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What do bibliometric indicators tell us about world scientific output?

This issue of the UIS Bulletin on Science and Technology Statistics, published in collaboration with the Institut National de la Recherche Scientifique (INRS) (Montréal, Canada), presents a bibliometric analysis of 20 years of world scientific production (1981-2000), as reflected by the publications indexed in the Science Citation Index (SCI), with a particular emphasis on developing countries.

What are bibliometric indicators?

Bibliometric indicators seek to measure the quantity and impact of scientific publications -as a proxy for the overall output of scientific research- and are based on a count of scientific papers and the citations they receive. Together with patent indicators, they are one of the most frequently used indicators of research and experimental development (R&D) 'output'. Bibliometric indicators have been widely used in national science and technology statistics publications to measure scientific capacity and linkages to world science, both in developed and developing countries.[1]

Bibliometric indicators are also increasingly used in evaluation processes at universities and public and private research institutions, in addition to establishing various types of incentives for researchers. Used in 'peer-review' processes, bibliometric indicators take advantage of the "publish-or-perish" pressure that drives productivity and pushes scientists to publish in the most widely read and cited journals, seeking to increase the "scientific impact" of their research results.

[1] Bibliometric indicators made one of their first appearances in such reports in: National Science Board, *Science Indicators 1972*, Washington D. C., 1973.

What can bibliometric indicators tell us?

Bibliometric indicators are constructed using databases of scientific papers. The most frequently used, and most likely the best suited database for bibliometric purposes, is the *Science Citation Index (SCI)*[2]. This database indexes papers from a group of journals which are considered by the editors to have the highest impact; that is, the ones most frequently cited in other papers. The journals included have an international scope, covering "mainstream science", in a large number of scientific disciplines *(see Box 1)*. Papers published in these journals tend to be overwhelmingly written in English.

Box 1
Classification of fields of science covered by *SCI*:
- Biology
- Biomedical research
- Chemistry
- Clinical medicine
- Earth and space
- Engineering & technology
- Mathematics
- Physics

These characteristics of the data-base present both advantages and disadvantages for measuring scientific output. On one hand, they provide information about the numbers,

[2] SCI is published by Thomson ISI (www.isinet.com).

character and impacts of scientific output in a given country or region, or in a given discipline, as well as on the intensity and type of linkages between countries, research institutions, or even individual researchers.

On the other hand, they pose certain problems for the interpretation of indicators, particularly as they relate to scientific output in developing countries:

- The inherent linguistic bias tends to hamper access to publication by (non-Anglophone) authors from developing countries, who frequently have difficulties in writing in English and lack resources for translation.
- The international scope implies that the scientific research published in national journals, frequently in national language and targeting problems of local interest, is insufficiently covered.
- The limited coverage, excluding in particular social and human sciences[3] and concentrating more on basic science than on applied science or technological development, implies that these data do not reflect the full scope of R&D activities.

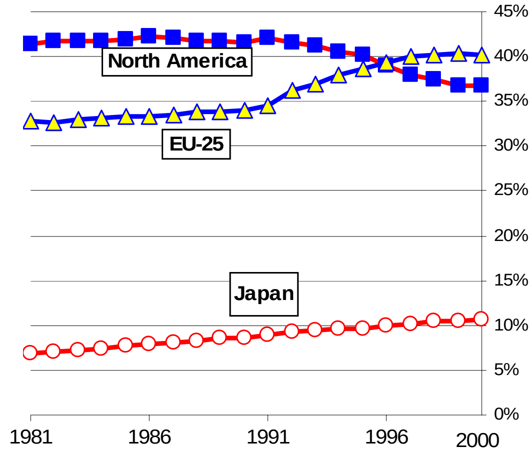
Keeping in mind their pros and cons, bibliometric indicators still provide the best available measures of scientific "output" by the world's countries.[4]

Scientific publications statistics

In 2000, the SCI included a total of 584,982 papers, representing a 57.5% increase from 1981, when 371,346 papers were published worldwide. Authors with addresses in developed countries[5] wrote 87.9% of the papers in 2000, a decrease from 93.6% in 1981. Developing countries, on the other hand, saw a steady increase in their share of scientific production: from 7.5% of world papers in 1981 to 17.1% in 2000. It is worth noting that this is due to the growth in some particular regions, as shown in Figure 2 and discussed below.

Since 1981 the world map of publications changed significantly *(see **Figure 1**)*. North America lost the lead it had in 1996, and in 2000 produced 36.8% of the world total,

Figure 1: Share of world publications: North America, EU & Japan, 1981-2000



a decrease from 41.4% in 1981. The opposite trend can be found in the European Union, which in 2000 published 40.2% of the world total, up from 32.8% in 1981. Japan went up from 6.9% to 10.7% in 2000. Collectively this 'triad' has therefore maintained its dominance, accounting for 81% of the world total of scientific publications in 2000, up from 72% in 1981.

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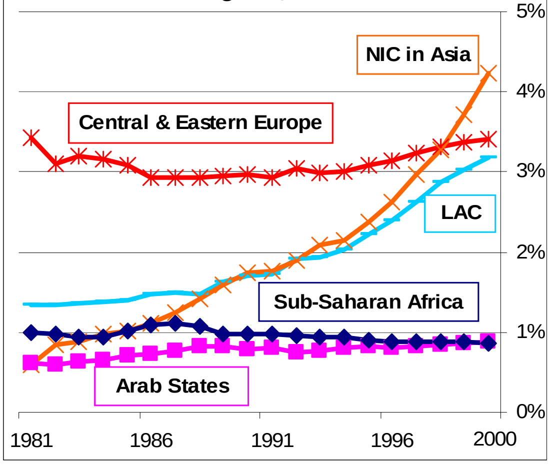
3 These fields of science are covered in other Thomson ISI databases (i.e. Social Science Citation Index, Arts and Humanities Citation Index), which are not so widely used in bibliometric indicators, partly due to the bias towards the English language mentioned before and to the fact that researchers in these disciplines frequently publish other type of work, such as monographs or books not indexed in these databases.

4 The source of the statistics cited in this issue is B. Macaluso, Statistics on World Science, INRS, 2004.

5 The terms 'developed' and 'developing' countries are used following the classification of the UN Statistical Division: http://unstats.un.org/unsd/methods/m49/m49regin.htm

At the other end of the spectrum *(see **Figure 2**)*, sub-Saharan African publications remained stable at around 1% of the world total, while the share of publications from the Arab States increased from 0.6% in 1981 to 0.9% in 2000, reaching the same level as the sub-Saharan African region. At the same time, the Central Eastern European share remained stable around 3% of the world total.

Figure 2: Share of world publications: other regions, 1981 to 2000



In contrast, both the Newly-Industrialised Countries (NIC) in Asia (a group that includes China) and Latin America and the Caribbean (LAC) increased their share significantly. The first group grew from 0.6% of the world total in 1981 to 4.2% in 2000, issuing 11 times more publications at the end of the period. China accounted for 85% of the publications in this group, an increase from 63% in 1981. The share for LAC countries increased from 1.3% to 3.2%.

R&D expenditure and scientific publications

The picture of world science can be further analysed by looking simultaneously at R&D expenditure[6], and scientific output (publications) *(see **Table 1**)*.

[6] See UIS (2004), A Decade of Investment in R&D: 1990-2000, *UIS Bulletin on S&T Statistics*, 1/2004, http://www.uis.unesco.org/.

North America shows a relative decline from 1990 to 2000 in both respects. Interestingly, Asia showed a sharp increase in R&D expenditure and publications. Oceania and Latin America increased their share in publications, while maintaining R&D expenditure constant.

Table 1	World share in publications		World share in R&D expenditure	
	1990	**2000**	**1990**	**2000**
North America	41.6%	36.7%	38.2%	37.2%
EU-25	34.0%	40.2%	24.9%	23.1%
Asia	14.5%	21.1%	23.0%	30.5%
LAC	1.7%	3.2%	2.8%	2.9%
Africa	1.4%	1.4%	1.3%	0.8%
Oceania	2.8%	3.3%	1.0%	1.1%

Europe also increased its share of publications but lost ground in expenditure. This might reflect a consolidation in Europe around more basic research (better represented in SCI), than technological development. This could also reflect the relatively lesser importance of defence R&D in Europe, compared with the US, since the results of this type of research are less frequently published and can involve large amounts of resources.

Africa shows an alarming drop in its (already low) proportion of global R&D expenditure, while the share of publications with authors in Africa remained constant throughout the period.

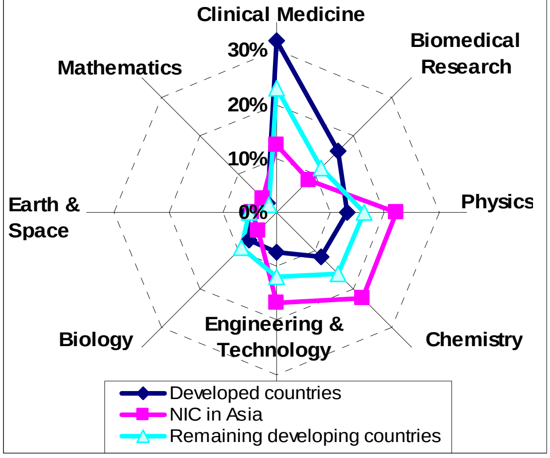
Publications by field of science

Scientists in a given country do not necessarily publish in all scientific fields covered by the SCI, which is reflected by national variation in publications by field *(see **Figure 3**)*.

The share of physics, chemistry and engineering papers is significantly higher in the newly-industrialised countries in Asia, while clinical medicine and bio-medical research make up a larger part of the publications of developed countries. The remaining developing countries show a pattern that is very similar to the developed ones.

Countries and regions can therefore be "specialised" in terms of their scientific production. The Specialisation Index (S.I.) is an indicator of such specialisation *(see **Box 2**).*

Figure 3: Distribution of SCI papers by fields of science, 2000



According to this measure, Africa is considered specialised in biology –a field that includes agriculture and food sciences– (S.I.=2.2 in 2000), Oceania in earth and space (1.7), Asia in engineering and technology (1.4) and physics (1.4), North America (slightly) in biomedical research (1.3) and earth and space (1.3), and Latin America and the Caribbean in engineering and technology (1.8), and (slightly) in chemistry and earth and space (1.3).

Box 2:

Specialization Index (S.I.)=

$$\frac{\text{share (\%) of publications of region X in field Y}}{\text{share (\%) of world publications in field Y}}$$

S.I. > 1 indicates that region X is specialized in field Y
(has scientific activity above world average in this field).
S.I.< 1 indicates an 'under-specialization' of region X in field Y.
S.I. ~= 1 indicates that region X is similar to the world average in field Y.

The pattern of specialisation shown here indicates that, while some degree of specialisation exists, the regions of the world are not highly specialised and conduct research activities with similar intensity in the various scientific fields.[7]

International collaboration

Over the 20 years under analysis, international collaboration in science and technology has increased. One indicator of this process is the rise in papers co-signed by authors from different countries. The share of world papers with authors in two or more countries has more than tripled between 1981 and 2000, from 5.7% to 18.4%.

The proportion of publications from authors in developed countries co-signed with authors in other countries has risen more than three times from 6.0% to 20.4% between 1981 and 2000, and in developing countries the share of collaborative papers doubled from 15.1% to 30.8%.

Of the total 107,637 internationally collaborative papers in 2000, 74.0% were collaborations between scientists in different developed countries ("North-North"[8]), 24.5% collaborations between authors in developed and developing countries ("North-South"), and only 1.6% between scientists in different developing countries ("South-South"). From the total number of papers by authors in developing countries, 28.9% were written in collaboration with authors in developed countries ("South-North") and 1.9% with scientists in other developing countries ("South-South"). "South-North" collaboration represents therefore 93.7% of total collaboration involving developing country authors. On the other hand, developed countries collaborate mainly between themselves: 75.1% of their collaborative papers were written with authors in other developed countries in 2000, down from 80.9% of papers in "North-North" collaboration in 1981.

[7] This does not imply that scientific research is homogeneously distributed between regions, but rather that the distribution of research by fields is somewhat similar in the different regions of the world.

[8] "North" is used here for developed countries and "South" for developing countries, regardless of actual geographical locations.

Conclusions

Bibliometric indicators discussed in this bulletin show that the distribution of scientific production around the world is changing. Developed countries' share of world scientific publications has declined over the last 20 years. Some developing regions are increasing their production in this field (Latin America, Asia) but others are not (Africa).

One way in which scientists in developing countries achieved these results was by collaborating with researchers from developed countries.

These trends parallel those observed for other indicators, such as the evolution of R&D expenditure as presented in the UIS S&T Statistics Bulletin no. 1. Therefore, using multiple indicators focusing on different aspects of scientific and technological activities can provide a better understanding of its patterns and evolution in developing countries.

Bibliometric indicators do not measure all scientific production since, as mentioned, important areas of research are not in the scope of SCI. These indicators however reflect trends occurring in "mainstream" science, which is considered to be a reflection of the forefront of scientific research. In this sense, bibliometric indicators point to a twofold rise in the developing world's scientific production, both in terms of volume of papers (presence) and patterns of international collaboration (linkages).

The statistical trends reported here reflect therefore an increase in the production and international collaboration of researchers in developing countries. At the same time, these increasing trends might also be influenced by the extended use of SCI-based bibliometrics in evaluation processes. In this framework, scientists in developing countries are not only publishing more, but at the same time they might be shifting from publishing in local journals towards "mainstream" journals, choosing research topics more suitable to these journals' editors, and engaging in international collaboration in order to improve their access to these journals.

If they were interpreted as exhaustive measures of scientific output, bibliometric indicators would present certain biases. However, when interpreted with caution, they can reveal some insights into trends in aspects of scientific production at a global level.

Table 2

Papers in SCI by region, 1981-2000

	1981	1985	1990	1995	1996	1997	1998	1999	2000
World	**371,346**	**417,358**	**463,486**	**526,481**	**539,195**	**546,678**	**558,515**	**571,676**	**584,982**
Developed Countries	347,521	391,854	432,208	485,122	493,476	496,864	504,055	511,355	519,872
Developing Countries	27,820	31,456	41,006	57,951	63,872	69,660	76,278	84,193	91,534
Least Developed Ctries.	625	697	887	1,275	1,244	1,332	1,361	1,444	1,474
OECD	313,322	356,219	396,447	465,348	475,575	480,893	491,185	500,669	510,252
Americas	**158,108**	**180,067**	**199,347**	**221,032**	**220,883**	**219,671**	**222,401**	**224,719**	**230,060**
North America	153,801	175,015	192,695	211,559	210,448	207,868	209,313	210,509	214,973
Latin America & Caribb.	4,963	5,836	7,945	11,707	12,908	14,380	16,051	17,330	18,606
Europe	**163,471**	**182,730**	**203,598**	**235,059**	**243,178**	**249,116**	**254,424**	**260,612**	**264,829**
European Union 25	121,924	139,148	157,586	203,897	211,994	218,407	224,885	230,928	234,991
C.I.S. (Europe)	30,932	32,358	34,837	24,902	24,990	24,857	24,042	24,560	24,597
Central Eastern Europe	12,746	12,853	13,755	16,188	16,937	17,742	18,488	19,290	19,977
Africa	**5,305**	**5,881**	**6,539**	**7,367**	**7,298**	**7,531**	**7,698**	**8,067**	**8,311**
Arab States (Africa)	1,614	1,686	2,027	2,626	2,616	2,706	2,845	3,052	3,310
Sub-Saharan Africa	3,695	4,204	4,521	4,756	4,700	4,845	4,874	5,045	5,029
Asia	**45,906**	**54,554**	**67,217**	**89,091**	**96,352**	**101,532**	**108,510**	**116,060**	**123,572**
NIC in Asia	2,215	4,234	8,058	12,474	14,160	16,230	18,295	21,251	24,735
Arab States (Asia)	689	1,313	1,638	1,763	1,790	1,873	1,921	1,984	1,971
C.I.S. (Asia)	-	-	24	1,161	1,051	1,031	980	954	1,023
Other Asia	1,316	1,877	2,438	3,043	3,054	3,237	3,501	3,787	4,042
Oceania	**10,456**	**11,565**	**12,792**	**16,474**	**17,083**	**17,755**	**18,575**	**18,832**	**19,179**

Source: ISI, compiled in B. Macaluso, Statistics on World Science, INRS, 2004.
Note: Totals and subtotals are not the sum of the parts, since papers in international co-operation are counted in every region or sub-region for which an author's address is present.
C.I.S.: Community of Independent States. The Russian Federation is included in the C.I.S. (Europe).
NIC: Newly Industrialized Countries.

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