Country Report

Measuring Research and Development in Developing Countries: Main Characteristics and Implications for the Frascati Manual

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This article seeks to present the main characteristics of Research and Development (R&D) in developing countries using mainly available R&D statistics and to draw some implications for the Frascati Manual methodologies and its application. The main characteristics presented include trends and concentrations, relative share of Highly Qualified Skills (HQS) abroad, R&D expenditures, impact factor and the relative importance of international collaboration. R&D statistics in developing countries are still scarce, particularly in Africa. Furthermore, they may not fully explain the characteristics of R&D in developing countries, for example, the dynamics of R&D systems, R&D practices, informal behaviours and contributions, just to mention a few. It is, therefore, argued that beyond indicators, there is a need for complementary surveys to derive, inter alia, descriptors and narratives. In the concluding part, the particular characteristics of R&D in developing countries and the resulting consequences for R&D measurement are discussed, focusing on implications and recommendations, in view of a possible addition and/or future revision of the Frascati Manual.

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Introduction

THE CAPACITY TO generate and apply scientific and technological knowledge has led to growing disparities between the Triad (North America, Japan and Western Europe) and the non-Triad countries (predominantly developing and less developed countries in the rest of the world) as well as among the non-Triad countries themselves leading to new categories such as the emerging BRICS (Brazil, Russia, India, China and Singapore). These disparities can be measured using a variety of socio-economic as well as Science and Technology/Research and Development (S&T/R&D) indicators, thus making it possible to rank the relative position of a given country in the world and construct groupings or typologies of countries, for example, industrialised countries, newly industrialised and emerging countries, developing and least developed countries (LDCs). Yet, a country's position is never guaranteed forever; political stability, political will and support, rewards and major budget increases or the lack thereof can make a significant difference in a relatively short period of time.

The above-mentioned indicators can also be used to describe specific and measurable characteristics of R&D in a given country or in a given group of countries. They are not only important in international comparisons, but are also essential in guiding policy-makers in developing and targeting new policies, ensuring a certain standard of performance and building up a sense of accountability. Yet, numerous studies point to the paucity of reliable and sustainable statistical information on R&D/S&T activities and the lack of a central institutional mechanism to collect such information in many developing countries and in particular in Sub-Saharan Africa, Arab States in Asia and in the Caribbean and Oceania (Table 1).

Despite the limitations of R&D statistics in many developing countries, this article seeks to present the main characteristics of R&D in developing countries.[1]

Definitions, Limitations and Scope of the Article

As defined in the Frascati Manual (OECD 2002), 'Research and experimental Development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge to devise new applications'. The term R&D includes all fields of S&T (natural

TABLE 1
Availability of R&D Statistics by Region

Regions	*Countries and territories included*	*Data published by the UIS*	*Coverage (%)*
Total	**215**	**127**	**59**
Developed countries	59	50	85
Triad (OECD + EU)	43	43	100
Others in Europe	16	7	44
Developing world	156	77	49
In Africa	54	27	50
Sub-Saharan Africa	46	22	48
Arab States in Africa	8	5	63
In Asia	43	26	60
Excluding Arab States	31	23	74
Arab States in Asia	12	3	25
In the Americas	42	22	52
Latin America (RICYT)	23	18	78
Caribbean and territories	19	4	21
In Oceania	17	2	12

Source: UNESCO Institute for Statistics (UIS) 2008.
Note: OECD, Organisation for Economic Cooperation and Development; EU, European Union; RICYT, Red de Indicadores de Ciencia y Tecnología (Network of S&T indicators).

sciences, engineering, social sciences and humanities), and covers three main activities: basic research, applied research and experimental development. However, for a broader knowledge-based economy, R&D statistics are not enough. The R&D data need to be examined within a conceptual framework that relates them to other types of resources and to the desired outcomes of given R&D activities. One such outcome entails technological innovation and other forms of innovative activities described in the Oslo Manual (OECD 2005). The scope of this article, however, will be limited to R&D characteristics as defined above and will not include technological innovation.

Furthermore, R&D indicators may not fully explain the characteristics of R&D in developing countries, for example, the dynamics of R&D systems, R&D practices, informal behaviours and contributions as well as unexpected changes, just to mention a few. It is, therefore, argued that beyond indicators, there is a need for complementary approaches including sociological surveys to derive, *inter alia*, descriptors and narratives

(Mouton and Waast 2008).[2] In addition to R&D indicators, both descriptors and narratives are important in analysing the characteristics of R&D, particularly in developing countries.

A developing country is a country which has a relatively low standard of living, an undeveloped industrial base and a moderate-to-low Human Development Index (HDI) score and per capita income[3]; 115 countries are currently categorised as developing countries. This includes the newly industrialised countries (NICs), which are not listed as either developed countries or least developed countries (LDCs).

Since 1971, the United Nations (UN) has denominated LDCs, a category of countries that are deemed highly disadvantaged in their development process, countries that, more than other countries, face the risk of failing to come out of poverty. As such, the LDCs are considered to be in need of the highest degree of attention on the part of the international community. There are currently fifty LDCs in the UN list, two-thirds of which are in Africa. Countries with more advanced economies than other developing nations, but which have not yet fully demonstrated the signs of a developed country, are grouped under the term NICs (Box 1). It is noteworthy that two former developing countries now rank among the thirty members of the OECD (see Box 1). Chile is being considered for membership and five countries are classified as 'enhanced engagement countries', namely Brazil, China, India, Indonesia and South Africa.

Box 1
Developed and Developing Countries

LDCs: fifty countries (under USD 750 per capita for inclusion, above USD 900 for graduation); two-thirds are in Africa (see list in Appendix 1).
Developing countries often include the NICs not listed as developed or LDCs.
NICs: South Africa, Mexico, China, Malaysia, Brazil, India, Philippines, Thailand and Turkey.
OECD countries (thirty members): Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, UK and US.
Triad countries: North America (USA and Canada), Europe and Japan.

In this article, the term developing countries covers the 115 developing countries (including NICs) and the 50 LDCs.

Trends and Concentrations in World Science (Scientific Publications Mainly)

A Concentration in the Triad Countries but a Growing Share in Developing Countries

As suggested above, the world can be divided into Triad and non-Triad countries. Triad countries include North America, Japan and Europe; the non-Triad countries are composed the rest of the world. With about 15 per cent of the world population, the Triad countries earn approximately two-thirds of the world's income today. The following discussion shows that S&T activities worldwide are even more concentrated than economic activities.

Despite its limitations and drawbacks,[4] one of the most reliable ways to measure the relative importance of a given country or group of countries in the world of science is its world share of scientific publications. In the absence of other R&D indicators, scientific publications are a fair approximation of a country's active scientific manpower (Schubert and Teles 1986). Table 2 shows that in the Triad countries, scientific production (measured in number of mainstream scientific publications) is even more concentrated than economic resources. In 2006, Europe, North America and Japan accounted for 77.1 per cent of world scientific publications, a significant drop, however, from its 2001 relative world share figure (83.1 per cent). Interestingly, although not strictly comparable, the 2001 figure for the Triad countries is approximately the same as the one reported by Eugene Garfield for 1973 (Garfield 1983), although at that time, the USA share was much bigger (43 per cent compared to 32.0 in 2001) than that of Europe and Japan.

Table 2
Scientific Production (World Share of Scientific Publications) in the Triad Countries

	World share (%) of scientific publications		
Areas/Countries	*2001*	*2006*	*Evolution 2006/2001*
Europe	42.2	39.3	–7
North America	32.0	30.2	–6
Japan	8.9	7.6	–15

Source: Thomson Scientific data (OST 2008).

In the meantime, the share attributed to the developing countries, and in particular a few countries in Asia and Latin America, has risen significantly. Back in 1973, developing countries as a whole accounted for 5 per cent of the scientific publications published in the world and only India, South Africa and Argentina appeared in the list of top twenty-five countries (Garfield 1983). Ranking eighth in 1973, India was clearly the scientific superpower of the Third World. South Africa (twenty-third, between Austria and Finland) and Argentina (twenty-fifth) were a distant second and third. In the early 1980s (1981–85), developing countries accounted for 5.8 per cent of the world scientific production with 3.7 per cent for Asia, 1.1 per cent for Latin America, 0.6 per cent for North Africa and Middle East and 0.4 per cent for Sub-Saharan Africa, respectively. Recent developments in Asia and in Latin America have led to a very significant increase in the world share for the developing countries and, subsequently, growing disparities among these countries. Thus, while the world share produced by developing countries accounted for 20.0 per cent in 2006 (Table 3), it is largely due to Asia's scientific production (14.8 per cent), and in particular to China (7.0 per cent), experiencing a significant increase from its 2001 relative world share figure (+96 per cent).

Table 3
Scientific Production (World Share of Scientific Publications) in Developing Countries

	World share (%) of scientific publications		
Areas/Countries	*2001*	*2006*	*Evolution 2006/2001*
Asia (excluding Japan)	9.4	14.8	+87
China	3.6	7.0	+96
ASEAN	0.7	1.0	+42
Latin America (including Mexico)	2.6	3.2	+46.4
Brazil	1.2	1.6	+35
Africa	1.2	1.2	0
North Africa	0.5	0.5	+11
South Africa	0.4	0.4	–9
Near and Middle East (excluding Israel)	0.5	0.8	+90
Total Developing Countries	13.7	20.0	

Source: Thomson Scientific data (OST 2008).

In Latin America, Brazil, with a 35 per cent increase, was a major contributor to the region's growth in world share of scientific publications during the same period.

Overall, there has been a relative decrease in world share of scientific publications in the US (–7 per cent), the EU (–7 per cent) and Japan (–15 per cent). Russia suffered the sharpest decrease (–29 per cent). In the rest of the world, the figures rose for all developing regions except Africa.

Figure 1 below puts the top twenty publishing countries in Asia (excluding Japan), Latin America and Africa in a comparative perspective. By far, the first in this grouping, China, with close to 60,000 publications in 2006, is getting close to Germany and UK in Europe and surpassed France in 2005. China publishes more than the countries in the next three positions combined, namely, South Korea, India and Brazil. Furthermore, China's scientific output is twenty times more than Chile's (tenth) and seventy times more than Pakistan's (twentieth). South Africa and three countries in North Africa (Egypt, Tunisia and Morocco) are the only African countries in that group.

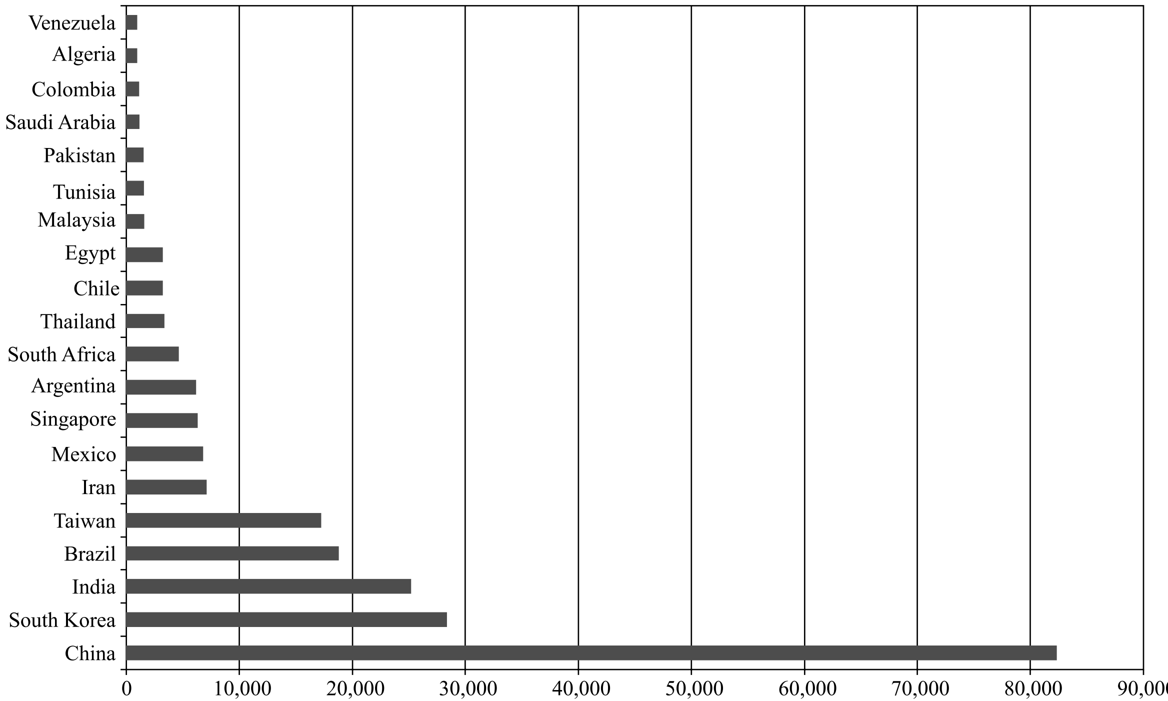
Trends and Concentrations in Africa, Latin America and Asia

Africa

In Africa, the front-runner (South Africa) accounted for 29 per cent of the African world share in 2008, the first five countries (South Africa, Egypt, Tunisia, Morocco and Algeria) accounted for more than two-thirds (69.2 per cent) and the first ten out of Africa's fifty-three countries accounted for 82 per cent.

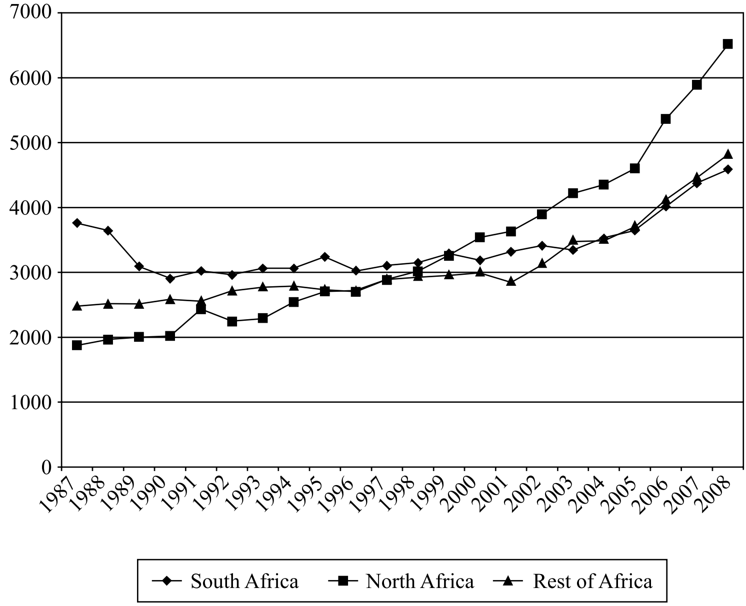
One can distinguish three groups of countries of more or less the same importance in number of publications that evolved differently over the last twenty years: South Africa, Sub-Saharan Africa (excluding South Africa) and North Africa (Figure 2; Gaillard et al. 2005). South Africa, which accounted for close to half of the African continent's scientific production in 1987, experienced a sharp decline with a 25 per cent drop in its scientific production in three years (1987–90). Today, South Africa's number of publications has increased again significantly over the last five years to exceed since 2006, the level it was twenty years ago. During the period under review in Figure 2, Sub-Saharan Africa (excluding South Africa) doubled its scientific publication output, despite the sharp decline of Nigeria (Figure 3), which was the scientific superpower of Sub-Saharan Africa up to the mid-1980s (Chatelin et al. 1997). In 2008, this second group of countries accounts for 30 per cent of the African continent's scientific output.

FIGURE 1
Top Twenty Countries in Asia, Latin America and Africa in Number of Scientific Publications in 2008



Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

FIGURE 2
Number of Scientific Publications in North Africa, South Africa and the Rest of Africa (1987–2008)

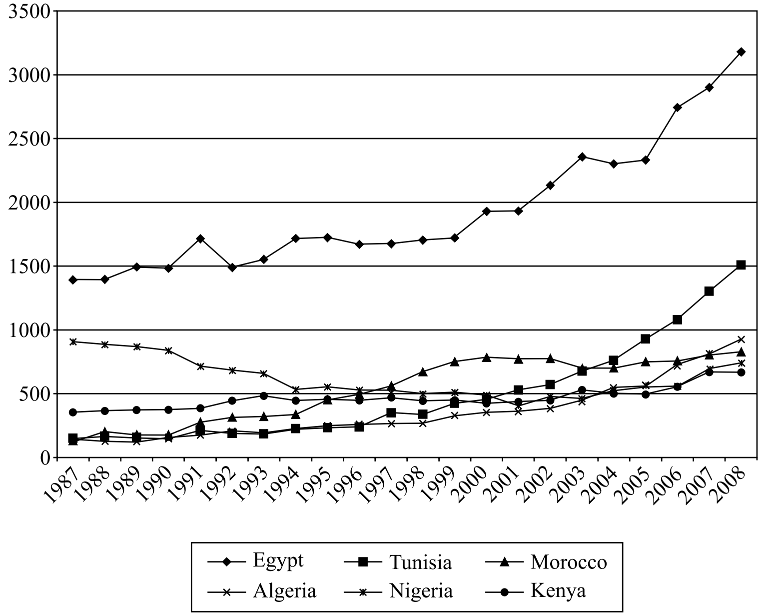


Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

The North African countries that were lagging behind at the end of 1980s (except Egypt) followed an upward trend as of the mid-1990s and accounted for 40.9 per cent of the African continent's scientific production in 2008, compared to 23 per cent in 1987 (for more details, see Figure 3).

Yet, given the fact that Africa's absolute growth in publications was under the worldwide growth rate, its world share has decreased. According to Robert Tijssen (2006), Africa lost 11 per cent of its world share betweens its peak year, 1987, and 2004. Egypt and the Maghreb countries were the only countries that contributed to a modest growth of Africa's world share in the late 1990s and early 2000s. Part of Africa's decline (and in particular South Africa's decline) could also be partly attributed to the removal of African journals from the Science Citation Index (SCI).[5]

FIGURE 3
Number of Scientific Publications in the Top Six African Countries (Excluding South Africa)



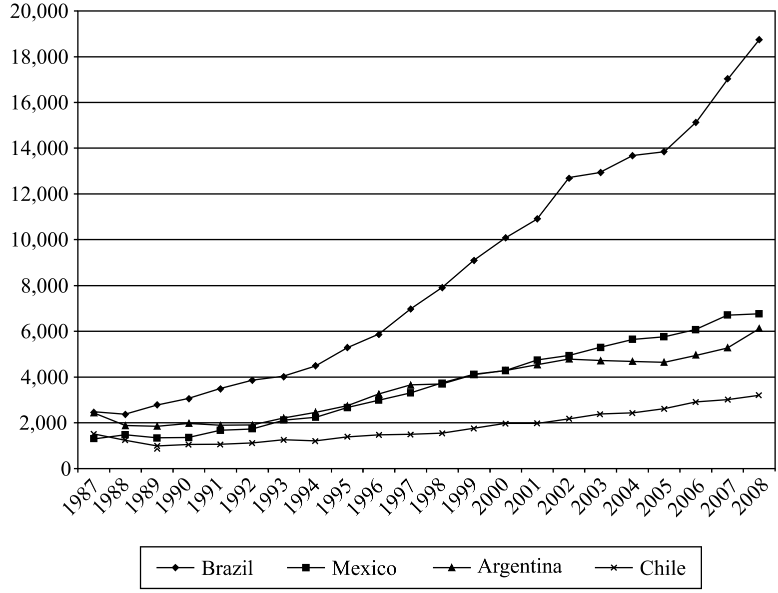
Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

While the top ten African countries now account for 82 per cent of the overall Africa's scientific output, the large majority of the African countries have a very small and/or erratic scientific production. More than two-thirds (36 countries) have fewer than 100 publications a year; 10 countries produce between 50 and 100; 15 between 50 and 10 and 11 fewer than 10. Africa's total publications output is less than Brazil's.

Latin America and the Caribbean

Science in Latin America and the Caribbean is even more concentrated than in Africa: nearly half (47.2 per cent) of Latin America's world share in 2008 was concentrated in Brazil, the front-runner country, while the top four countries together (Brazil, Mexico, Argentina and Chile—see Figure 4) accounted for 87.7 per cent. The recent growth of Brazil's scientific production is impressive, particularly over the last three years.

FIGURE 4
Number of Scientific Publications in the Top Four Latin American Countries (1987–2008)



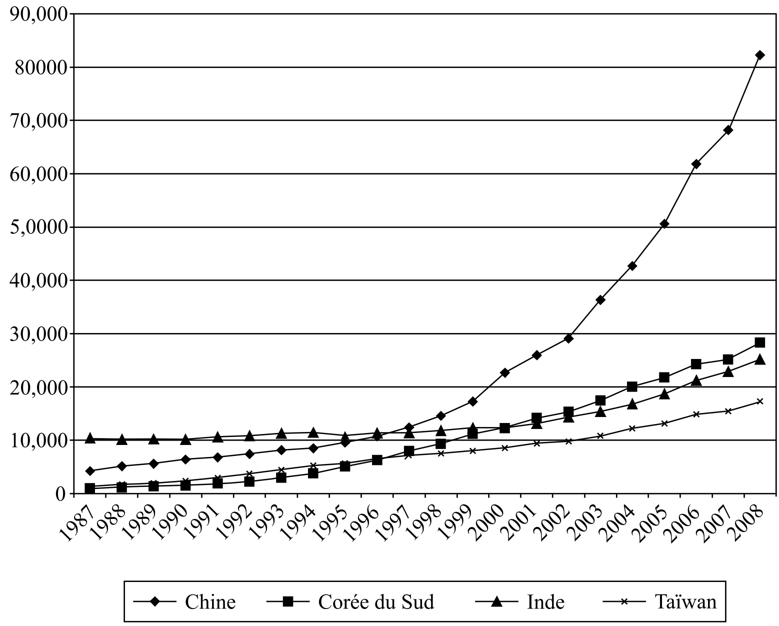
Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

At the other end of the spectrum, there are 20 countries (out of 33), that produce fewer than 100 publications a year. All of them (except Paraguay) are in the Caribbean and Central America. Fourteen of them (all in the Caribbean) produce fewer than thirty publications a year (of which eight produce fewer than ten publications a year). In the middle group, there are 9 countries that produce between 144 (Bolivia) and 1102 (Colombia) publications a year and account overall for 11 per cent of the Latin America and Caribbean share.

Asia (Including Central Europe, Near and Middle East)

The concentration of scientific activities in Asia is very similar to Latin America but at a higher level of production for the top four countries. The front-runner, China, with more than 80,000 publications, concentrates 43 per cent of the region's world share. The top four countries (China, South Korea, India and Taiwan—see Figure 5) account for 80 per cent. The top eight countries (adding Singapore, Iran, Thailand and Malaysia) account for 94 per cent. The growth of China's scientific production (surpassing India's in the mid-1990s) is impressive, particularly during the last ten years. Other countries, such as Iran (7074 publications in 2008), have also experienced an impressive growth (close to a tenfold growth over the last ten years!).

Figure 5
Number of Scientific Publications in the Top Four Asian Countries 1987–2008 (Excluding Japan)



Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

Following the trend in the other regions, there are 14 countries (out of 43) that produce fewer than 100 publications, out of which 5 produce fewer than 25. In the middle group there are 20 countries that produce between 100 (Syria 136) and 1000 (Saudi Arabia 1107) publications.

Institutional Concentration

The Smaller the Country, the More the R&D Capacities and Output are Concentrated in a Very Few Institutions

Scientific institutions in developing countries (as in the rest of the world) vary greatly in numbers, institutional arrangements and specialisations. Just to mention a few characteristics. These institutional disparities can be found across all the continents. Yet, modern science-leading countries worldwide share a number of features, including the existence of a critical mass (core) of relatively stable and well-resourced research and higher education institutes as well as well-functioning science governance systems.

This is not the case in many developing countries and, in particular, in the smaller countries (the majority of the developing countries) where the bulk of research is most often concentrated in one or very few institutions, although the number of institutions has increased rapidly during the last decades. Extreme cases are found in African countries with the smallest R&D capacities, for example, Swaziland with a very small and concentrated research capacity at the University of Swaziland.[6]

While other small or medium countries may have developed a relatively large number of institutions, active and visible research activities are most often concentrated in a small number of them. Lebanon is such a case with a small but diverse and dispersed institutional landscape embedded in no less than forty-one universities and higher education institutions (twelve of them with science and/or technology faculties) and six research centres. However, most Lebanese research is highly concentrated in three universities, accounting for 84 per cent of the overall number of publications (Gaillard 2007a). In fact, more than 50 per cent of the total number of publications is concentrated in only one university: the American University of Beirut (AUB), the oldest of the three universities and most visible since it fully integrated a 'publish or perish' culture and has the largest institutional research budget in Lebanon. Furthermore, the number of publications indexed increased significantly between 1996 and 1999 and 2000 and 2003 (58 per cent), but this increase was more largely generated by AUB (75 per cent). For more details, see Table 4.

TABLE 4
The Top Science Producers in Lebanon (1996–2003)

Institutions	*1996–99*	*2000–03*	*Total*
American University of Beirut (AUB)	347	607	954
Lebanese University (UL)	137	162	299
Saint Joseph University (USJ)	124	160	284
Beirut Hospitals	38	63	101
Lebanese American University (LAU)	21	42	63
CNRS Research Institutes (4)	12	15	27
Balamand University (BU)	3	22	25
Beirut Arab University (BAU)	6	15	21
Others	22	36	58
Total	710	1122	1832

Source: Gaillard (2007a).
Notes: Conseil National de la Recherche Scientifique (CNRS, National Scientific Research Council) has four institutes.

A Concentration of Scientists in the Triad Countries but a Growing Share in Non-Triad Asia

According to OST (2006), they were 6.18 million full-time equivalent (FTE) scientists in the world in 2005.[7] S&T human resources are highly concentrated in a small number of countries around the world. With 1.39 million scientists, the US is home to more than one-fifth of the world population of scientists (22.6 per cent), whereas the EU, with 1.31 million scientists, is home to 21.2 per cent.

However, China, the second country in number of scientists (1.12 million FTE, 18.1 per cent world share) now outstrips Japan (705,000 scientists, 11.4 per cent world share). In 2005, these two countries together accounted for close to 30 per cent of the world's population of scientists. With 465,000 scientists, Russia ranks fourth (7.5 per cent of world share). Other non-Triad countries (in addition to China) that concentrate more than 1 per cent of world share are South Korea, Taiwan and Brazil. In 2005, China accounted for 51 per cent of Asia's FTE scientists (excluding Japan) and Brazil for 54 per cent of Latin America's FTE scientists. Similar, relatively reliable statistics do not exist for Africa and many Arab countries. Estimates suggest that South Africa, with 14 million FTE scientists (0.3 per cent world share), accounts for more than 13.8 per cent of the FTE scientists in Africa and Egypt for more than 50 per cent of the FTE scientists in North Africa. North Africa would account for about one-third (36 per cent) of Africa's FTE scientists.

Between 1998 and 2003, the number of scientists the world over rose by 20 per cent (OST 2006): Africa (52 per cent),[8] Asia (36 per cent) and Latin America (11 per cent). The strong increase in the number of scientists in Asia may explain, in part, the decrease in world shares of scientists in Europe (–3 per cent) and in North America (–11 per cent). China's progression in number of FTE scientists (+78 per cent) changed the world landscape. South Korea and Singapore also registered strong increases (+63 per cent and +76 per cent, respectively) but started with much lower numbers. Outside Asia, the only country showing a comparable positive evolution was South Africa (+66 per cent).

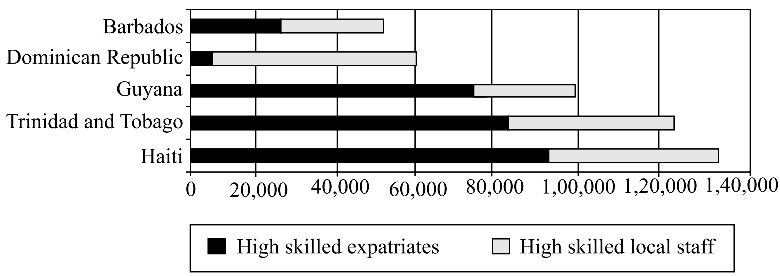
A Sizeable Share of Highly Qualified Skills Abroad Originates in the Developing Countries

The movement of scientists and scholars throughout the world is as old as science itself. The diametric contrast in opinions on the effects of international scientific migration (ISM) can be traced to its character as a polymorphic, recurrent phenomenon whose costs and benefits have been endlessly, but never successfully evaluated. The question is still open. There are several relatively recent phenomena that revived the debate on ISM perceived as a brain drain by many countries including developed countries in Europe: the collapse of the communist system and the migration of Soviet and Eastern European professionals to other professions and countries; the large-scale return of highly qualified staff and scientists to South East Asian NICs, and more recently China; the fact that the countries affected by the brain drain attempted to organise their S&T diasporas into institutionalised networks so as to facilitate the circulation of people and information and to initiate collaborative research programmes between the national and expatriate scientific communities. Yet, a number of developing countries remain typical examples of the recurring brain drain problem.

One of the main difficulties is to measure migration (often unclear definition of concept, lack of mechanism for observing movement, unreliable and non-standardised available statistics). The fact that departures are recorded (to some extent) but returns are not may in part explain certain overestimated figures for the brain drain. The OECD has contributed to creating a tool to measure migration: a database[9] on migrants and expatriates constructed from information gathered in twenty-nine of the thirty OECD countries.[10] These data make it possible to identify highly qualified migrants or emigration rates for highly educated persons by country of birth or origin. The emigration rate of highly educated persons by country of origin is calculated by dividing the highly educated expatriate population in a given country by the total of highly educated native-born population of the same country. Highly educated persons are defined as persons with a tertiary level of education.

This database can be used to produce the total number of highly skilled expatriates (HSE) and the percentage of HSE by country of birth (Dumont and Lemaître 2005). The results show that the percentage of HSE is significantly higher in the small and medium countries of the Caribbean and Africa (Figures 6 and 7).

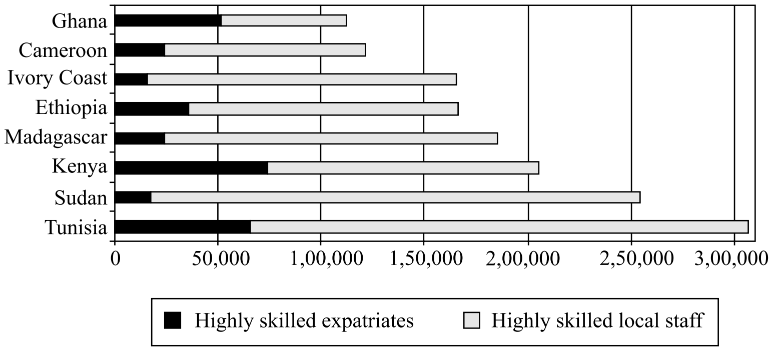
FIGURE 6
Highly Skilled Expatriates in the Small Caribbean Countries



As shown in Figures 6 and 8, the smaller the national highly skilled resource base, the higher the percentage of HSE. As might be expected, countries that suffer long civil wars (for example, Haiti, Angola, Mozambique) and countries composed largely of migrant populations (for example, Mauritius) are particularly affected by the brain drain. In a recent study in Lebanon, we estimated that at least half the Lebanese scientists lived outside the country today (Gaillard 2007a).

Conversely, although, in absolute terms, the bigger countries in Africa, Asia and Latin America are severely affected by the emigration of their highly skilled personnel, its relative importance may be less significant (Figure 9). The OECD data estimate indicates that India has more than

FIGURE 7
Highly Skilled Expatriates in Medium Countries in Africa



one million HSE, but this represents less than 4 per cent (3.43 per cent) of its total highly skilled population. The figure for China with a total of more than 600,000 HSE is less than 3 per cent (2.61 per cent) of its highly skilled population abroad.

Can S&T Diaspora Help Mitigate the Brain Drain?

Against this backdrop, recent policy documents and political discourses assert that the hundreds of thousands of scientists expatriated from developing countries should no longer be seen as a bane, but on the contrary constitute a boom for many of them. The idea is spreading rapidly in many developing countries and seems to be unanimously supported: the 'S&T diaspora' will make up for the shortcomings and weaknesses of the national scientific communities. This idea, attractive as it may be, needs to be approached with caution.

People advocating the use of the diaspora see it as a way to mobilise the country's emigrant scientists and technologists all over the world to the benefits of their home countries, thanks to improved access to scientific information and expertise through extensive social, technical and professional networks, increased training opportunities and the development of collaborative projects between expatriate and home-based scientists. The diaspora model is appealing to politicians and policy-makers since it appears to offer a low-cost, self-managing, efficient, easy solution. The option is also appealing to expatriates who feel motivated by an opportunity to contribute to the development of their country

FIGURE 8
Highly Skilled Expatriates in Some Smaller and Less Populated African Countries

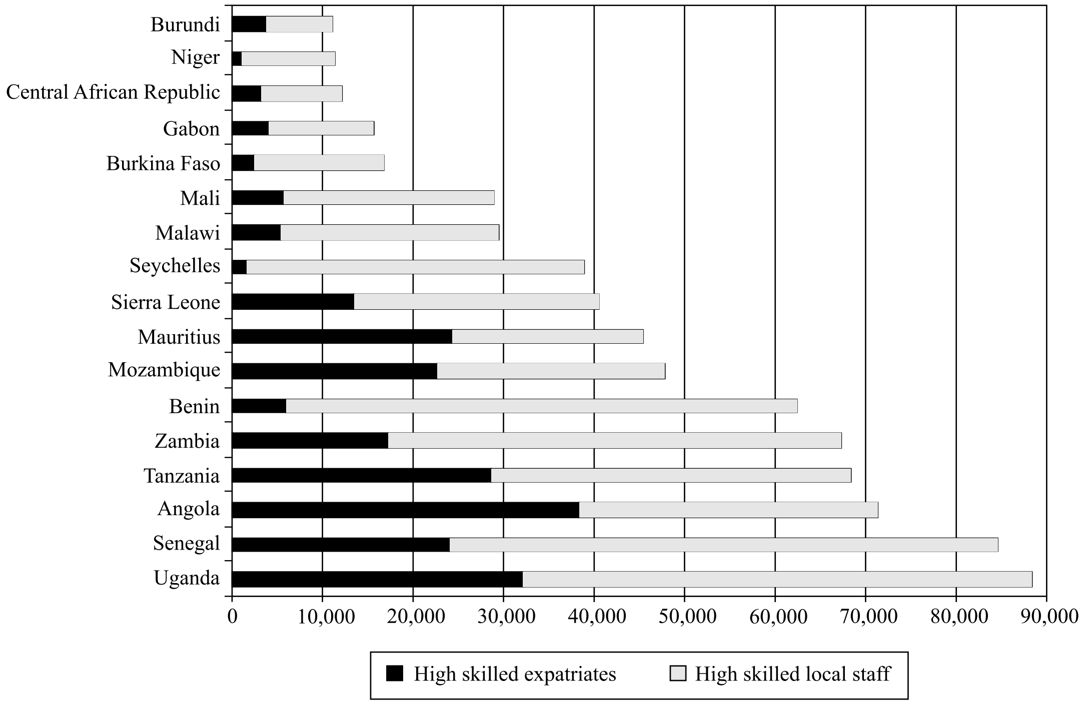
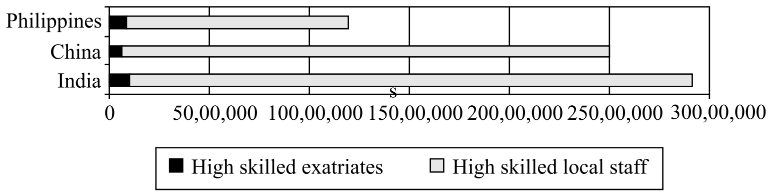


FIGURE 9
Highly Skilled Expatriates in Some Highly Populated Asian Countries



of origin from a foreign location where they want to remain without feeling guilty. Over the last decade, an increasing number of countries have undertaken initiatives to create databases of expatriate scientists, and to mobilise, organise and reconnect their scientists abroad with the scientific community at home. Yet, the sustainability and effectiveness of this approach remains to be proved, and the fate of some important S&T diasporas (for example, Red CALDAS in Colombia and the South African Network of Skills Abroad in South Africa) already shows that the promise of the diaspora approach is more difficult to achieve than some may imagine. These important institutionalised initiatives need to be evaluated.

The diaspora model will never be a low-cost, self-sufficient answer to Africa's scientific needs. To be successful, a number of conditions discussed elsewhere need to be fulfilled (Gaillard J. and Gaillard A.M. 2003). Its effectiveness depends substantially on the internal dynamics of the home-based scientific communities. A network of expatriates is at best an extension of a national scientific community; it can never be a substitute. Efforts should therefore, first and foremost, focus on strengthening national scientific capacity, particularly through training, recruiting and retaining the next generation of scientists. Failing this, the diaspora model will be no more than a smart cloak that hides shabby clothes.

A High Concentration of R&D Expenditures in the Triad Countries and Lower R&D Investment Intensity in Most Developing Countries 11

R&D expenditure in the world has grown worldwide during the last ten years. In 2005,[12] North America accounted for more than one-third (35 per cent), Europe for more than one-fourth (27.2 per cent) and Japan for 13.2 per cent. The Triad countries accounted for nearly three-fourth

(75.4 per cent) and the OECD countries for 78 per cent. Asia (without Japan) accounted for 19 per cent (11.8 per cent for China alone), Latin America for 2.4 per cent (1.3 per cent for Brazil alone), Near and Middle East for 1.2 per cent and Africa for 0.7 per cent (0.5 per cent for South Africa alone).

While R&D investments in most Triad countries are between 1.5 per cent and 3 per cent of the gross domestic product (GDP), most developing countries invest much less than 1 per cent of GDP in R&D. New EU members, for example, Baltic countries and Poland, invest between 0.5 per cent and 1 per cent. Southern European countries invest between 0.6 per cent and 1.2 per cent (Greece 0.57 per cent, Portugal 1.18 per cent, Italy 1.14 per cent and Spain 1.20 per cent). The top investors in Europe are Finland (3.5 per cent) and Sweden (3.63 per cent).[13]

The R&D budgets of Sub-Saharan African countries is around or less than 0.3 per cent of GDP, with the exception of South Africa (0.9 per cent). In North Africa, Morocco (0.75 per cent) and Tunisia (1.03 per cent) have increased their R&D investments during recent years, while Egypt and Algeria have kept theirs relatively low. In some countries (Algeria is a typical case), low relative R&D budgets may be due to the low absorption capacity of the national scientific communities.

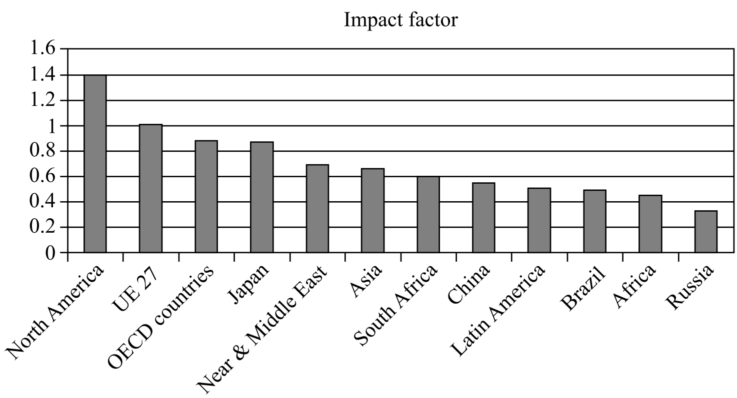
In Latin America, Brazil reported the highest level (0.9 per cent), followed by Chile (0.7 per cent) and Cuba (0.6 per cent). Spending levels in Argentina, Costa Rica and Mexico were about 0.5 per cent. The top investors in Asia have been Japan (3.39 per cent in 2006), the Republic of Korea (3.22 per cent in 2006) and Singapore (2.31 per cent in 2006). China reported 1.42 per cent in 2006, while Iran, Malaysia and India invested between 0.6 per cent and 1 per cent of GDP in R&D. The figures are between 0.1 per cent and 0.3 per cent in Central Asia. The world champion is Israel with 4.74 per cent in 2007.

Less International Impact in Most Developing Countries

The term 'impact' is defined here in terms of citations received by a given publication. All publications cite other works, and most publications are cited elsewhere. ISI–SCI registers these citations. This means that the number of citations received by a scientific article over a given period of time is measured. The world share of citations and the impact index can also measure the impact or visibility of science in a given country or region. The world share of citations is a ratio of all the citations by the world's researchers that relate to the publications of the country under study. The impact factor is the ratio, for two successive years, of the mean number of citations per publication by one country to the world mean. Both measure the attraction and the visibility of published articles but not necessarily their quality.[14]

Overall, articles published by developing countries (DC) scientists are less often cited than those authored by scientists from leading scientific countries (Figure 10). A number of reasons contribute to this bias; some have nothing to do with quality.[15] But, the impact index may be of interest, particularly in comparing groups of countries. Most countries in Africa, Asia and Latin America, for instance, have an impact factor below or around 0.5, whereas North America scores 1.4 and Europe 27 scores 1.

FIGURE 10
Impact Factor (Two Years), 2006



Source: Thomson scientific, OST data treatment 2008.

Great care must be taken, however, when interpreting the level of small scientific countries where, for example, a very small number of articles co-published with a large number of foreign authors in high-impact journals can boost and bias the impact factor.

A Higher Level of International Collaboration in Developing Countries

As a result of the growing complexity of science, the ease of face-to-face contact, the Internet and government incentives, S&T activities are being conducted in an increasingly international manner (Figure 11). In 2006, for instance, 30 per cent of the world's scientific and technical articles had authors from two or more countries, compared to slightly more than 10 per cent in 1988. One-quarter (26.6 per cent) of articles by US authors had one or more non-US co-authors in 2006; the percentage is more or less similar for the Asia-8[16] and slightly lower for China and Japan (National Science Foundation [NSF] 2008; Observatoire des Sciences et Techniques [OST] 2008). Between 2001 and 2006, international co-publications have increased in all countries except China, Turkey and Brazil. The higher EU-15 level (36 per cent in 2006) partly reflects the EU's emphasis on collaboration among the member countries as well as the relatively small science base of some EU members. Other countries' high levels of collaboration (46 per cent in 2006) reflect science establishments that may be small (for example, developing countries), or that may be in the process of being rebuilt (for example, Eastern European countries).

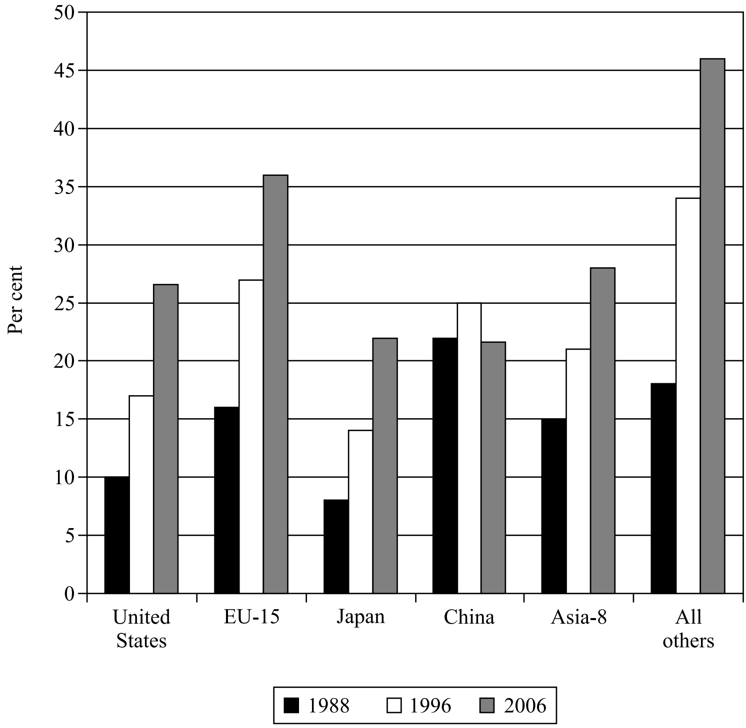
Figure 11 also shows that the internationalisation of science measured as relative importance of foreign co-authorship increased fastest in developing countries and Eastern European countries (category 'All others' in Figure 11). However, as illustrated in Figure 12, developing countries displayed a variety of situations from moderately internationalised (for example, India and China) to very highly internationalised (for example, Costa Rica, Kenya and Senegal).

India and South Africa

The case of India (Figure 13) and South Africa (Figure 14) illustrate the relative growth of the share of Indian and South African publications co-signed with foreign authors (with a distinction between European authors in yellow and other authors in blue) over the last twenty years, and indicate an increase in internationalisation of science in both countries. The increase of international co-authored papers has been one of the world's highest over the last ten years in South Africa, whereas it remained pretty much unchanged in India since 2001.

In general, the larger the country and the national scientific community, the smaller the share of publications signed with foreign co-authors.

FIGURE 11
Share of Scientific Publications with International Co-authorship, By Country/Region (1988, 1996 and 2006)

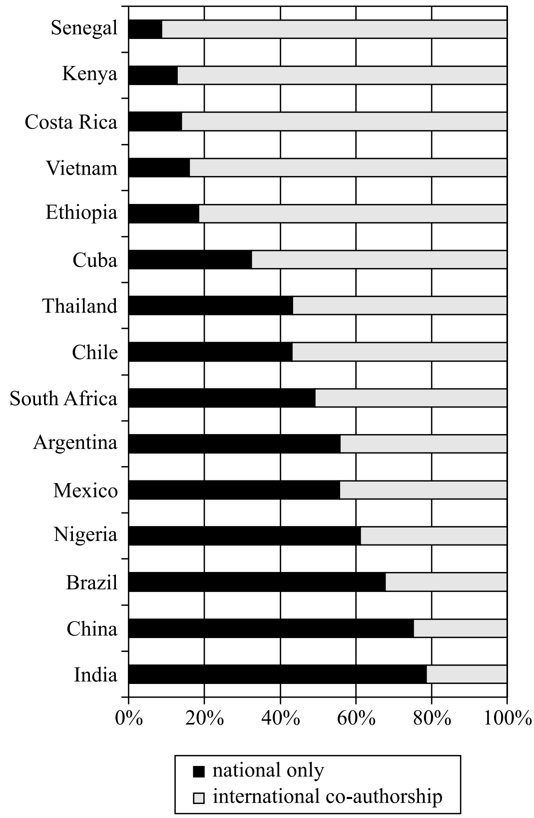


Source: Thomson ISI and SCI, NSF and OST computing 2008.

Senegal

Senegal is an extreme case of highly international science with the share of national science now amounting to a tiny portion of the total Senegalese scientific publications. With less than 200 publications a year (144 in 2006), Senegal was thirteenth in Africa, just after Ghana and before Zimbabwe in 2006. The share of Senegalese scientific production without international co-authorship has decreased steadily over the last twenty years (pink part in Figure 15 below) from slightly less than 40 per cent in 1987 to slightly over 10 per cent between 2004 and 2008. Furthermore,

FIGURE 12
Share of Scientific Publications with National and International Co-authorship in Fifteen Developing Countries in 2006

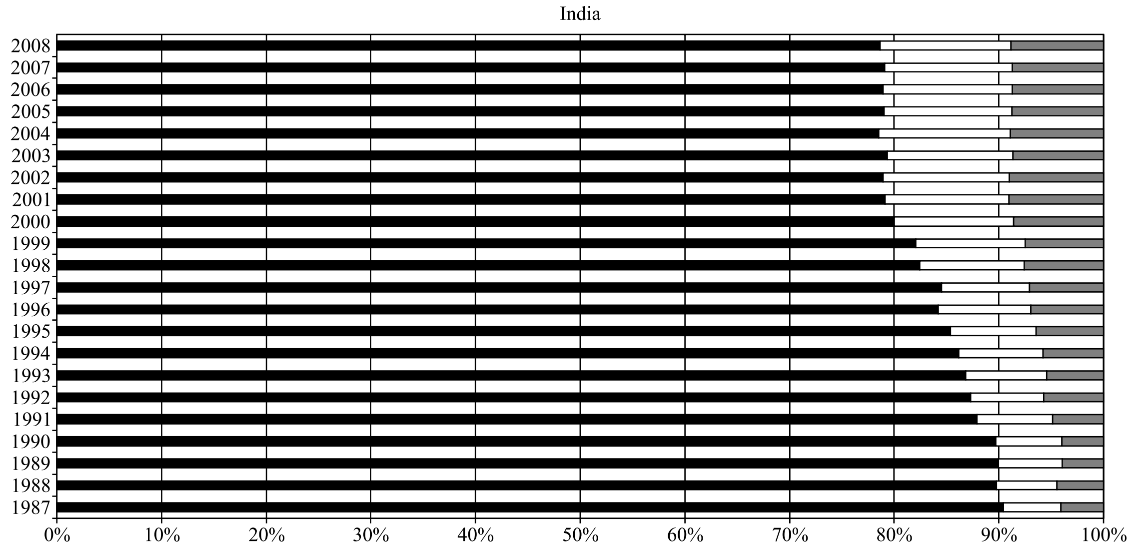


Source: Thomson Scientific data, IRD, computed by P.L. Rossi.

considering publications by the French Research Institute for Development (IRD) staff with a Senegalese address, we see that IRD accounts for a sizeable share of this national production.

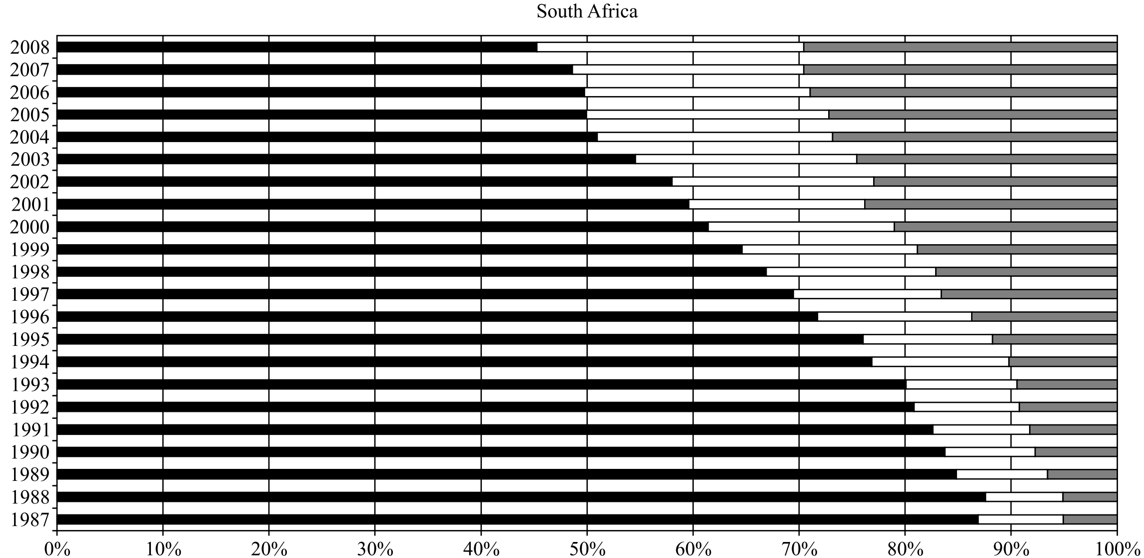
The total share of IRD publications in and on Senegal was 29 per cent for the period 1987–99 and 38 per cent for the period 2000–04. Over this last period, more than 40 per cent of the publications were authored or co-authored by IRD staff.

FIGURE 13
Share of Scientific Publications with National and International Co-authorship in India (1987–2008)



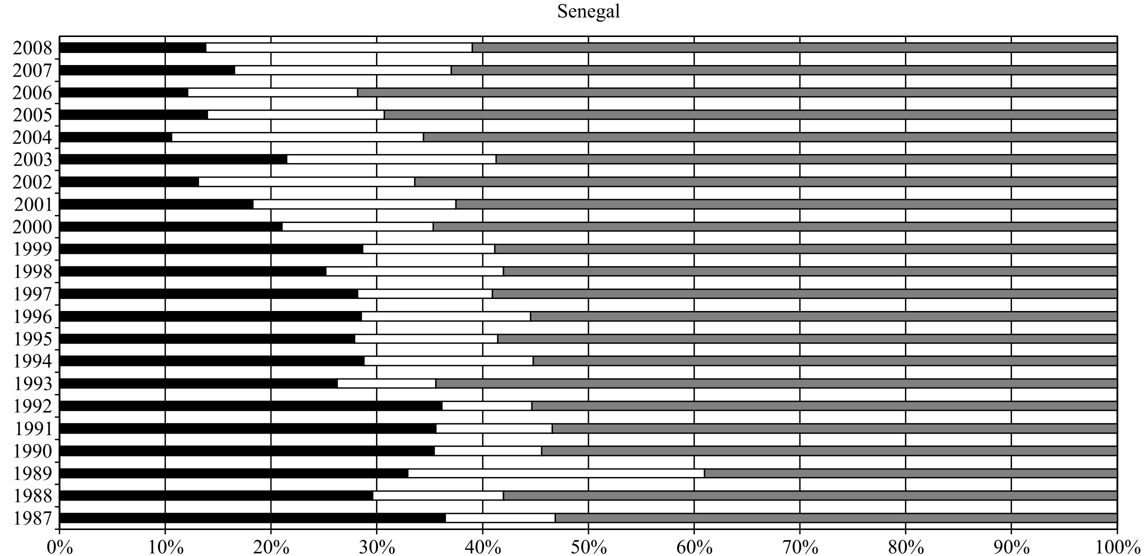
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
With UE	423	452	402	405	514	618	611	662	701	789	804	895	919	1059	1183	1287	1326	1495	1633	1850	2000	1968
Without UE	573	586	623	635	765	753	876	920	889	1003	954	1175	1288	1400	1547	1722	1849	2115	2282	2626	2787	2785
National only	9402	9111	9173	9068	9315	9425	9788	9843	9290	9543	9607	9719	1008	9855	1034	1127	1220	1319	1475	1676	18111	1751

FIGURE 14
Share of Scientific Publications with National and International Co-authorship in South Africa (1987–2008)



	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
■ With UE	191	186	203	224	249	273	289	313	380	415	514	537	620	669	789	782	820	946	994	1164	1293	1161
□ Without UE	303	266	266	247	276	293	320	395	396	441	434	505	546	560	552	650	699	781	835	852	954	986
■ National only	3268	3189	2626	2433	2496	2392	2451	2356	2463	2171	2155	2103	2127	1955	1978	1980	1824	1796	1824	1997	2126	1776

FIGURE 15
Share of Scientific Publications With and Without International Co-authorship in Senegal (1987–2008)



	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
With UE	51	47	32	43	39	52	76	69	65	66	65	76	80	86	75	81	101	99	124	107	129	75
Without UE	10	10	23	8	8	8	11	20	15	19	14	22	17	19	23	25	34	36	30	24	42	31
National only	35	24	27	28	26	34	31	36	31	34	31	33	39	28	22	16	37	16	25	18	34	17

France is by far the leading international scientific partner. Over the last three years, more than 50 per cent of the Senegalese scientific publications were co-signed with French co-authors out of the approximately 70 per cent for the EU countries in total.

Science is unarguably becoming increasingly dependent on international collaboration. But, although international collaboration is part of the strength of a national science system, there is a limit beyond which it can become a threat or at least a major weakness. In the case of Senegal, this threshold has no doubt been passed and leads to a number of questions. Is Senegalese national science increasingly embedded in international science, or is it simply vanishing as the share of international co-authorship increases? Is the impact of IRD and France on the Senegalese scientific production too predominant? Is Senegalese science a national science? Has enough been done to ensure the long-term sustainability of a local science base in Senegal as well as in certain other African countries such as Ethiopia and Madagascar? To what extent does the globalisation and internationalisation of science make the notion of national system irrelevant, particularly in smaller developing countries?

Conclusion: Implications for the Frascati Manual

The characteristics of developing countries, briefly described in this article, have a number of implications for the work of the UIS and the use and validity of the Frascati Manual. Many of these implications are related to the difficulty of collecting R&D indicators in developing countries (and in particular LDCs) in the absence of a dedicated central institutional unit.

The first implication is related to the paucity of reliable, up-to-date statistical information on human resources and research budgets in many of the developing countries, particularly in Sub-Saharan Africa and the Arab countries. With special attention to UIS S&T data coverage in Africa, emphasis should be placed on filling the gaps, particularly targeting the main R&D players on the African continent who are not providing regular indicators to the UIS, that is, Egypt, Nigeria and Kenya, respectively, the second, sixth and seventh science producers that accounted for 25 per cent of the Africa's overall production in 2006. With regard to the Arab countries, although progress has been made, thanks to a recently completed EU-funded project[17] aimed at describing the scientific and technological capabilities in eight research partner countries of the Mediterranean (Morocco, Tunisia, Algeria, Egypt,[18] Lebanon, Syria, Jordan and Palestinian Territories), much remains to be completed, consolidated and validated.

The second implication is related to the high concentration of scientific activities in a small number of countries in each region. Although ideally, R&D statistics should be gathered from each country, it may not make much sense to devote special effort to gathering this information in countries with very little potential and scientific output.[19] As a first priority, as suggested above, the focus should be on large and medium scientific countries, at least in the beginning.

The third implication is related to the professional crisis and the changing nature of scientific work in many countries, which makes it more complicated to assess R&D personnel data, particularly within the universities, where, in most countries, the bulk of R&D personnel is employed. Given the fluidity of a large number of contractual part-timers who teach in the universities, there is a high risk of counting them twice, or more. Given the fact that many staff members have a second job or a parallel, additional remunerated activity to compensate for the drop in their purchasing power, they may not devote much time to scientific research at all. This leads to further difficulties in estimating the number of staff truly involved in R&D activities and the time they spend on it. A recent survey carried out in Lebanon (Gaillard 2007a) also points to the fact that no single national estimate can be applied across all the institutions since they are all different.

The fourth implication is related to the difficulty of evaluating national R&D budgets accurately. An increasing number of private funding sources (notably, foundations and non-governmental organisations [NGOs]) provide support to individuals, groups or programmes and not to institutions. Tracing the amount and flow of these funds is not easy, since, in most cases, they are not declared. In addition, many institutions (in particular, universities) do not have an official, transparent research budget since research is a subordinate function to teaching, the main or even exclusive function. Furthermore, there is often a discrepancy between voted and allocated budgets. And many national research systems have a limited absorption capacity as can be seen by the differences between budgets allocated and budgets spent,[20] and a relative mobilisation capacity of projects stemming from national or institutional calls for proposals.

Finally, confusion between S&T and R&D expenditures often leads to overestimated or underestimated R&D budgets. All these characteristics make it difficult to construct an R&D national budget.

The fifth implication is related to the increasing international circulation of scientists and engineers, particularly from developing countries, and the proposal to organise them into an S&T diaspora that, through 'remote mobilisation' all over the world, will generate a number of benefits for their home countries. In some countries, the S&T diaspora is estimated as equal to or larger than the S&T potential at home (for Lebanon, see Gaillard 2007a). Since this extended, internationalised scientific community might be able to benefit the home country, it should be mapped and measured. This approach requires a number of difficult steps, the first one being the creation of a database of highly qualified nationals living abroad. Should the IUS and OECD (Frascati Manual) look into this?

The sixth implication[21] was briefly mentioned in the introduction to this article. R&D indicators alone cannot fully explain the characteristics of R&D in developing countries, for example, the dynamics of R&D systems, R&D practices, informal behaviours and contributions as well as unexpected changes, just to mention a few. It is, therefore, argued that to go beyond indicators, additional surveys should be conducted to produce descriptors (Box 2)[22] and narratives (Box 3)[23] on additional issues including:

Box 2
Examples of Descriptors

- Date (decade) of establishment of first public and private research institutes, public and private universities, postgraduate programmes, scientific journals, professional associations, academies of science, ministries of science, research and/or higher education, science policies and higher education documents, S&T Observatory, and so on.
- Number and relative importance of public and private research institutes, public and private universities, postgraduate programmes, scientific journals, professional associations, academies of science, ministries of science, research and/or higher education, science policies, higher education documents, and so on.
- Scientific cooperation and agreements (national and international).

1. the contextualisation of the science system within the broader political, economic, educational and social systems;
2. the history of science in the country under review;
3. the governance of science in the country and available policy documents;

Box 3
Examples of Narratives

- Strengths and weaknesses of the national research system, including the university system.
- Domains and topics of scientific research; specialities, niche areas of research in the national system and at universities.
- Role of government, other national agencies and international institutions in funding research (public and private)—impact on the national research agenda and priorities.
- Profession and status of academics and knowledge workers.
- Scientific mobility and brain drain challenges.

4. knowledge and R&D performers;
5. informal S&T structures (academies, associations, trade unions, journals, invisible colleges, and so on);
6. specific indicators on human resources and some considerations on research as a profession including status, salaries, and so on;
7. R&D funding including the specific role of international donor and funding agencies in funding and determining the country's research activities, programmes and policies;
8. research outputs (postgraduates, publications, papers and patents) and
9. scientific cooperation and agreements.

The seventh and last implication is related to the increasing globalisation and internationalisation of research activities, which is partly linked to the international circulation of scientists and engineers mentioned in the fifth implication above. As illustrated in Figure 11, during the last twenty years, the internationalisation of science, measured in relative importance of foreign co-authorship, increased much faster in developing countries than in the rest of the world. Although situations in developing countries vary, all the countries are more internationalised today than they were twenty years ago, and some countries, such as Costa Rica, Ethiopia, Kenya and Senegal, are very highly internationalised. When as much as 90 per cent of a country's scientific production, measured in number of publications, is co-signed with foreign co-authors, does the term 'national science' mean anything? To what extent does globalisation and internationalisation make national boundaries and the notion of a national system irrelevant?

Finally, we hope that the findings and recommendations presented above will be useful as an input for a future revision of the Frascati Manual, also to the extent that some of the issues discussed here could also have implications going beyond developing countries. As far as developing countries are concerned, these recommendations have already been used by the UIS in a paper presented at OECD in June 2008 (Fernandez 2008), which was presented and discussed at an expert meeting that took place in Windhoek, Namibia, last 14–16 September 2009.[24] As a follow-up to this expert meeting, this draft document is being developed as a stand-alone document on R&D in developing countries and its implications for measurement. This stand-alone document will also serve as a base for an Annex to the Frascati Manual.

Appendix 1
United Nations List of Least Developed Countries (LDCs)

Afghanistan	Madagascar
Angola	Malawi
Bangladesh	Maldives
Benin	Mali
Bhutan	Mauritania
Burkina Faso	Mozambique
Burundi	Myanmar
Cambodia	Nepal
Cape Verde	Niger
Central African Republic	Rwanda
Chad	Samoa
Comoros	Sao Tome and Principe
Democratic Republic of the Congo	Senegal
Djibouti	Sierra Leone
Equatorial Guinea	Solomon Islands
Eritrea	Somalia
Ethiopia	Sudan
The Gambia	Timor-Leste, Democratic Republic of (East Timor)
Guinea	Togo
Guinea-Bissau	Tuvalu
Haiti	Uganda
Kiribati	United Republic of Tanzania
Lao People's Democratic Republic	Vanuatu
Lesotho	Yemen
Liberia	Zambia

NOTES

1. An earlier version of this article was presented and discussed at a workshop organized by the UNESCO Institute for Statistics (UIS) and held in Montreal, Canada, in December 2007 (Gaillard 2007b). Other papers commissioned by the UIS for the same workshop are relevant to the present discussion (for example, Kahn et al. 2008; Arber et al. 2008).
2. Descriptors are basic nominal measures (not standardised) that provide basic information on quantities of units of analysis. Narratives are sections of 'thicker' descriptions that may be historical but at least provide more contextual accounts of key themes and topics (Mouton and Waast 2008).
3. Developing country status brings certain rights in the international community. There are, for example, provisions in some World Trade Organization (WTO) agreements which provide developing countries with longer transition periods before they are required to fully implement the agreement, and furthermore developing countries are entitled to technical assistance.
4. The data source (Thomson Scientific, formerly Institute for Scientific Information [ISI]) is highly selective and only screens the world's most prestigious journals (in the case of SCI, the ones whose articles are most frequently cited) most of which are published in the North.
5. It is noteworthy that the number of South African journals dropped from thirty-five to nineteen during the years 1993–2004 (Mouton et al. 2006).
6. Research for the two main industries in the country, forestry and sugar, is outsourced to institutes in South Africa.
7. 2005 is the latest year for which we have reliable and comparable human resources data for most countries.
8. Mainly, thanks to the increase in South Africa (66 per cent).
9. The construction of this database draws on the work of Barro and Lee (2000) and of Cohen and Soto (2001).
10. Iceland is the only country that did not participate.
11. This section draws on OST (2006), UIS (2004) and UIS (2007).
12. 2005 is the latest year for which we have reliable and comparable data on R&D budgets worldwide (except for the OECD countries).
13. Gross domestic expenditure on R&D (GERD) as a percentage of GDP in this paragraph or for 2007 or latest available year (OECD 2008).
14. These tools and their possible uses are recurrently discussed in scientific literature and were extensively criticised. Ultimately, the impact index was corrected, see Monastersky (2005).
15. On the issue of lack of citation and visibility of third world science, see Gaillard (1989).
16. Asia-8 is composed of South Korea, India, Indonesia, Malaysia, Philippines, Singapore, Taiwan and Thailand.
17. Evaluation of Scientific and Technological capabilities in MEditerranean countries (ESTIME).
18. Egypt did not participate in the project.
19. Although the limit is very difficult to define, a country producing fewer than twenty publications a year cannot be considered as a very important player.

20. This was observed in several countries involved in the ESTIME project, including Algeria, Tunisia and Lebanon.
21. This part draws on the country review template proposed by Mouton and Waast (2008).
22. Descriptors: Descriptors are basic nominal measures (not standardised) that provide basic information on quantities and units of analysis.
23. Narratives: Narratives are sections of 'thicker' descriptions that may be historical but at least provide more contextual accounts of key themes and topics.
24. Expert Meeting on Measuring Research and Development in Developing Countries: Preparation of an Annex to the Frascati Manual, Windhoek, Namibia, 14–16 September 2009, in which the author of this article participated.

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