations, but has increased its share of international collaborations over time, along its steady but moderate growth in overall scientific output. Russia is a clear outlier: while overall its total scientific output decreased after the break-up of the country, its international scientific copublications did not decrease. International co-publications even increased, explaining Russia's high and increasing share for international co-publications.

Table 10: Trends in Share of international publications in total number of publications for BRICs and fast growing science countries

Country	1988	1996	2003
RUSSIA		26.8%	40.5%
INDIA	10.4%	16.1%	21.9%
BRAZIL	29.6%	41.8%	36.2%
CHINA	22.5%	28.0%	26.8%
S KOREA	27.4%	26.8%	28.0%
TURKEY	22.4%	22.6%	21.5%

Source: NSF, Science and Engineering Indicators 2006

3.2.2. Who collaborates with whom?

If we take a look at partnerships in international co-publications for 2005 (NSF, S&E 2008)), we see that the most important dyads still involve the US with a large Triad partner (resp Germany, UK, Canada, Japan). Nevertheless, the China-US dyad comes in 6th position; close behind US-France.

Table 11: Top 10 Dyads in International Co-publications

Share of Top-10 dyads in total number of international co-publications (2005))

[14] At the same time, more and more foreign students come to study in Chinese universities, mostly from Asia (South Korea, Japan, and Taiwan) and Africa. In 2004 there were 110000 foreign students in China. All this reflects the increasing attractiveness of the Chinese Higher Education institutions.

[15] International co-publications are not perfect measures of international collaboration. A few caveats: (i) not all international collaborative actions result in international co-publications and (ii) the results from international collaboration can also spill over to national (co-) publications.

	DYAD	Share in world international publications	International Collaboration Index
1	US-GER	5.9%	0.69
2	US-UK	5.8%	0.72
3	US-CAN	5.2%	1.19
4	US-JAP	4.0%	0.91
5	US-FRA	3.7%	0.59
6	US-CHINA	3.3%	0.91
7	US-ITA	3.1%	0.76
8	UK-GER	2.9%	0.79
9	GER-FRA	2.4%	0.86
10	US-AUS	2.1%	0.80
11	US-SKorea	2.0%	1.25
12	US-Nethl	2.0%	0.70
13	US-ESP	1.8%	0.61
14	US-SUI	1.7%	0.70
15	GER-RUS	1.6%	1.41

Source: Own calculations on basis of NSF, S&E Indicators, 2008

Note: shares do not add up to 100%; Articles are on whole-count basis, i.e. each collaborating country credited one count.

To account for unequal country sizes, the International Collaboration Index (ICI) is also given. It is calculated by dividing a country's rate of collaboration with another country by the other country's rate of international coauthorship: (ICPij/ICPj)/(ICPi/ICP). A number higher than 1 represents a larger than expected co-publication dyad. Shaded cells have ICI>1.

Table 12 looks in more detail to the partnering of top Triad countries with BRICs countries or other fast emerging science countries. For the US, China is the most important non-Triad partner, and also with South Korea and Turkey relatively strong ties exist. This pattern of co-authoring in publications is therefore remarkably similar to the pattern of foreign student flows (see section 2.2). For Japan, the importance of China and South Korea as partners, reflects closer cultural and geographic proximity and the strategic priority given to regional Asian collaboration [16].

Table 12: BRICs and fast growing science countries as partners for Top10 Triad science countries (2005)

	US	GER	UK	FRA	JPN	CAN	ITA	ESP	AUS
RUSSIA	3.5%	8.0%	3.5%	5.6%	4.9%	2.9%	5.4%	4.1%	2.0%
INDIA	2.1%	2.2%	1.6%	1.7%	3.3%	1.3%	1.3%	1.3%	2.0%
BRAZIL	2.6%	1.9%	2.1%	2.8%	1.2%	2.1%	2.1%	2.5%	1.5%
CHINA	7.5%	4.1%	4.6%	3.5%	12.8%	6.1%	2.4%	2.0%	8.8%
S KOREA	4.6%	1.3%	1.3%	1.2%	7.5%	2.2%	1.2%	1.1%	1.9%
TURKEY	1.2%	0.7%	0.8%	0.4%	0.6%	0.3%	0.8%	0.3%	0.3%

Source: Own calculations on basis of NSF, S&E Indicators, 2008

Cells give the share of the row country in the column's country's international co-publications.

Column ordering of countries is descending in the share of world international co-publications (US: 43.7%; GER:20%; UK:18.6%; FRA:14.4%; JPN:10%; CAN:10%; ITA:9.5%; ESP: 6.8%; AUS: 6.0%)

Row ordering of countries is descending in the share of world international co-publications (China: 8.2%; Russia:5.5%; South Korea: 3.7%; Brazil: 2.9%; India: 2.6%; Turkey:1.1%)

Shaded cells represent "strong" ties, i.e. where the share of the row country in the column's country's international co-publications is larger than the row country's share in world international co-publications.

[16] E.g., in 2006, the MEXT launched the Asia Science and Technology Strategic Co-operation Promotion Programme, encouraging Japanese research institutes and universities to start collaborative R&D projects with their Asian counterparts.

Ties between the EU and the BRICs and other emerging science countries are still very modest and often historically and geographically marked. For almost all EU countries, Russia is the most important partner, with China only second. This is despite Russia's declining share in world publications. Especially for Germany, the relationship with Russia is "strong". China is relatively weak as partner for EU countries. Only for the UK China comes first, before Russia; India and Brazil are the least important partners for Triad countries to collaborate with, commensurate with their lower share in world publications. Brazil's ties with Portugal and Spain carry a cultural and historical imprint[17]. India is perhaps the most strikingly absent BRICs' co-authoring partner for the EU (particularly surprising for the UK). Also the other emerging science countries, South Korea and especially Turkey, are still low on the radar screen of the top EU science countries for co-partnering.

Despite the still low importance of non-Triad countries as co-authoring partners, policy interests in these new emerging countries is rising in the EU, often influenced by a broad range of other than S&T policy issues. A recent survey in EU countries identified China as most often mentioned priority country for S&T cooperation (EC-DGRTD (2007)). [18]

Table 13: Top 5 co-publications partners of the BRICs & other Emerging Science countries (2005)

Rank	China		India		Russia		Brazil	
	Country	Share	Country	Share	Country	Share	Country	Share
1	USA	40%	USA	36.2%	GER	28.6%	USA	38.9%
2	JAP	15.7%	GER	17.3%	USA	26.9%	FRA	13.9%
3	UK	10.5%	JAP	13.1%	FRA	14.6%	UK	13.3%
4	GER	9.8%	UK	11.8%	UK	11.9%	GER	12.8%
5	CAN	7.4%	FRA	9.9%	ITA	9.3%	CAN	7.1%

Rank	S Korea		Turkey	
	Country	Share	Country	Share
1	USA	54.7%	USA	44.8%
2	JAP	20.2%	UK	13.9%
3	CHN	10.0%	GER	12.4%
4	GER	6.8%	ITA	6.9%
5	UK	6.7%	JAP	5.6%

Source: Own calculations on basis of NSF, S&E Indicators, 2008

Note: Table gives % in total column country's international co-publications. Shaded cells represent "strong" ties, i.e. where the share of the row country in the column's country's international co-publications is larger than the row country's share in world international co-publications.

Taking the perspective of the BRICs and the other emerging science countries (Table 13), we find also for these countries that the most important partners are the top Triad partners, with the US coming first, as it was also the major destination of human capital flows. The relatively strong ties between China, Japan and South Korea are an indication of Asian regional integration (Jin at al (2007)).

The EU is not a strong science partner for BRICs, with the exception of Russia. Not only is the EU not very high on the radar screen for Chinese collaborative efforts, the share of the EU-27 in total

[17] For Portugal, Brazil is the first BRICs partner before Russia, for Spain Brazil is the second partner after Russia.

[18] Co-publications between ERA countries and China have increased by 15% over the period (2000-2006) and represent the fastest rising category of extra-EU international collaboration (DGRTD, Key Figures 2008)).

Chinese international co-publications has even been declining over time. This does not hold for the US, whose share as partner for Chinese international collaboration has remained dominant over time[19]. This correlates with the large and stable flow of Chinese human capital into the US (see section 2.2), which forms the basis on which stable international US-Chinese networks are built. With the EU lacking this Chinese human capital circulation, it is more difficult to build up similar strong and stable networks. The same holds true for Korea and Turkey, where the dominance of the US as international partner for scientific co-publications also mirrors the strength of the flows of human capital from these countries to the US.

3.2.3. Impact of co-publications on catching-up in scientific quality

In this last section we want to investigate whether the international collaboration has been used by non-Triad fast emerging countries to fuel their growth/catching up process, documented in section 2. Whether international publications can be used as a mechanism to catch-up depends inter alia on the quality of the research done in international collaboration. International scientific collaboration is typically assumed to reflect higher quality research, as international partners can exploit more synergies from combining complementary capabilities. This is usually confirmed in bibliometric analysis when looking at citation rates as a quality measure (*Glänzel*, 2001): international collaborative research results in papers that are cited more than expected, at least on average, for collaboration with all international partners and in all fields combined. But does this also hold for catching-up countries?

As Table 14 illustrates, international co-publications have higher than expected citations for all countries considered, including for the catch-up countries. When considering trends over time, the TRIAD's international collaborative research quality is characterised by stagnation (partially even by a certain regression for Japan). By contrast, the RCR values of the dynamic set of countries reflect a substantial growth in quality of international collaborative research: while the RCR values of China's, Korea's, and Turkey's international co-publications still was rather moderate in 1991, indicator values of these countries evolved to distinctly higher than- expected levels in 2003. Brazil had the lowest increase in RCR values, it also had the lowest growth rate among the fast emerging countries. Turkey has the highest growth, but also the smallest absolute numbers. With most of their international collaborations with top Triad countries (as Table 12 has shown), the increase in the quality of their international collaborative research, has helped these fast emerging countries to catch up.

But since the share of international collaboration is not on the rise (see Table 10), the catching-up in overall quality of these countries, seems not only due to the higher quality of international collaborative research, but also has to be based on an increase in the quality of nationally produced research. Part of this increase in the quality of domestic (co-)publications should also be, at least partly, associated with domestic science capacity building. This domestic capacity building could nevertheless, at least partly, be from absorbing and learning from the frontier countries. International scientific spillover can be an important contributor to these countries own indigenous science building, as these countries have a high international openness.

Table 14: Evolution of the Relative Citation Rate of internationally co-authored papers

	1991		1997		2003	
	All papers	**Int Coll**	**All papers**	**Int Coll**	**All papers**	**Int Coll**
EU15	1.04	1.21	1.05	1.22	1.04	1.18
US	1.07	1.22	1.09	1.24	1.10	1.21

[19] Compared to co-publications between ERA countries and China (2000-2006), which have been growing at 15%,, other Chinese international co-publications have risen faster (with US: 19%, with Other Asia-Oceania: 17%) (DGRTD, Key Figures 2008)).

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
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

Source: GLÄNZEL ET AL (2006)

4. Conclusions

The evidence on scientific publications and workforce clearly demonstrates that despite the continued dominance of the US and the increasing importance of the EU, the TRIAD is in relative decline. Other geographic sources of science outside the TRIAD are rising, both in quantity, but also, although still to a lesser extent, in quality. Especially China drives this non-TRIAD growth. The data show a slow but real process of increasing convergence, with the catch-up of non-Triad countries and the sources of new scientific knowledge more evenly spread across the globe. This global convergence nevertheless leaves a less equal non-TRIAD science community, as the growth of some emerging countries, i.c. China, is not matched by other non-TRIAD countries. The process of growing international integration can not yet be associated with the shaping of a truly global integrated research community, but rather a **multi-polar** one.

Despite the rise of Asia's own scientific production and the relative decline of the US, The international flows of students and scholars, mostly originating from Asia and destined for the US, have not diminished over time. On the contrary, they continue to increase.

Even though international co-publications are on the rise and important for the emerging countries, the patterns of scientific collaboration are sticky and only change gradually. Ties with the BRICs and other emerging science countries are often historically and geographically marked. The data suggest a high correlation between the patterns of international mobility of scientists and the patterns of international collaborations. This correlation may explain why particularly the US, being a central node in the labour mobility patterns, also continues to be a central node for international scientific collaboration with the non-Triad countries. China's spectacular rise in the scientific publication rankings has not yet made it into a commensurate partner position for especially EU countries, although it has attracted recent policy attention for targeted preferential ties.

On who reaps the benefits from global integration, the evidence suggests a win-win, with the quantity and quality of scientific publications increasing for all countries involved, although the benefits are (potentially) larger for catch-up countries, particularly for those catch-up countries that succeed in actively tying their own domestic scientific capabilities to the process of global science integration. Catch-up countries with a high outflow of own students seem most successful in catching-up. Despite the high stay rates, the country of origin can still benefit if these students return in later stages of their career and/or keep connected with their home country. The large similarity between the pattern of flows of people and co-publications is suggestive in this respect. But, as the heterogeneity among the catch-up countries has shown, global integration is not a necessary nor sufficient condition for catching-up. Other aspects need to be factored in, such as the relative strength of the domestic science system and its capacity to absorb and learn from the global knowledge frontier.

What does the rise of non-TRIAD countries and particularly China's rise in the global science community, bear for the scientific and economic position of the West? Will the erosion of the TRIAD dominance in science diminish its advantage in knowledge based value creation? In any case, the issue will not be how to hide away from the process of global integration of science, but rather how to benefit from it as much as possible. Countries will need not only to improve the competitiveness of their national science and innovation systems in a global environment, but to learn better how to connect into global science networks to achieve national benefits.

When Freeman (2005) asked a Harvard physicist, whose most important work was done collaboratively with overseas scientists and engineers, "so you are helping them catch up with us", the scientist replied: "no, they are helping us keep ahead of them". As the recent data seem to suggest, with the rapid catch-up of non-Triad countries, that may be a serious challenge for the future, even more so for the EU than for the US. Although recent policy communications suggest that policy makers are at least aware of the challenges, having more and better quality evidence on the process and effects of global science integration, would allow them to better design policy initiatives.

References

Black, F. and P. Stephan (2007), *The importance of foreign PhD students to US Science*, in P. Stephan and R. Ehrenberg (Eds), Science and the University, The University of Wisconsin Press.

EC-DG Research (2007), CREST-WG Report on "*Internationalisation of R&D-Facing the challenges of Globalisation,* Brussels.

EC-DG Research (2008), *Key figures 2008,* Brussels.

EC-DG RELEX (2007), Fraunhofer report on EU-China S&T relations, Brussels

Freeman, R., (2005), *Does globalisation of the Scientific/Engineering workforce threaten US economic leadership?* NBER Working Paper 11457.

Glänzel, W. (2001) National characteristics in International Scientific Co-authorship, *Scientometrics*, 51, 1, 69-115.

Glänzel, W., K. Debackere, M. Meyer (2008), Triad or Tetrad? On global changes in a dynamic world, *Scientometrics*, 74, 1.

Hicks, D., (2007), *Global research competition affects measured US academic output*, in P. Stephan and R. Ehrenberg (Eds), Science and the University, The University of Wisconsin Press.

Jin, B., Rousseau, R., Suttmeier, R. and Cao, C (2007), The role of ethnic ties in international collaboration : the overseas Chinese phenomenon, Proceedings of ISSI 2007 : 11th International Conference of the International Society for Scientometrics and Informetrics, 427-436.

King, David, "The Scientific Impact of Nations," *Nature*, Vol. 430, 2004, pp. 311–316.

OECD (2007) *STI Scoreboard*, Paris

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, Committee on Science, Engineering, and Public Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Washington, D.C.: National Academies Press, 2006.

National Science Foundation (2008), *Science and Engineering Indicators*, 2008

Schubert, A. and W. Glanzel (2006), Cross-national preference in co-authorship, references and citations, *Scientometrics*, 69, 2, 409-428.

Segal, Adam, "Is America Losing its Edge? Innovation in a Globalized World," *Foreign Affairs*, November–December 2004, pp. 2–8

Thursby, J. and M. Thursby (2006), *Here or There? A survey of factors in multinational R&D location*, The National Academies Press, Washington D.C

Veugelers, R. (2008), Globalisation of Science: Trends, Modes and Impact, KUL-MSI WP.

Wilson, C. and Markusova V. (2004) changes in the scientific output of Russia from 1980 to 2000, as reflected in the Science Citation Index, in relation to national politico-economic changes, *Scientometrics*, 59, 3, 345-389.

Zitt, M. and E. Bassecoulard (2004)," Internationalisation in science in the prism of bibliometric indicators", in F. Moed, W. Glänzel and U. Schmoch (eds.), *Handbook of Quantitative Science and Technology*

Research – The Use of Publication and Patent Statistics in Studies of S&T Systems, Kluwer Academic Publishers, 407-436.

Zhou, P. and L. Leydesdorff (2006), The emergence of China as a leading nation in Science, *Research Policy*, 35, 1, 83-104.

APPENDIX: MEASURES FOR CONCENTRATION/INEQUALITY

Concentration ratios calculate the share of the largest entities in the total: CN=Share of the N largest countries in the total world publications (C4, C10, C20..).

The **Herfindahl index**, is a measure of concentration widely applied in competition law and antitrust. It is defined as the sum of the squares of the shares of each individual country : ie the sum of the weighted shares of each country, with the weights being the country share. As such, it can range from 0 to 1 moving from a very large amount of very small countries to 1, reflecting a single monopolistic producer.

The **Gini-coefficient** is a measure of inequality, often used as a measure of inequality of income distribution or inequality of wealth distribution. It is defined as a ratio with values between 0 and 1: A low Gini coefficient indicates more equal income or wealth distribution, while a high Gini coefficient indicates more unequal distribution. The Gini coefficient is the area between the line of perfect equality and the observed Lorenz curve, as a percentage of the area between the line of perfect equality and the line of perfect inequality. The **Lorenz curve** is a graphical representation of the cumulative distribution function. In casu, it would represent the distribution of publications, where it shows for the bottom *x*% of countries, what percentage *y*% of the total world publications they have.

The **Theil index**, is another statistic used in economics to measure inequality. It is calculated as follows:

$$T=1/N * (\sum_I (\ln (PUB_I / avgPUB_{WORLD}) * (PUB_I / avgPUB_{WORLD})$$

As the Theil coefficient varies from 0 to its maximum value (ln N), a relative version of the Theil coefficient is most often used, which varies from 0 to 1.

Relative T index= T/ Max T with Max T= ln N with N=number of countries

Decomposing the Theil Index

$$T_{World} = T_{within} + T_{between}$$

$$T_{within} = s_{TRIAD} * T_{TRIAD} + s_{NTRIAD} * T_{NTRIAD};$$

$$T_{between} = s_{TRIAD} * \ln (avgPUB_{TRIAD}/avgPUB_{WORLD}) + s_{NTRIAD} * \ln(avgPUB_{NTRIAD}/avgPUB_{WORLD})$$

Decomposing the World's scientific inequality:
Triad versus Non-Triad (2000-2005)

	Relative T= T_{World}/MaxT	**T_{World} =**	**$T_{between}$ +**	**T_{within}**	**$Share_{Triad}$**	**T_{Triad}**	**Relative T_{Triad}**	**$T_{Non-Triad}$**	**Relative $T_{Non-Triad}$**
2000	0.26	0.97	0.22	0.75	0.84	0.81	0.26	0.42	0.14
2005	0.23	0.87	0.14	0.73	0.78	0.79	0.25	0.51	0.17

Source: Own calculations on the basis of NSF, S&E Indicators, 2008

* Only countries with at least 1000 publications are included (N=42, of which 22 in Triad and 20 Non-Triad). This set represents 97% of all world publications;