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Scientometric Study

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Scientific Collaboration between Canada and Developing Countries, 1992-2003

Prepared for the

Office of the National Science Advisor

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Grégoire Côté
and Éric Archambault

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514.495.6505 • 4572 avenue de Lorimier • Montréal • Québec • Canada • H2H 2B5
info@science-metrix.com • www.science-metrix.com

Executive summary

Providing assistance to poorer countries preoccupies several of the richer countries. The old model of donating aid, often with conditions, is slowly being replaced by initiatives that aim at building capacity in the developing countries so that interventions are more durable and rewarding. The development of a strong science base is perceived as an important step in that direction. Scientific collaboration is one way to help poorer countries to acquire knowledge and to develop their scientific and technological activities. Canada has recently decided to step up this form of aid. This is a real challenge since, among the richer countries, Canada currently has one of the lowest rates of scientific collaboration with developing countries. In order to exceed or even match the level of collaboration of the leading OECD countries will require enormous efforts from Canada and enlightened choices to maximize the impacts of such collaboration for both the foreign and the Canadian researchers. The underlying assumption in this report is that collaboration must be mutually beneficial in order to favour sustainable development.

A proper identification of needs and strengths of the countries involved enables the benefits from cooperation to be maximized over the long run. This report uses bibliometric tools to describe the current state of the scientific systems and trends in scientific output of developing countries in 1992-2003. It identifies these countries' relative strengths, measures actual collaboration levels with Canada in the different scientific fields and subfields and provides recommendations as to the areas where collaboration should be promoted.

When considered as a group, the share of scientific publication from developing countries is clearly increasing. In 2003, just over 18% of papers where from developing countries, and this level had been increasing by about 0.5 percentage points per year, an encouraging but still slow rate. The impact of their research is also increasing, with an increase of 25% in expected citations over the period studied.

For individual countries, the statistics presented clearly show that scientific activity in the developing world is heterogeneous. Some countries considered in this study have a level of publication similar to Canada (Russia, China, India) whilst there are others whose outputs a thousand times smaller. However, most of the countries with low publication output have high growth rates, such that they are forecast to reach the Canadian level in a few years. This is the case for Iran and Turkey for example, and it is associated with significant development in their scientific systems: the numbers of institutions, programs and networks are growing, their research findings are being published in world-level journals, and their scientists are increasingly participating in international conferences. Canada could develop collaborations with these countries that would be beneficial for both parties. On the other hand, collaboration with countries with very low levels of scientific activity, which has not increased significantly over the last 12 years, needs to be evaluated carefully, and perhaps on a researcher by researcher basis. Collaboration with these countries would therefore be similar to the more traditional unidirectional aid model, and thus identification of these countries' needs is fundamental.

Most developing countries have high levels of international collaboration, a feature often associated with a dependence on other countries for research and development. Increasing collaboration is also a general trend in high income countries. There are several factors that explain the propensity to collaborate, and the main ones encouraging developing countries are:

- *Internet*: makes previously difficult–to-find scientific literature easily accessible; also, emails favour interactions;
- *Equipment*: most scientific equipment, not just state-of-the art, is expensive for many poor countries;
- *Experts*: developing countries usually have a very small share of scientific expertise; they need to access expertise from other countries;
- *Global objectives*: many global problems are intimately related to poverty, and the northern countries are giving growing attention to developing countries' views and knowledge.

Internationally coauthored papers are generally published in journals that are cited more frequently than the average, and single authored papers are generally published in less frequently cited journals. Not surprisingly, papers from high income countries are generally published in higher impact journals than papers from developing countries. Looking at the evolution of collaboration of these two groups in the 1992-2003 period, we can see that:

- the gap between the high income countries and the developing countries has significantly decreased over the period;
- for high income countries, collaborating with other high income countries yields publications in journals that are more likely to be cited, whereas collaborating with developing countries yield papers in the same range as their average; this could be perceived as a disincentive to collaborate with developing countries relative to collaborating with other high income countries but also could be perceived as being an "as good as" solution since there is nothing to lose by collaborating with developing countries compared to not collaborating at all;
- for the developing countries, the difference between collaborating with other developing countries and collaborating with high income countries is not significant.

Although these observations give a good overall picture of what can be expected from collaboration with a given group, they are based on averages and the individual reality is more complex. For example, there are cases where collaborating with a developing country yields higher impact papers and cases where collaboration with a high income country yields less often cited papers. Thus, detailed knowledge of the strengths of individual countries allows the potential scientific impacts of collaboration to be maximized.

Collaboration patterns already exist between developing countries and high income countries. In most cases, these relations are related to geographical proximity and colonial history: whereas the US is more active in South America, the UK and France are very active in Africa. Canada does not follow any clearly defined patterns, and has some important relationships with Middle-Eastern, Eastern European, Latin American and Asian countries. Its scientific collaboration with Iran is unique and should probably be encouraged as Iran is undergoing the highest growth in science. Canada's relationship with Brazil is also intense: Brazil's scientific system is maturing quickly thus opening up several fields for mutually beneficial collaboration.

Further collaboration with developing countries would surely benefit from information on countries' strengths and weaknesses. This report examines the level of specialization, the expected scientific impact, and the intensity of current scientific collaborations with Canada for 57

developing and lower income countries in the 8 main fields of natural sciences and engineering. Generally, biology, chemistry and physics are the fields where developing countries have achieved the most while biomedical research and clinical medicine have received less attention, despite the fact that health is one of the most important concerns in the developing world. The field of biology is probably where Canada is best placed to help developing countries through collaboration as it has strengths in almost every subfield. This report also gives a more detailed picture of the current position in 17 countries (Argentina, Brazil, Chile, China, Costa Rica, Egypt, India, Indonesia, Jordan, Kenya, Mexico, Nigeria, Senegal, South Africa, Thailand, Tunisia and Vietnam) and makes recommendations for stepping up collaboration at the subfield level.

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1 Introduction

Providing aid to people from poorer countries to give access to clean water, decent food, healthcare and other basic needs has been a long running preoccupation of the richer nations. Recently, this support has been growing and has been better orchestrated, and is involving governments more actively. The old model of money, food and equipment donations is progressively being replaced by a more strategic and more knowledge-based approach (Burnside and Dollar, 2000). These changes were necessary since the old approach had significant problems, probably the most striking being that aid money did not translate into real help (Feyzioglu et al., 1998). For instance, in some cases, money was deflected from its intended recipients, or was "lost" in complex bureaucratic organizations. In other cases, the underdeveloped infrastructure of recipient countries did not allow them to use the money effectively. These problems were compounded by the relatively ephemeral effect of such donations.

Efforts are now being oriented towards building capacities in developing countries (UNDP, 2001). Direct technology transfer is one possible means of giving aid, but involve problems related to intellectual property, and also makes the beneficiary dependent on the donor for implementation, maintenance and improvements to the technology. So, capacity building needs to be viewed holistically and should include knowledge transfer and training (Keller, 1996; Wagner, 2001). This model, although it is certainly more efficient than the old way of distributing aid, still follows the pattern of donor-receiver, and may not be targeting the recipient country's needs and strengths (Jentsch and Pilley, 2003). It is being realized that aid in the form of collaboration should be mutually beneficial in order to maximize the benefit to the poorer countries and to stimulate the richer countries to sustain the collaboration (Kumaraswamy and Shrestha, 2002).

The Canadian government is backing this mode of aid giving with a clear commitment to mobilizing Canadian strengths in science and technology (S&T) to assist developing nations. An important first step is to foster scientific collaboration with developing countries in the areas of research that will be rewarding for both partners. Figure 1 shows that Canada has been involved in coauthorship of scientific papers with scientists from developing countries and that this activity has nearly doubled over the last 12 years from 3.4% in 1992 to 6.4% in 2003. This increase in coauthorship with developing countries is greater than the increase in Canada's international collaboration generally, which rose by 50% over the period, from 23.6% in 1992 to 35.5% in 2003.

If Canada's rate of collaboration with developing countries reflected their share of world publications, collaboration would have grown from 15.6% in 1992 to 18.2% in 2003. Because Canadian researchers seeming to prefer to collaborate with developed countries, the share is actually lower: 12.5% in 1992 increasing to 15.3% in 2003. This difference is fairly small given that many factors such as cultural and geographical proximity, history of collaboration, common languages, and higher expected impact, favour collaboration with high income countries. Despite this small difference, Canada ranks last amongst the G7 countries and is in the lowest ranking among the world's high income countries in terms of collaboration with developing countries. This can be explained at least in part by the fact that Canada collaborate intensively with the US, which boosts the Canadian percentage of collaboration with high income countries and, accordingly, reduces the percentage of collaboration with developing countries. However, this is only part of the explanation. For Canada to be among the leaders in scientific collaboration with developing countries efforts are required.

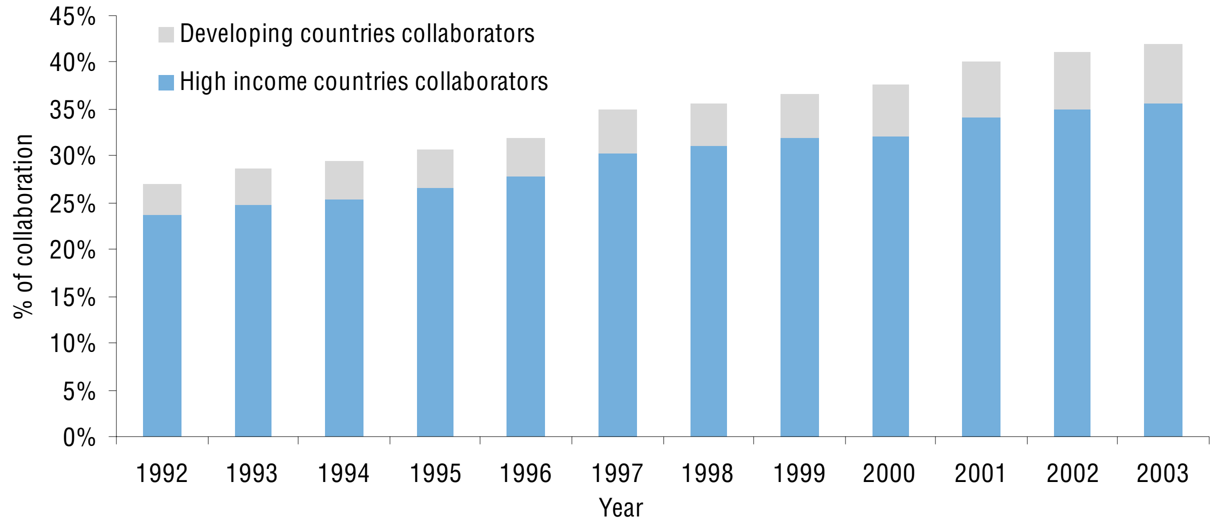

Figure 1 Evolution of the share (%) of Canadian papers in collaboration with developing countries and high income countries, 1992-2003

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

As already mentioned, awareness is growing that maximizing the benefits of collaboration means that both developing and developed countries should gain from the relationship. Matching developing and developed countries' scientific strengths is a useful starting point to operationalize this paradigm. This report uses bibliometric methods to identify the strengths and weaknesses of developing countries and of Canada, to identify complementarities, and differentiate the fields where scientific collaboration should be encouraged.

Section 2 draws a general picture of developing countries' scientific activity using bibliometric indicators, and positions these countries relative to high income countries. This makes it clear that the developing world is not homogeneous, but rather comprises a mosaic of nations with a variety of economic, social and, particularly, scientific needs (Moreno-Borchart, 2004). For example, the number of scientific papers published in major international journals ranges from 6 in the last 12 years for Afghanistan, to 260,216 for Russia, and 187,083 for China. Some countries, such as Brazil, China and India, have made good progress in establishing their own research base, but most low-income countries effectively have no or very little research and development (R&D) activity. Section 3 looks at developing countries' collaboration generally, and with Canada and other scientifically advanced countries particularly. Finally, Section 4 examines the strengths and weaknesses of developing countries in the different fields and subfields of science, and compares these with current pattern of collaboration in order to identify where Canada can reciprocally increase the scientific impact of collaboration.

2 Scientific publications in developing countries

Scientific achievement, and more particularly the publication of research results in international journals, is concentrated in the richest countries. The 46 countries considered by the World Bank to be high income countries, and which represent 15% of the world's population, account for 56% of world gross domestic product (GDP) and publish 84% of all scientific papers[1]. In fact, as shown in Figure 2, a country's scientific output is strongly correlated with its GDP. This means that for many of the poorest countries, the science system is so underdeveloped that scientific collaboration would not be of any help to their populations.

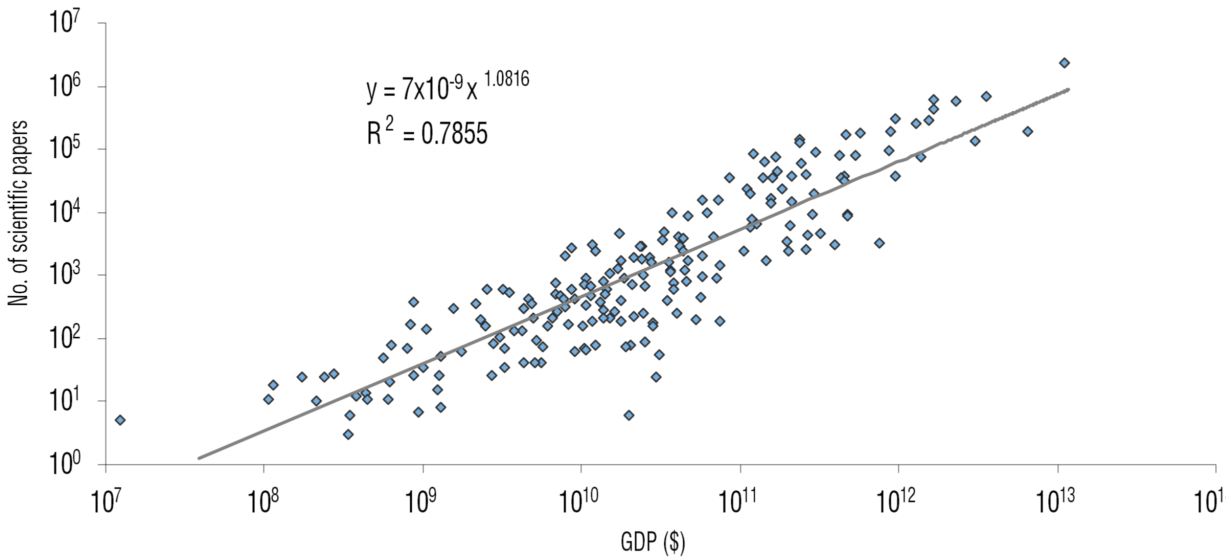

Figure 2 Relation between GDP and scientific output (1992-2003)
Source: Data compiled by Science-Metrix from the CIA World Factbook and from data prepared by OST from SCI (Thomson-ISI)

Thus, although it might be interesting to examine the scientific output and collaboration patterns of all developing countries, the impact of collaboration will be higher if the focus is on those countries whose scientific system has reached a certain threshold. Countries with underdeveloped scientific capabilities will not generally attract foreign collaborators and would not have the capability to convert the knowledge into wealth and other social benefits. This study focuses on a selection of the more scientifically developed countries. The selection was made by omitting high income economies[2] and by retaining the countries with an average of 100 scientific papers per year from 1992 to 2003 from those that remained.

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[1] This figure is obtained by looking at the scientific papers indexed in the Science Citation Index (SCI). For more information about this database's coverage and limitations, please see the methods section of this report.

[2] As defined by the World Bank - www.worldbank.org/data/countryclass/classgroups.htm

2.1 Natural sciences and engineering

As has been shown, high income economies are responsible for the majority of the published papers in natural sciences and engineering (NSE), but the share of developing countries is growing. Figure 3A shows that the percentage of developing country participation (share of developing countries in addresses of authors of scientific papers) is growing significantly. The small decrease at the beginning of the period is essentially due to a general slowing down of publications by Russia and other ex-USSR scientific systems after the breakdown of the USSR. Since that time, the share has grown almost linearly by 0.5 percentage points each year, which is encouraging but still a very slow pace.

Figure 3B shows that the average relative impact factor (ARIF) for developing countries has risen fairly consistently during the 12 years since 1992. ARIF is an index computed from citations to scientific papers. Citations are a good proxy for the quality of published research. An ARIF score above 1 means that a country's papers are published on average in journals that are more cited than others, whereas a score under 1 means that on average the country tends to publish in less cited journals. The ARIF score for developing countries in 2003 was 0.78. This means that developing countries publish in a pool of journals that are cited 22% less often than the average journal. For a description of this indicator and others used in this report please see the methods section provided in the appendix.

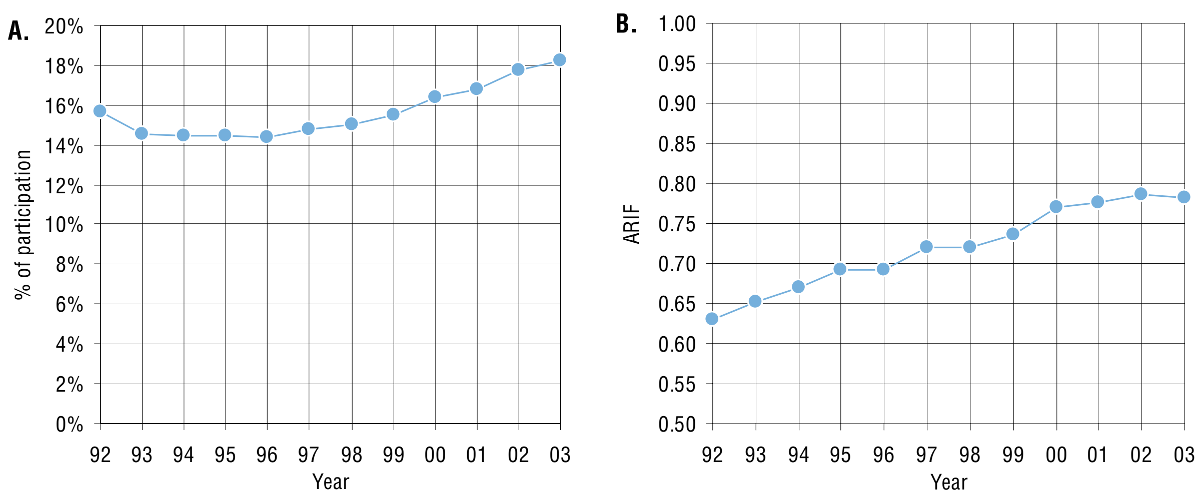

Figure 3 A. Evolution of participation of developing countries, 1992-2003
B. Evolution of ARIF of developing countries, 1992-2003

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

There is a wide variety of scientific advancement levels among developing countries. Figure 4 presents countries with at least 100 published papers per year. Again, it is clear that the largest part of the scientific literature comes from a few high income countries. Generally, the top positions are occupied by high income countries and the lowest by developing countries.

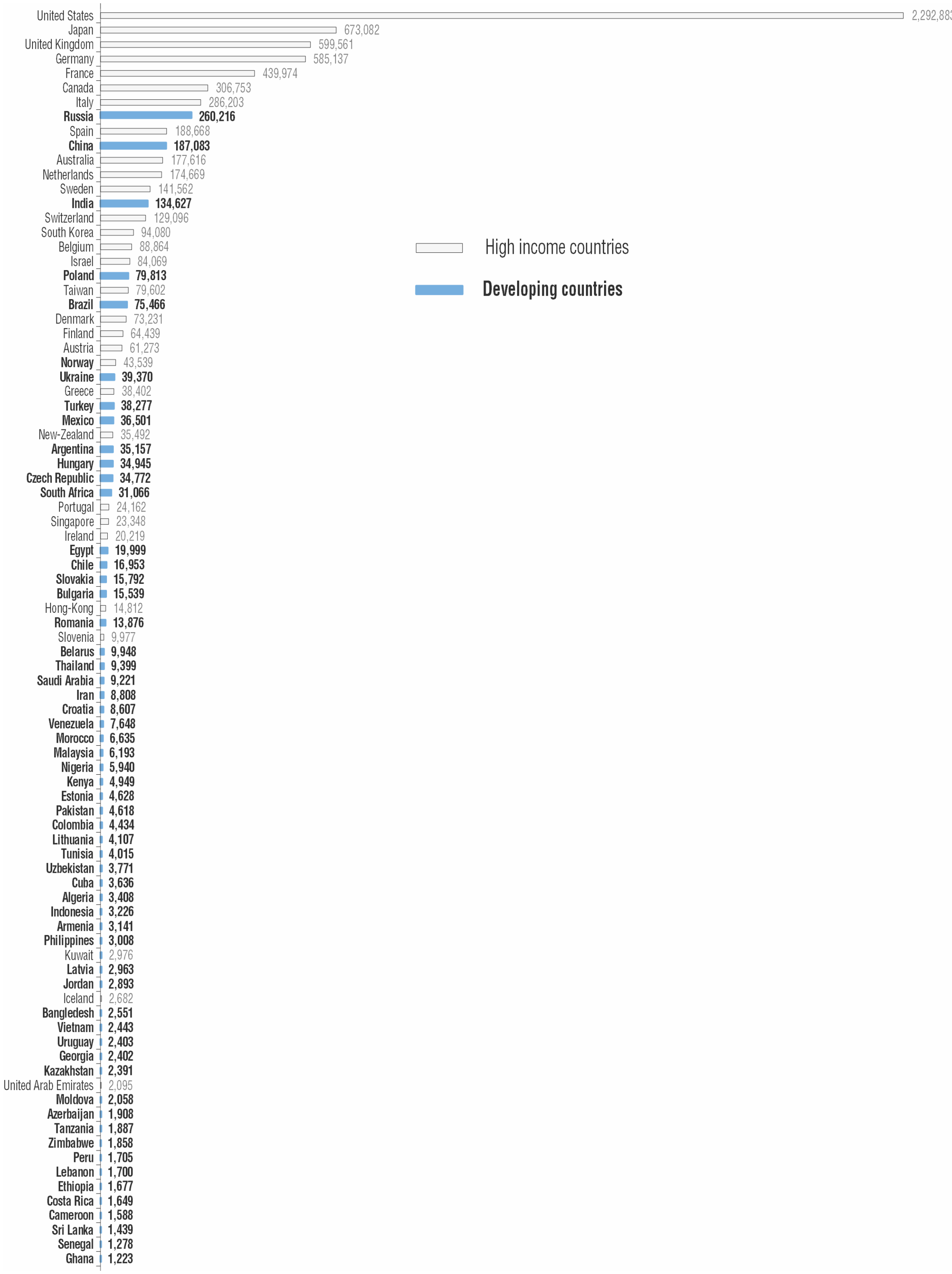

Figure 4 Scientific papers in NSE of selected countries (1992-2003)

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

The separation between high income countries and developing countries is not absolutely clear-cut; it is at the level of 30,000-40,000 publications over the period. This level of publication is about the same as that of British Columbia or Alberta. The developing countries that are above this level are generally rapidly growing economies and are heavily populated. Hence, if number of papers per capita is considered, Russia, which ranks 8th in terms of number of papers, drop to 36th position. Similarly, China drops from 10th to 69th position; India drops from 14th to 72nd; Poland drops from 19th to 31st; Brazil drops from 21st to 55th and Ukraine drops from 26th position to 45th. Similarly, some of the high income countries do not show very high publication rates. Kuwait and the United Arab Emirates, two oil-based economies, and Iceland, for instance, are all sparsely populated countries and show low rates of publication. For example, Iceland (≈ 300,000 inhabitants) is 69th in terms of the number of papers, but ranks 9th in terms of papers per capita.

Figure 5 shows that many countries that are ranked very low in terms of number of papers are countries that are experiencing significant growth. With the exception of a few (mostly ex-USSR) countries, all the countries presented have a positive growth rate. The countries with a well established scientific system generally show an annual growth of less than 5%, with Canada experiencing the lowest growth at 0.6% annually. Iran is by far the fastest growing country, with an average yearly growth of 25%, which represents a doubling in only 3 years. At this rate, Iran with 177 papers in 1992 would reach Canada's annual output (≈28,500 papers) in 2017.

It can be assumed that the reason for this marked increase in Iranian scientific output is mainly changes in the country's research policy: the Science, Research and Technology Ministry in Iran gives substantial financial awards to scientists who publish in international journals. Turkey, Lebanon, China and Singapore are also experiencing fast growth rates, that is, around 15%. Of these countries, China stands out with an output already higher than that of Canada. If these countries continue to grow at the same rate then China, which outstripped Canada in 2001 and Italy in 2002, will overtake France in 2005, the UK in 2007, Germany in 2008, Japan in 2009 and the US in 2016. Many other developing countries are showing strong growth rates that should result in publication levels similar to those of the leading countries in the near future.

Figure 6 presents the ARIF for selected countries. Again, countries with the highest ARIF are mostly the higher income countries. However, there are some high income countries with an ARIF below the world average, which is due to the predominance of the US whose high impact factor and large share of world papers pulls the average up. With an ARIF of 1.04 which is higher than the world average, Peru stands out in 7th place, just below the UK (6th) and Canada (5th). Other developing countries worth noting are Costa Rica (26th), Indonesia (28th), Uruguay (30th), Vietnam (31st), Colombia (32nd) and Philippines (33rd), all with ARIF slightly above 0.9. Of the high income countries with very low ARIF, Kuwait and the United Arab Emirates rank lowest.

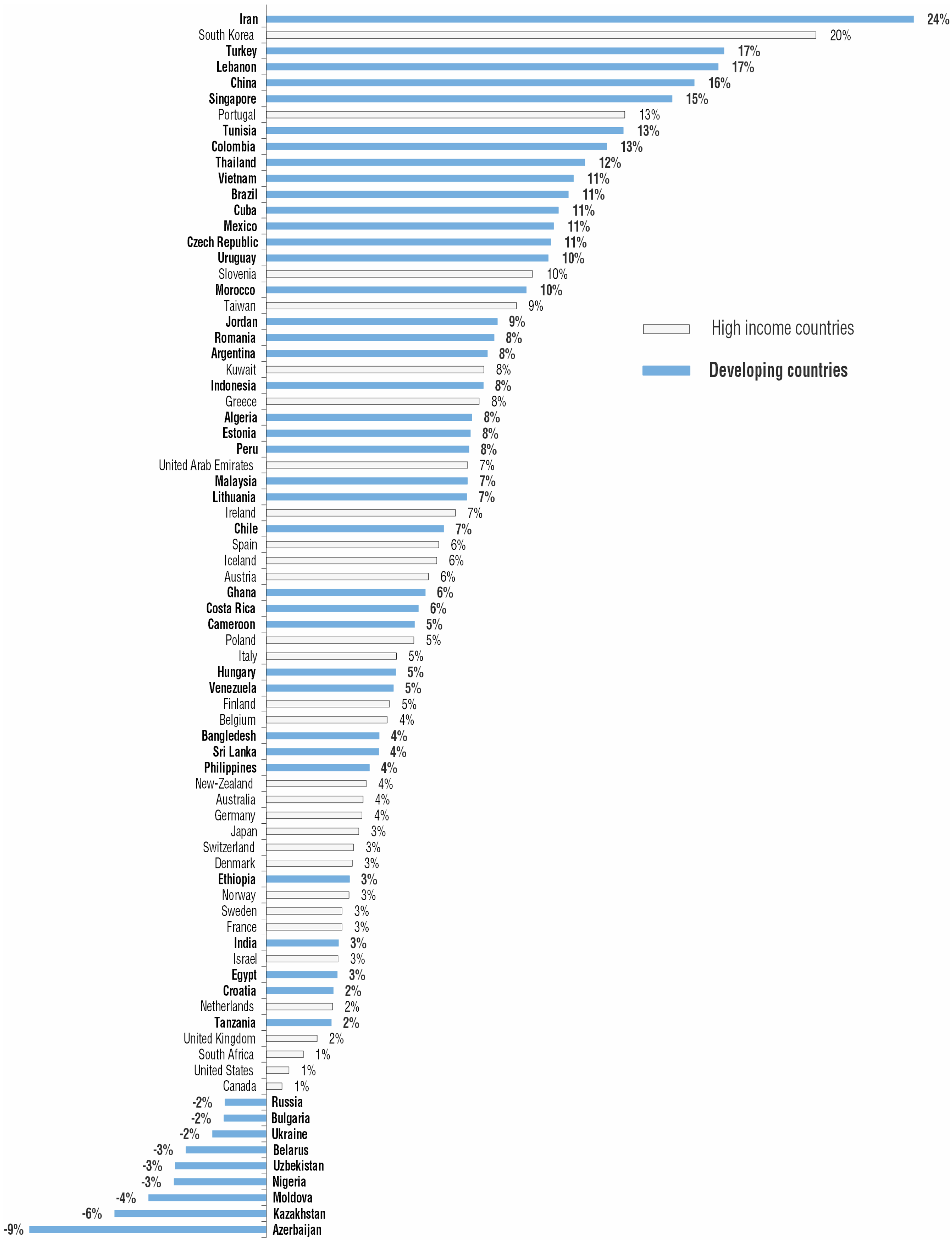

Figure 5 Growth of scientific papers in NSE of selected countries (1992-2003)

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

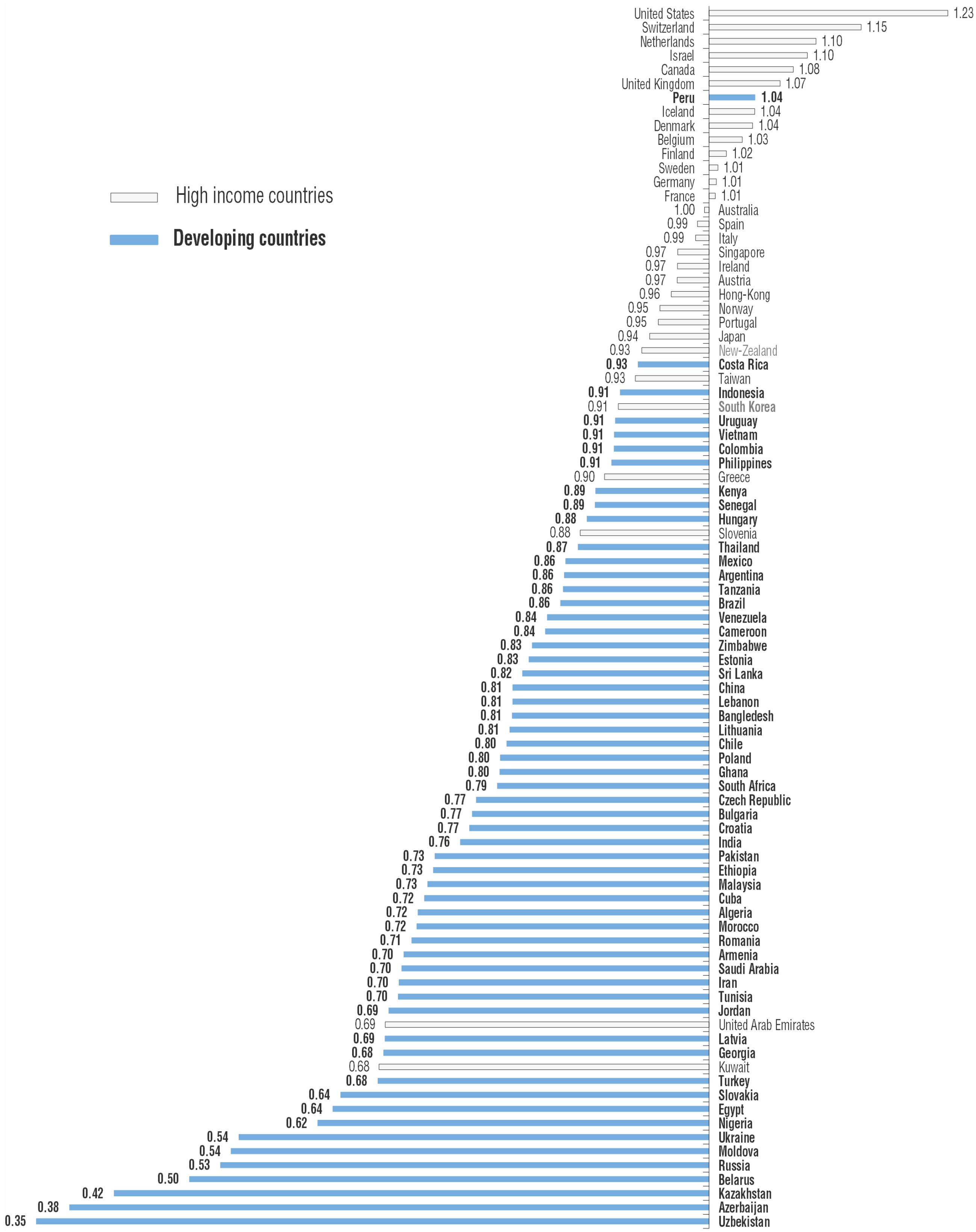

Figure 6 ARIF of scientific papers in NSE of selected countries (1992-2003)

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

2.2 Social sciences and humanities

The developing countries' share of world papers in social sciences and humanities (SSH) increased from 5.7% to 6.6% over the 1992-2003 period, a share about three times smaller than for NSE. These countries are not catching up rapidly: the increase over the 12-year period was slightly less than 1%. This may seem surprising given that research in SSH does not on the whole demand expensive equipment and thus could more easily be conducted by poorer countries. This relatively low share can be explained in part by the fact that the Thomson ISI databases overestimate English journals: papers in the SSH area are often written in languages other than English and published in journals with a local readership. Data obtained from the Thomson ISI database therefore might be biased, particularly in SSH, towards high income countries where English is spoken (Hicks, 1999, 2004).

The number of papers indexed in the Social Sciences Citation Index (SSCI) and the Arts & Humanities Citation Index (AHCI) amount to nearly 1.1 million papers over the period 1992-2003, and represent about one-sixth of the total papers indexed in the SCI. It is reasonable then to expect ratios on the same scale for individual countries. It would also be expected that fewer countries would be included as for some the number of papers would not be sufficiently significant to support analysis. Figure 7 shows the number of publications in SSH for countries with at least 50 papers per year on average in 1992-2003. The ranking of countries for SSH is different from NSE, but even more markedly than for NSE, the leading countries in SSH are mostly high income countries. Russia, China and India, respectively 8^{th}, 10^{th} and 14^{th} in NSE, rank 13^{th}, 18^{th} and 21^{st} in SSH. Poland is much higher for NSE (19^{th}) than SSH (35^{th}). Conversely, South Africa is ranked 20^{th} in SSH compared with 34^{th} in NSE. Mexico is also doing relatively well in SSH in 25^{th} position compared to 29^{th} for NSE. Canada ranks 6^{th} in NSE while it was ranked 3^{rd} in SSH with only the US and the UK ahead.

Growth in SSH (data not shown) is generally roughly the same as in NSE, the exceptions being Croatia with an average annual growth of 19% in SSH (compared to 2% in NSE), and China, with a growth rate in NSE of 16%, and in SSH of 24% – a doubling in only three years. At the other end of the scale are Uruguay and Cuba who have grown by 10% and 11% respectively in NSE, but in SSH show almost negative growth. Finally, Iran, which shows the highest growth rate in NSE (24%), has a smaller but still significant growth rate of 15% in SSH.

The limitations of using the impact factor in SSH have been discussed in the literature. The main limitation is that citations accrue more slowly in SSH than in NSE. Thus, the two-year window used by Thomson ISI to calculate its impact factor might not be very appropriate for SSH (Glänzel and Schoepflin. 1999; Van Raan. 2003). Also, no impact factor is calculated for journals in the AHCI. However, country-level statistics are sufficiently consistent to allow cross-country comparison. As was the case in NSE, the top positions are mostly occupied by the high income countries (data not shown). But there are some surprises, such as China, which is 49^{th} in NSE but 7^{th} in SSH. China's score in SSH is 0.99, a score on a par with average world papers and almost the same as Canada. Chile, Hungary and Nigeria, respectively ranking 14^{th}, 18^{th} and 22^{nd}, are the next highest scoring developing countries with ARIF above that of many high income countries.

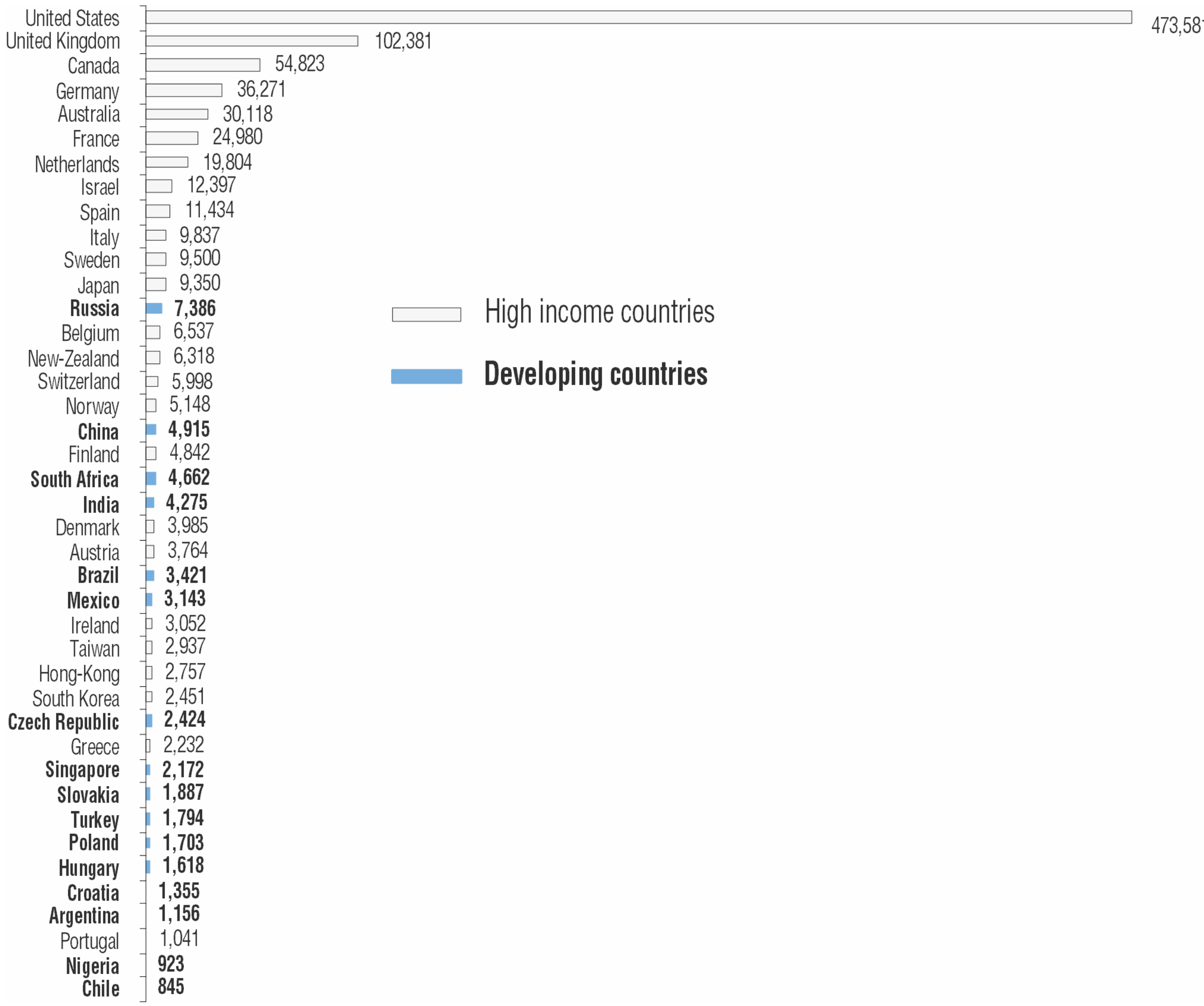

Figure 7 Number of scientific papers in SSH of country with an average of at least 50 papers per year (1992-2003)

Source: Data compiled by Science-Metrix from data prepared by OST from SSCI & AHCI (Thomson-ISI)

3 Scientific collaboration in developing countries

This section provides an overview of international collaborative activity in developing countries and examines its evolution over the twelve years from 1992 to 2003. Section 3.1 specifically studies collaboration in NSE and focuses on the recent evolution of collaboration patterns. It also looks at the quality of collaborative research in developing countries, in high income countries and between these two groups. Finally, it looks at the intensity of developing countries' collaboration with Canada and other high income countries. Section 3.2 briefly describes collaboration of developing countries in SSH and highlights the differences with NSE. Section 3.3 focuses on collaboration between the African countries and Canada and the United Kingdom.

3.1 Natural sciences and engineering

Collaboration between scientists from different countries is increasing. In bibliometric terms it is measured by the growing number of scientific papers with authors from at least two countries. There are many factors that explain increasing collaboration including:

- information flows increasingly easily and rapidly; the internet is one of the most important drivers of information diffusion (Walsh et al., 2000);
- very expensive equipment is scarce and often has to be shared (Katz and Martin, 1997);
- scientific staff are becoming more and more specialized, and experts are often dispersed across countries (Luukkonen et al., 1992);
- increased attention is being paid to global objectives; disease, pollution, the economy are being approached from a transnational viewpoint;
- international collaboration is prestigious and increases reach; incentives from institutions and government are reinforcing this (Katz and Martin, 1997).

Particularly important for developing countries are that:

- The *internet*: makes previously difficult-to-find scientific literature easily accessible, and email favours interactions[3];
- *Equipment*: most scientific equipment, not just state-of-the art, is expensive for many poor countries;
- *Experts*: developing countries usually have a very small share of scientific expertise; they need to access expertise from other countries;
- *Global objectives*: many global problems are intimately related to poverty and the northern countries are giving growing attention to developing countries' views and knowledge.

Figure 8A shows how the production of scientific papers with international collaborators has evolved for developing countries and for high income countries. Data presented are in percentages and are averages for each group of countries: it should be remembered that there is huge variance within each group. For example, among developing countries, international collaboration rates for 2003 ranged from 21% for Turkey and India, to 91% for Tanzania, and reached 100% for many small

[3] This factor is controversial and some authors suggest that internet further ostracizes poorer countries. For example, see Arunachalam (1999).

countries. Nevertheless, there is a clear upward trend for both developing and high income countries. It should be noted though that the high income countries have lower rates of international collaboration and that the increase in collaboration has stopped or slowed significantly in the last three years, whilst for developing countries average rates are still increasing.

Figure 8B shows that the share of high income countries' collaborations with developing countries is rising rapidly. 25% of their international collaborators were from developing countries in 2003, which, even if the share of developing countries is only 18% overall, indicates a preference for collaboration with developing countries, despite the fact that publications from these countries usually have lower impact, and cultural, historical and geographical factors would seem to favour collaboration with other high income countries (Zitt et al., 2000).

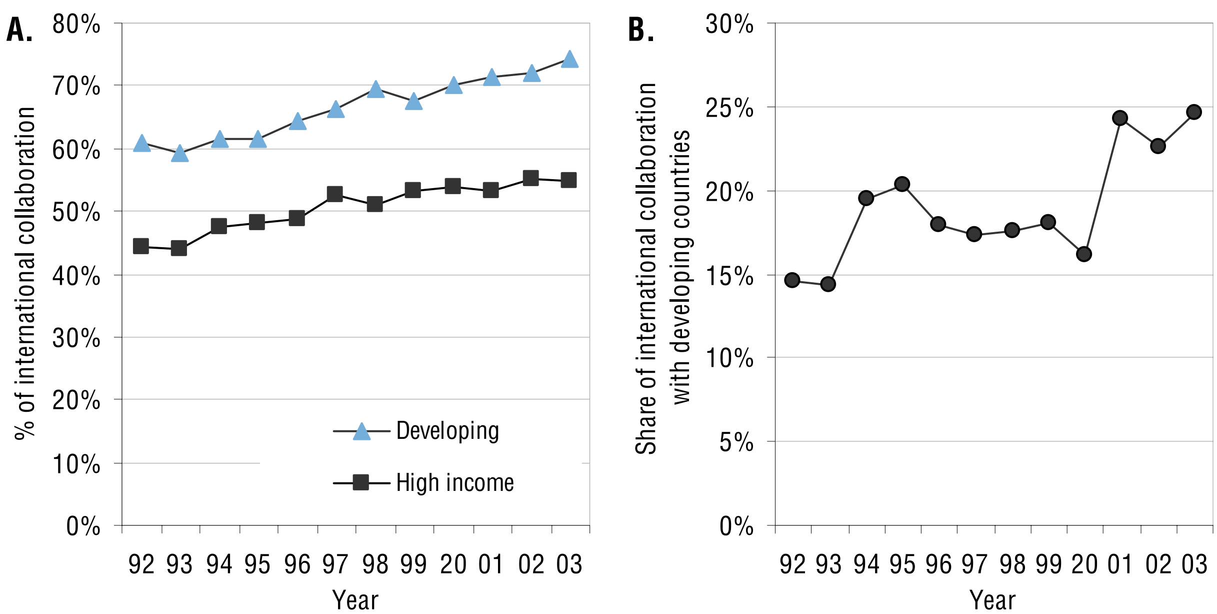

Figure 8 A. Percentage of international collaboration, 1992-2003
B. Share of international collaboration, 1992-2003

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

At the beginning of this section, some explanations were provided for this general increase in international collaboration. In the context of greater emphasis on international collaboration, it is interesting to examine whether international collaboration results in better science. One way to assess this question is to compare the impact of collaborative scientific papers with that of scientific papers generally, based on ARIF scores. There are many examples of such measurements and discussion of their significance in the literature (Glanzel and Schubert, 2001; Katz and Hicks, 1997; Van Raan,1998). Figure 9 presents data showing the various patterns of collaboration between high income and developing countries. These data show that:

- high income countries (H) have significantly higher ARIF than developing countries (D). However, the gap was smaller in 2003 than in 1992;

- for high income countries, collaborating with other high income countries (H-H) yields publications in journals that are more likely to be cited often and results in higher ARIFs, whereas collaborating with developing countries (D-H) does not affect their score either way. This could be perceived as a disincentive to collaborate with developing countries relative to collaborating with other high income countries or it could be seen as an "as good as" solution, since there is nothing lost from collaborating with developing countries compared to not collaborating at all;
- for developing countries, collaborating with other countries results on average in higher ARIF. In 1992, it was very rewarding to collaborate with high income countries: currently the difference between the ARIF of collaborations with high income countries (D-H) and with developing countries (D-D) is very small or even non-existent.

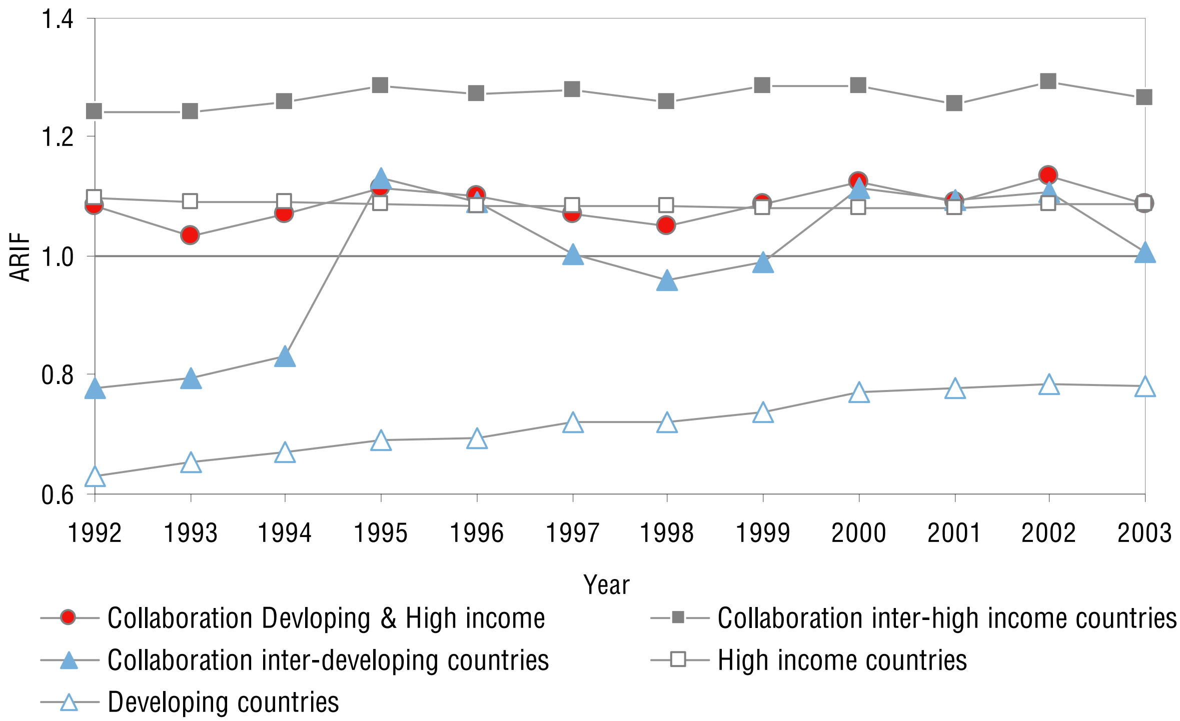

Figure 9 Evolution of the ARIF of developing countries, of high income countries and of papers in international collaboration between a developing countries and high income countries, between two developing countries and between two high income countries, 1992-2003

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

These statistics are based on average scores and there are many cases where collaborating with high income countries leads to lower impact and, conversely, many cases where collaborating with developing countries leads to higher impact. This indicates the importance of the choice of collaborator to increasing the reach of scientific research. Section 4 of this report investigates the strengths of selected developing countries in different fields of science to highlight where the rewards from collaboration would be maximized for both Canada and developing countries.

There are some important preferences in the existing patterns of collaboration. For example, Canada favours collaboration with Brazil: Brazil is shown to be the 3rd "favourite" country among developing country collaborators, while it ranks 5th in terms of developing countries' volume of publications. Table I shows Canada's collaboration with selected developing countries, and collaboration of these countries with Canada and other selected G7 countries as percentages. 5.7% of Brazil's international collaborations are with Canada. This is slightly more than would be expected from Canada's share of world papers (4.5%). However, based on their usual share of world publications the US, the UK, Germany and particularly France all have higher rates of collaboration with Brazil than Canada. Collaboration between Brazil and France accounts for 14.3% of all Brazil's international collaborations, while France only produces 6.5% of world papers. Iran is probably the most favoured developing country for Canadian collaborators: 0.3% of Canadian collaborations are with Iran while Iran is responsible for only 0.1% of world publications. This reveals that there are three times as many collaborations as would be expected if Canada did not have any preference. The corollary to this is that 15.2% of Iran's collaborations are with Canada which is even more remarkable and positions Canada as the collaborator of choice for Iran[4].

Many other favoured or not so favoured partnerships can be seen from Table I. As a baseline, it should be remembered that Canada is responsible for 4.5% of world papers, the US for 34%, UK and Germany for 9% and France for 6.5%. Anything in the same range would indicate no preference: for example between 4% and 5% of collaboration with Canada is normal. Anything below would indicate disinterest whilst anything above would denote a preference. Generally, collaborations are related to geographical proximity and, to a lesser extent, colonial history. The main patterns are:

- Latin-American countries have a strong preference for collaboration with the US. Lebanon also has a strong preference for collaboration with the US;
- East European countries have a very strong relationship with Germany, which is also, but to a lesser extent, an important collaborator for Middle Eastern countries;
- Middle Eastern countries collaborate frequently with the UK. Also, most ex-British African colonies, and the Asian countries show a clear preference for collaboration with the UK;
- France is favoured by its ex-colonies, especially those in Northern Africa.

Collaborators that favour Canada do not follow clearly defined patterns. Although there are strong relationships in the Middle-East and Africa, Canada is also an important collaborator for some countries in Eastern Europe, Latin America and Asia. Conversely, some countries' collaborations with Canada are fairly limited compared to their collaborations with the other G7 countries such as is the case for Cameroon, Colombia and Vietnam.

[4] Support for collaboration with Iran may have to take account of other important foreign policy issues that are outside the scope of this report. For political reasons, Iran is often not included in the list of countries and territories eligible to receive Canadian official development assistance.

Table I Percentage of Canadian collaboration with selected developing countries and percentage of collaboration of these countries with Canada, US, Germany, UK and France, NSE (1992-2003)

					% of country collaboration with:									
Country	**% of Canadian collaboration**	Rk	**% of international collaboration**	Rk	**Canada**	Rk	**US**	Rk	**Germany**	Rk	**UK**	Rk	**France**	Rk
China	2.9%	1	27.2%	55	6.1%	7	34.4%	13	11.4%	28	9.5%	31	5.9%	39
Russia	2.6%	2	29.3%	52	3.7%	35	23.9%	32	25.2%	6	9.1%	35	12.5%	20
Brazil	1.6%	3	38.9%	42	5.7%	12	38.7%	6	10.7%	30	12.2%	21	14.3%	14
Poland	1.6%	4	45.9%	36	4.5%	19	25.6%	28	23.6%	10	10.9%	25	15.9%	10
India	1.3%	5	17.7%	57	5.7%	13	37.2%	10	15.8%	19	12.1%	22	9.1%	26
Mexico	0.9%	6	44.6%	38	5.8%	11	43.8%	3	7.1%	37	9.5%	32	11.1%	23
Hungary	0.9%	7	53.6%	25	4.9%	15	30.5%	20	23.1%	11	12.1%	23	12.6%	18
Czech Republic	0.6%	8	49.9%	29	4.0%	28	19.9%	36	24.7%	7	12.4%	19	15.7%	11
South Africa	0.6%	9	34.4%	47	6.1%	8	32.6%	17	14.8%	20	21.6%	9	7.6%	31
Argentina	0.5%	10	37.0%	43	4.3%	26	33.8%	14	10.6%	31	7.8%	44	11.8%	21
Chile	0.4%	11	49.5%	31	5.1%	14	37.8%	8	13.7%	24	9.2%	34	13.9%	15
Iran	0.3%	12	27.5%	54	15.2%	1	27.1%	25	6.6%	41	20.4%	10	5.2%	40
Turkey	0.3%	13	22.0%	56	3.8%	31	37.4%	9	12.8%	25	19.2%	12	6.6%	37
Kenya	0.3%	14	66.3%	13	8.6%	2	34.6%	12	6.3%	43	30.8%	2	3.3%	52
Egypt	0.3%	15	30.9%	49	4.5%	20	33.1%	16	14.5%	23	8.7%	37	3.7%	48
Ukraine	0.2%	16	36.6%	44	1.8%	49	14.7%	47	19.0%	14	6.3%	49	8.0%	27
Thailand	0.2%	17	61.1%	18	4.5%	22	34.9%	11	4.6%	50	15.2%	17	4.5%	45
Romania	0.2%	18	51.7%	26	3.3%	38	20.3%	34	22.4%	12	8.5%	38	24.6%	7
Slovakia	0.2%	19	49.6%	30	2.9%	42	18.3%	38	23.7%	9	13.2%	18	13.4%	16
Saudi Arabia	0.2%	20	29.0%	53	7.7%	3	32.1%	18	3.8%	54	18.3%	13	4.6%	43
Venezuela	0.2%	21	49.5%	32	4.7%	16	37.8%	7	5.4%	48	10.2%	29	15.1%	13
Morocco	0.2%	22	73.9%	7	3.4%	36	9.4%	52	4.1%	52	2.9%	56	71.9%	3
Bulgaria	0.1%	23	45.7%	37	2.2%	46	17.6%	39	27.9%	3	8.2%	39	15.2%	12
Croatia	0.1%	24	44.2%	39	3.9%	29	26.8%	26	29.2%	1	7.9%	41	11.2%	22
Indonesia	0.1%	25	86.6%	1	3.8%	32	25.2%	30	7.5%	35	8.8%	36	7.5%	32
Malaysia	0.1%	26	46.8%	35	3.2%	39	14.0%	48	3.4%	56	22.5%	8	3.0%	53
Philippines	0.1%	27	69.3%	9	4.4%	23	33.3%	15	7.0%	39	7.8%	43	4.8%	42
Colombia	0.1%	28	67.7%	10	3.0%	41	40.4%	5	6.6%	42	11.2%	24	12.6%	19

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

Table I Percentage of Canadian collaboration with selected developing countries and percentage of collaboration of these countries with Canada, US, Germany, UK and France, NSE (1992-2003)

					% of country collaboration with:									
Country	**% of Canadian collaboration**	Rk	**% of international collaboration**	Rk	**Canada**	Rk	**US**	Rk	**Germany**	Rk	**UK**	Rk	**France**	Rk
Nigeria	0.1%	29	33.0%	48	4.5%	21	25.8%	27	12.1%	27	25.1%	5	3.7%	47
Pakistan	0.1%	30	43.6%	40	4.3%	25	29.6%	21	15.8%	18	24.0%	7	3.4%	50
Costa Rica	0.1%	31	79.7%	3	6.2%	6	49.3%	2	7.7%	34	7.7%	45	10.9%	24
Estonia	0.1%	32	54.7%	23	3.2%	40	14.9%	46	19.4%	13	7.6%	46	7.5%	33
Cuba	0.1%	33	61.4%	17	3.4%	37	8.0%	54	7.0%	38	4.4%	53	6.9%	35
Jordan	0.1%	34	40.4%	41	5.9%	9	29.0%	22	17.1%	17	17.1%	14	3.5%	49
Tanzania	0.1%	35	78.9%	4	4.6%	18	20.1%	35	5.4%	47	27.9%	4	1.9%	55
Lebanon	0.1%	36	49.0%	33	7.7%	4	41.5%	4	3.5%	55	12.4%	20	32.9%	6
Armenia	0.1%	37	48.0%	34	4.0%	27	25.1%	31	28.2%	2	9.4%	33	20.7%	8
Latvia	0.1%	38	55.7%	22	3.7%	34	12.1%	50	26.7%	4	7.8%	42	7.6%	30
Byelarus	0.1%	39	36.1%	45	1.7%	50	10.6%	51	25.7%	5	6.9%	48	7.2%	34
Tunisia	0.1%	40	56.1%	20	2.5%	45	7.5%	55	3.9%	53	3.1%	55	80.2%	1
Ghana	0.1%	41	66.6%	12	6.9%	5	25.6%	29	11.2%	29	30.7%	3	2.6%	54
Peru	0.0%	42	82.6%	2	3.8%	33	53.7%	1	5.2%	49	10.4%	27	7.9%	28
Zimbabwe	0.0%	43	63.0%	16	4.4%	24	31.1%	19	5.4%	46	25.1%	6	4.6%	44
Kazakhstan	0.0%	44	35.0%	46	5.9%	10	18.9%	37	14.7%	21	10.2%	30	4.1%	46
Ethiopia	0.0%	45	64.1%	15	3.8%	30	15.3%	44	9.8%	32	15.9%	15	6.1%	38
Uruguay	0.0%	46	64.4%	14	2.7%	44	27.3%	24	6.2%	44	7.6%	47	12.7%	17
Sri Lanka	0.0%	47	55.8%	21	4.6%	17	21.0%	33	4.2%	51	32.8%	1	3.4%	51
Vietnam	0.0%	48	77.7%	5	1.9%	48	12.4%	49	12.7%	26	10.6%	26	18.5%	9
Algeria	0.0%	49	67.5%	11	1.6%	52	5.0%	57	5.5%	45	4.5%	52	79.2%	2
Lithuania	0.0%	50	54.6%	24	1.5%	53	16.0%	42	17.2%	16	8.0%	40	10.8%	25
Uzbekistan	0.0%	51	29.4%	51	2.8%	43	16.2%	40	14.5%	22	4.2%	54	5.2%	41
Bangledesh	0.0%	52	60.0%	19	2.0%	47	28.0%	23	7.3%	36	19.9%	11	1.4%	56
Georgie	0.0%	53	51.0%	28	1.4%	54	15.8%	43	23.9%	8	5.6%	50	6.7%	36
Senegal	0.0%	54	77.5%	6	1.6%	51	14.9%	45	2.6%	57	10.3%	28	56.9%	4
Cameroon	0.0%	55	73.2%	8	1.3%	55	16.2%	41	9.0%	33	15.3%	16	47.6%	5
Moldova	0.0%	56	51.4%	27	0.9%	57	8.0%	53	18.4%	15	2.8%	57	7.9%	29
Azerbaijan	0.0%	57	30.2%	50	0.9%	56	6.9%	56	6.9%	40	4.9%	51	1.2%	57

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

3.2 Social sciences and humanities

As scientific production in the developing world is relatively low and concentrated in a few countries, it is difficult to produce robust statistics on trends in international collaboration in SSH. However, some general observations can be made:

- SSH research generally has a local focus making international collaboration less important;
- levels of international collaboration in SSH in both high income and developing countries were between 15% and 20% in 1992, and were closer to 35% in 2003 and roughly the same for both groups;
- the share of high income countries' collaborations with developing countries in SSH is lower than in NSE, but shows a comparable increase, from approximately 7% in 1992 to approximately 11% in 2003.

Table II presents statistics on the international collaboration of developing countries in SSH. Relationships between Canada and Russia, China, Brazil and Poland are important whilst with Chile, Mexico and Turkey they are less so.

Table II Percentage of Canadian collaboration with selected developing countries and percentage of collaboration of these countries with Canada, US, Germany, UK and France, SSH (1992-2003)

Country	% of Canadian collaborations	% of international collaboration	% of collaborations with: Canada	US	UK	Germany	France
Russia	2.1%	40.9%	10.0%	57.5%	12.2%	2.0%	1.3%
China	0.6%	17.7%	7.9%	53.6%	15.7%	3.2%	2.6%
South Africa	0.5%	24.1%	6.5%	51.3%	25.3%	3.3%	3.6%
India	0.5%	22.3%	4.5%	37.7%	15.7%	7.0%	2.5%
Brazil	0.5%	26.9%	9.3%	57.9%	19.3%	6.8%	3.5%
Mexico	0.4%	10.0%	5.3%	50.5%	14.8%	9.1%	8.0%
Czech Republic	0.3%	21.3%	4.5%	66.3%	10.8%	2.5%	3.4%
Slovakia	0.2%	26.6%	5.1%	45.5%	15.7%	12.6%	5.7%
Turkey	0.2%	26.0%	4.5%	39.5%	20.5%	13.8%	5.0%
Poland	0.2%	22.0%	9.4%	45.8%	22.2%	3.9%	1.0%
Hungary	0.1%	11.3%	5.1%	52.0%	16.7%	10.2%	6.5%
Croatia	0.1%	27.2%	5.7%	66.5%	9.1%	2.2%	4.8%
Argentina	0.1%	23.7%	3.6%	58.4%	14.2%	2.2%	4.4%
Nigeria	0.1%	8.5%	6.1%	37.4%	13.0%	8.7%	5.2%
Chile	0.0%	5.2%	2.0%	15.3%	29.6%	9.2%	3.1%
Share of world papers			5.0%	43.4%	9.4%	3.3%	2.3%

Source: Data compiled by Science-Metrix from data prepared by OST from SSCI & AHCI (Thomson-ISI)

3.3 Scientific collaboration of African countries

The African continent is clearly the least scientifically developed area of the world. Only 13 countries out of 55 have more than 100 scientific papers indexed in SCI per year, and thus only these countries are analysed in this report. Most of these African countries have really high rates of international collaboration, usually a good indication that a country's scientific system is not mature. An examination of the papers' titles, subjects and participating institutions indicates that in most developing countries, and more particularly in Africa, collaborations are instigated by a richer country either to help the local population or because the subject of the research is located in the "host" country (geological formation, endemic animal, etc.). Generally, the "preferred" foreign partner for an African country is a former colonial power, in most cases the UK or France. Of the 13 African countries analysed, Morocco, Algeria, Tunisia and Senegal are ex-French colonies, and have a preference for collaborating with France, and South Africa, Kenya, Nigeria, Tanzania, Ghana and Zimbabwe are ex-British colonies, which prefer to collaborate with the UK. Cameroon has a strong relationship with both France and the UK which is not surprising considering that the country was formed by the merging of French and British Cameroon. Egypt and Ethiopia have been relatively independent of imperial powers and thus have no marked pattern of collaboration with ex-colonizers.

Institutions and languages are two important vestiges of colonial history and are the main factors explaining scientific associations. For Canada, further analysis would be necessary to assess potential effects of colonial history on its relations with Africa, but initial observation shows similarities between the UK and Canada regarding their patterns of collaboration. Inversely, France and Canada have contradictory patterns: where France is preferred by some countries, Canada is ignored despite a common language. Although Canada and UK have many similarities regarding their scientific activities in Africa, the UK is more strongly present, even relative to its size, and even in some French speaking countries. However, as shown in Table III, compared to the UK, Canada is favoured by French speaking countries. However, none of these countries are very important collaborators for Canada, especially when compared to France. All other countries presented in this table have a stronger relationship with the UK, and for the majority the difference is very marked, especially for Gabon, Sudan and The Gambia.

In terms of relative importance of each field within international collaboration (Table III), there are clear differences. It should be noted that for both the UK and Canada, the pattern of collaboration with African countries differs from the general pattern of international (all countries) collaboration. Both the UK and Canada place more emphasis on biology and clinical medicine in their collaborations with African countries. Conversely, both countries place less emphasis in biomedical research, chemistry and physics. The UK puts more emphasis than Canada on biomedical research and clinical medicine whilst Canada emphasizes earth and space, engineering and technology, and mathematics. Canada's share of collaboration in mathematics is 10 times that of the UK, the latter being only moderately active in this field in Africa.

Table III Comparison of Canada and the UK regarding the share of their collaborations in NSE with selected African countries (1992-2003)

Country	No. of collaborations		% of collaboration of:		% Canada / % UK	
	Canada	UK	Canada	UK		
Morocco	168	141	0.16%	0.07%	2.2	Favoured by Canada
Tunisia	57	71	0.05%	0.04%	1.5	
P. Rep. Congo	18	31	0.02%	0.02%	1.1	
Benin	25	44	0.02%	0.02%	1.1	
Egypt	277	540	0.26%	0.27%	1.0	
Algeria	37	104	0.03%	0.05%	0.7	Favoured by the UK
South Africa	651	2313	0.61%	1.15%	0.5	
Kenya	283	1009	0.27%	0.50%	0.5	
Ethiopia	41	171	0.04%	0.09%	0.5	
Ghana	56	250	0.05%	0.12%	0.4	
Ivory Coast	14	75	0.01%	0.04%	0.4	
Nigeria	88	493	0.08%	0.25%	0.3	
Zimbabwe	51	294	0.05%	0.15%	0.3	
Tanzania	68	415	0.06%	0.21%	0.3	
Senegal	16	102	0.02%	0.05%	0.3	
Zambia	18	150	0.02%	0.07%	0.2	
Uganda	26	243	0.02%	0.12%	0.2	
Malawi	27	256	0.03%	0.13%	0.2	
Cameroon	15	178	0.01%	0.09%	0.2	
Gambia	14	369	0.01%	0.18%	0.1	
Sudan	5	132	0.00%	0.07%	0.1	
Gabon	1	69	0.00%	0.03%	0.0	

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

Table IV Field's share of international collaboration and of collaborations with Africa for Canada and the UK, (1992-2003)

	Canada		UK	
Field	**All countries**	**Africa**	**Africa**	**All countries**
Biology	8.6%	18.5%	18.8%	7.6%
Biomedical Research	18.4%	11.3%	15.4%	19.7%
Chemistry	7.6%	4.3%	4.3%	9.2%
Clinical Medicine	28.8%	33.4%	43.9%	27.3%
Earth & Space	10.8%	11.6%	7.9%	10.4%
Engineering & Technology	8.0%	11.2%	2.8%	6.0%
Mathematics	3.5%	3.4%	0.3%	2.1%
Physics	13.6%	5.0%	5.6%	16.8%
Unknown	0.7%	1.4%	1.0%	0.9%
Total	100%	100%	100%	100%

Source: Data compiled by Science-Metrix from data prepared by OST from SCI (Thomson-ISI)

4 Strengths, weaknesses and collaboration potential

Section 4 aims to further characterize the strengths and weaknesses of the developing countries and Canada, relative to the different fields and subfields of NSE, to identify avenues for potentially fruitful collaboration. The two indicators used for this characterization are the Specialization Index (SI) and the ARIF.

TheSI indicates a country's effort in a given field or subfield relative to other countries. For example, if a country has 10% of its papers in biology and biology papers in the world represent only 5% of all papers, then this country would be considered as specialized in biology, and, in this particular case, its SI would be 2, meaning twice as much effort in this country than in the world generally. Degree of specialization is usually a good indication of involvement in a field, which might be associated with a country's special programs, expertise and institutions, and is thus also a good indicator of potential in the field. To maximize the returns from collaboration, collaborative activities should be encouraged in fields where countries are most specialized and therefore where there is the greatest potential benefit.

The second indicator, ARIF, is based on citations in scientific papers. It is widely accepted that more a paper is cited, the greater is its impact on the scientific community and, by extension, on society. Highly cited papers are also believed to be the result of higher quality science, quality referring in this case to the importance of the work undertaken, and to the importance of the results of the work. Because of the way this metric is constructed, it could be misleading to use it to compare small entities like researchers or research laboratories, but it is a good measure of large aggregates such as countries where the law of large numbers applies. In this report, the ARIF is always calculated relative to the world, which means that a country with papers that on average are of same "quality" as the world average in a given field would have an ARIF of 1 for this field. Higher quality than the world average is denoted by an ARIF of above 1, whilst lower quality is denoted by a score below 1[5].

Section 4.1 positions the selected developing countries and Canada in eight fields of NSE based on their SI and their ARIF; Section 4.2 presents a more detailed analysis for 17 selected developing countries.

4.1 Scientific fields

This section presents a series of figures, one each for the eight NSE fields, and each plotting the position of the selected developing countries and Canada in that particular field based on SI and ARIF. Countries' positions are represented by circles of different sizes, the size being determined by the percentage of the country's papers in collaboration with Canada: large circles denote a large share of papers co-authored with Canada, whilst small circles mean less intense collaboration with Canada. These figures are useful to identify leaders and laggards in each field, and also position a country relatively to others in a given field.

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[5] For more details on this and the other indicators see the section on methods in the appendix.

4.1.1 Biology

Figure 10 shows the positions of developing countries regarding their specialization and impact in biology relative to the world[6]. A majority of developing countries have a clear specialization in biology. The Philippines is the most specialized with an SI of 6.8, denoting 7 times more papers than would be expected if this country had the same percentage of papers in biology as the rest of the world. Costa Rica, Ethiopia and Nigeria are also significantly specialized, with a proportion of papers in biology between 4 and 5 times higher than the world average. Canada, with an SI of 1.6, is not as specialized as many developing countries but, taking into account its large volume of publications, its effort in this field is quite important.

Some countries have very little concentration in this field. For example, Ukraine produces less than a quarter of the proportion of papers in biology observed at the world level. With the exception of Estonia, the Eastern Bloc countries have a low SI in this field,. China, with an SI of 0.58 (equal to about half of the proportion of biology papers at world level), also has a relatively scant scientific output in biology.

In terms of scientific impact in biology, it can be seen that all countries except Hungary and Canada, show an expected scientific impact which is below the world average. Russia, Belarus and the Ukraine have the lowest scores, with an expected impact less than half the world average in biology. Hungary, on the other hand, scores slightly above the world average and Chile, Uruguay, Philippines and Estonia, although below the world average, still have fairly high relative impact factors.

Canada is a particularly important collaborator for Iran, Tanzania, Costa Rica and Ghana, with respectively 8.2%, 5.2%, 5.1% and 5.0% of co-authored papers. For Saudi Arabia, Turkey, Jordan, Bulgaria and Bangladesh, Canada is not important as a collaborator: Canadian coauthored papers represent less than 1% of these countries' coauthored papers.

The salient features of scientific output in biology are:

- The Philippines is very specialized and its impact is among the highest for the developing countries, although still below the world average. Collaboration with Canada would improve its ranking in relation to the world average;
- Many other countries that are specialized in biology, have an impact lower than the world average and also have low rates of collaboration with Canada. These include Nigeria, Sri Lanka, Cameroon, Peru, Senegal, Colombia, South Africa, Pakistan, Argentina, Mexico, Bangladesh and Estonia. Collaboration with Canada in the field of biology should be encouraged;
- Hungary is the only developing country with an ARIF above the world average. Increasing collaboration between Hungary and Canada could help Hungary to further develop a field in which they already have good impact and produce high impact papers that would benefit both countries;
- Former Eastern Bloc countries generally are not specialized in biology and therefore have relatively low impact. Collaboration rates with Canada are generally low and it would probably be more beneficial to encourage collaboration in fields that are more promising for many of these countries, and especially for Ukraine, Belarus and Russia.

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[6] The field of biology includes: agriculture & food science, botany, dairy & animal science, ecology, entomology, zoology, marine biology & hydrobiology, general biology, and other aspects of biology apart from those relating to biomedical research and clinical medicine.

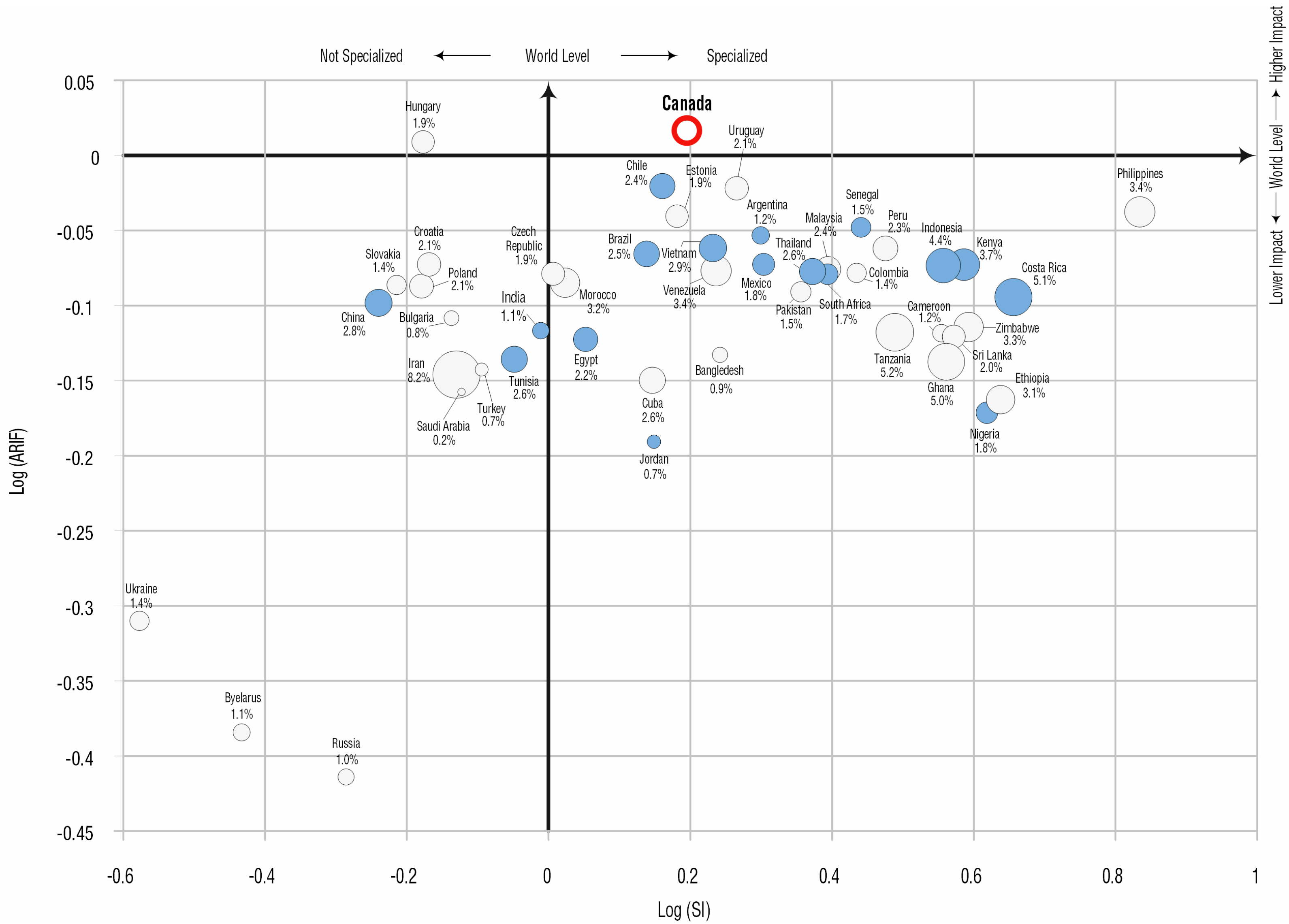


Figure 10 SI, ARIF and percentage of collaboration with Canada in biology (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.2 Biomedical research

Figure 11 shows the positions of developing countries regarding their specialization and impact in biomedical research relative to the world[7]. In general, developing countries are not specialized in biomedical research. Only Uruguay (SI=1.4), Senegal (SI=1.2), Cuba (SI=1.2), Slovakia (SI=1.1) and Belarus (SI=1.02) are specialized. Many developing countries (Romania, Iran, Ukraine, Egypt, Morocco, Turkey, China and Saudi Arabia) have a proporition of papers in biomedical research that is less than that observed at the world level, the most extreme case being Romania whose proportion of papers in this field is more than four times lower than the world level.

On average, developing countries publish their findings in less cited journals. The exceptions are Kenya, Peru and Bangladesh, with ARIF scores slightly above the world average. Indonesia and Tunisia have ARIF scores slightly lower than the world average, but are doing relatively well compared to other developing countries. Again ex-Eastern Bloc countries are the worst performers, with Belarus at the tail, their papers being published in journals which are cited almost 6 times less often than the average.

Countries where collaboration with Canada in biomedical research is very important comprise Peru, Costa Rica, Iran and Kenya, with 4.8%, 4.2%, 4.1% and 4.0% respectively of their papers being co-authored with Canadian researchers. Peru's top position in biomedical research is particularly remarkable as for all scientific fields combined it ranks only 33rd. Ukraine, Senegal, Estonia, Lithuania, Russia, India, Latvia, Bangladesh and Belarus have a weak relationship with Canada: all have less than 1% of co-authored papers with Canadian researchers.

The salient features of scientific output in biomedical research are:

- Kenya has a higher ARIF than Canada, Peru has an ARIF equal to Canada's, and neither country is specialized in biomedical research. Collaboration with Canada is important for both countries and should be encouraged to benefit from efforts in a field in which both countries are performing well;
- Uruguay, Senegal, Cuba and Slovakia are specialized in biomedical research but might increase impact by collaborating with Canada. None of these countries collaborates to a great extent with Canada;
- Many countries are not specialized in biomedical research and thus have a low impact, the most notable being Romania, Iran, Ukraine, Armenia and Russia. Collaboration with these countries should be directed towards other fields.

[7] The field of biomedical research includes: anatomy & morphology, biochemistry & molecular biology, biomedical engineering, biophysics, cellular biology, cytology & histology, embryology, general biomedical research, genetics & heredity, microbiology, microscopy, nutrition & dietetic, parasitology, physiology, virology, and of other miscellaneous biomedical research areas.

Figure 11 SI, ARIF and percentage of collaboration with Canada in biomedical research (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.3 Chemistry

Figure 12 shows the specialization and expected impact of developing countries in chemistry relative to the world scientific output[8]. Most developing countries are specialized in this field. For many of them the proportion of papers in chemistry is twice as high as that observed at the world level, especially in the case of Uzbekistan (SI=3.2), Kazakhstan (SI=2.8), Iran (SI=2.6) and Azerbaijan (SI=2.6). Canada (SI=0.69) is not specialized in this field. The countries with the lowest SI for chemistry are Colombia (0.65), Indonesia (0.60) and Nigeria (0.59).

All the developing countries considered have a lower expected impact than the world average. The lowest scorers are again former Eastern Bloc countries; the worst being Uzbekistan with an average expected impact 7 times lower than that of the world. Although none of the developing countries has an above average ARIF, some countries are doing fairly well, namely Estonia (0.98), Venezuela (0.94) and Argentina (0.90).

Canada is not an important collaborator for any of these countries. Countries with the highest proportion of their papers in chemistry co-authored with Canada are Pakistan (3.2%), Jordan (2.9%), Thailand (2.9%) and Nigeria (2.7%). Many countries have less than 10 papers coauthored with Canada over the 1992-2003 period and Kazakhstan, Lithuania, Azerbaijan, Armenia and Georgia had no collaboration with Canada in chemistry during this period.

The salient features of scientific output in chemistry are:

- Canada is generally not an important collaborator in chemistry for developing countries, but equally, Canada is not specialized in this field, and thus is has a lower share of world's papers in chemistry than its share in science generally;
- Estonia is not specialized in chemistry whilst Argentina and Venezuela have a minor specialization in this field, but these three countries have a relatively good expected impact and have the highest potential to deliver highly cited papers in collaboration with Canada; all three have very low rates of collaboration with Canada and these could be increased to reap greater benefits;
- Many developing countries are highly specialized in chemistry, but have low expected impacts. Only a few collaborate with Canada, and increased collaboration would greatly improve their impact. Good examples of where collaboration should be encouraged are: Uzbekistan, Kazakhstan, Azerbaijan, Moldova, Egypt, Latvia, Russia, Ukraine, Belarus and Bulgaria.

[8] The field of chemistry includes: analytical chemistry, applied chemistry, general chemistry, inorganic & nuclear chemistry, organic chemistry, physical chemistry and polymers.

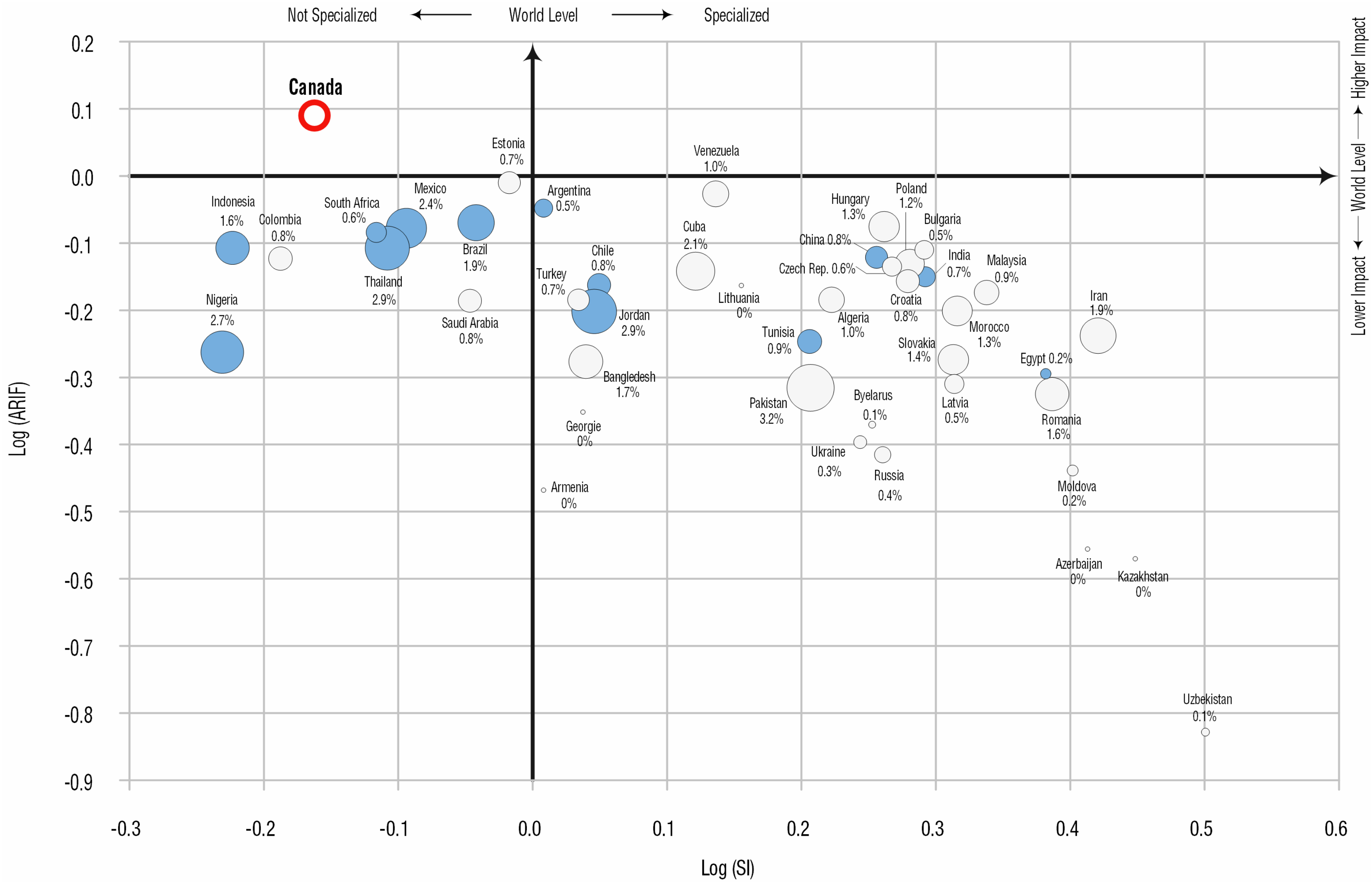


Figure 12 SI, ARIF and percentage of collaboration with Canada in chemistry (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.4 Clinical medicine

Figure 13 shows the specialization and expected impact of developing countries in clinical medicine relative to the world scientific output[9]. Only a few developing countries are specialized in clinical medicine, the least specialized being Ukraine, Belarus, Romania and Russia with a proportion of papers in clinical medicine 6 times smaller than the world proportion. The developing countries with a certain level of specialization in clinical medicine are located in Africa and the Middle East, the most specialized being Tanzania (SI=1.77), Kenya (SI=1.56), Lebanon (SI=1.54), Ghana (SI=1.43) and Ethiopia (SI=1.42). Canada, with a proportion of papers in clinical medicine comparable to that of the world, is not specialized in clinical medicine.

As in other fields of science, most developing countries have expected impacts lower than the world average (ARIF<1), the worst being Russia and the Ukraine with ARIF of 0.34 and 0.42 respectively. However, there are some exceptions, notably Peru and Vietnam, both with ARIF higher than Canada, and also Indonesia and Costa Rica with ARIF higher than the world average.

Kenya stands out as the developing country with the biggest share of papers co-authored with Canadian researchers (7.8%). Costa Rica's relationship with Canada in this field is also important (5.6%). Turkey and Latvia are at the tail with 0.4% of their papers in collaboration with Canada. Generally, developing countries do not collaborate often with Canada in clinical medicine.

The salient features of scientific output in clinical medicine are:

- Canada is generally not an important collaborator for developing countries in clinical medicine and this can be explained by the fact that it is not specialized in the field;
- Vietnam and Peru have a greater expected impact than Canada and, thus, collaborating with these countries could be beneficial for Canada;
- Vietnam, Indonesia and Costa Rica are not specialized in clinical medicine but have a high expected impact and more collaboration in this field would be beneficial for these countries;
- Many African countries specialize in clinical medicine, but generally publish their work in less cited journals. For many of them, collaboration rates with Canada are low and increasing them would increase their chances of being cited; the relationship with Kenya should be encouraged;
- Many countries are not specialized and have low impact in clinical medicine. However, as medicine is so important for developing countries, and as the field of clinical medicine covers so many specialties, an additional effort should be made to identify more precisely the specialties where collaboration might be worthwhile.

[9] The field of clinical medicine includes : addictive diseases, allergy, anaesthesiology, arthritis & rheumatology, cancer, cardiovascular system, dentistry, dermatology & venereal disease, endocrinology, environmental & occupational health, fertility, gastroenterology, general & internal medicine, geriatrics, haematology, immunology, nephrology, neurology & neurosurgery, obstetrics & gynaecology, ophthalmology, orthopaedics, otorhinolaryngology, pathology, paediatrics, pharmacology, pharmacy, psychiatry, radiology & nuclear medicine, respiratory system, surgery, tropical medicine, urology and veterinary medicine.

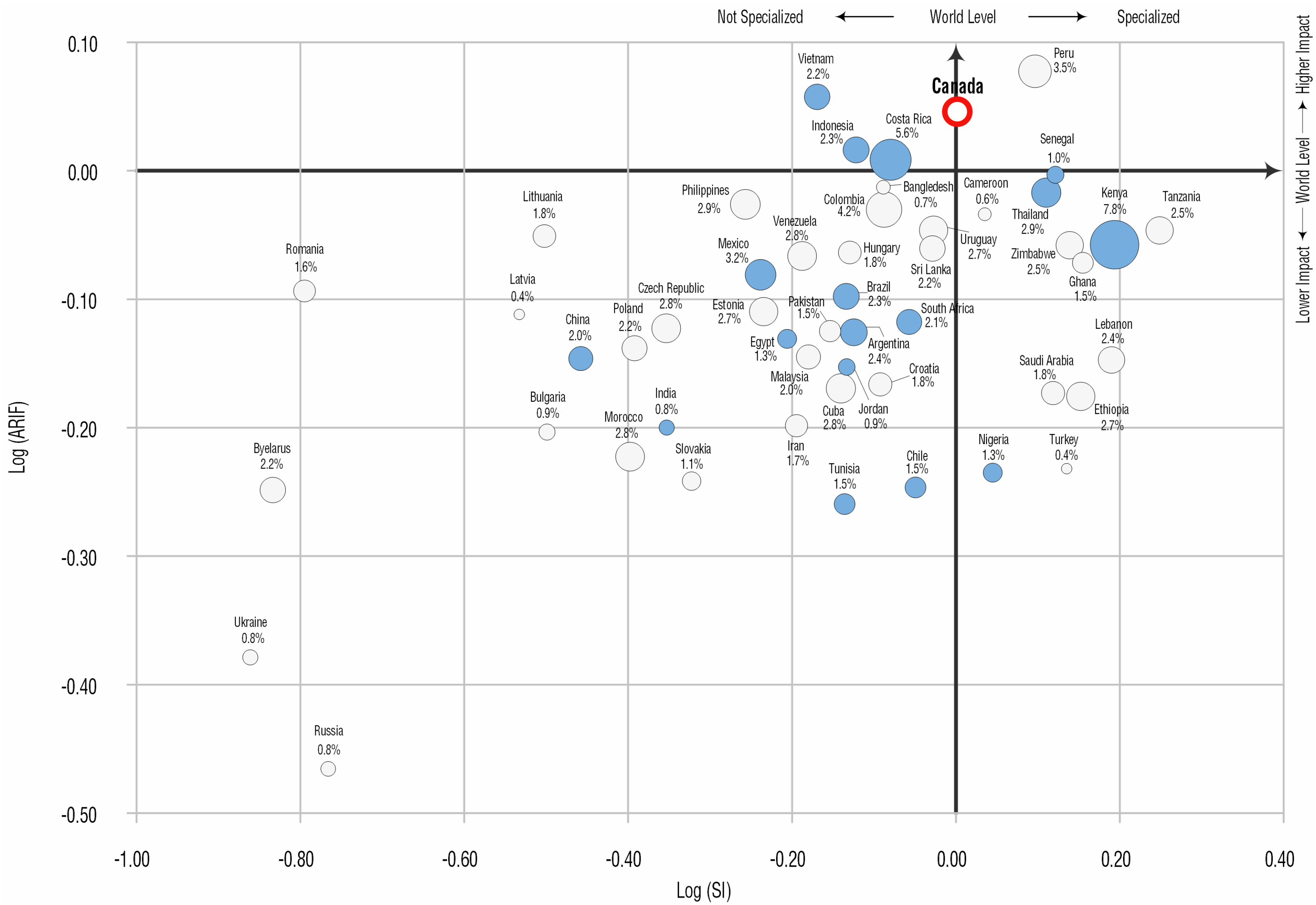


Figure 13 SI, ARIF and percentage of collaboration with Canada in clinical medicine (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.5 Earth & space

Figure 14 shows the specialization and expected impact of developing countries in earth & space relative to the world scientific output[10]. There are almost as many countries that are specialized as are not specialized, and most of them are not far from the world average. However some countries are more strongly specialized, e.g. South Africa (SI=2.11), Estonia (SI=2.20), Indonesia (SI=2.42) and Chile (SI=3.05), while some countries are not specialized at all, with Romania recording the lowest SI.

Only Chile has an ARIF above the world average; Mexico, Brazil, Poland and Hungary have ARIF less than 10% lower than the world average, which is good relative to other developing countries. The countries with the lowest ARIF in earth & space are Russia (0.57), Egypt (0.60), Ukraine (0.62) and Nigeria (0.63).

Chile is the developing country that has the most collaboration with Canada in the field, with 7.5% of its papers co-authored with Canada. Iran (6.1%), Slovakia (5.5%), Czech Republic (5.3%) and Mexico (5.0%) are other countries for which Canada is an important collaborator. This is rather surprising in that Slovakia and the Czech Republic rank 42nd and 28th in terms of the importance of relationships with Canada in science generally.

The salient features of scientific output in earth & space are:

- Chile is highly specialized and, after Canada, has the highest impact of all the countries considered in earth & space science; collaboration between Canada and Chile in this field is important and should be maintained as the potential for mutual benefit is good;
- The remaining Latin American countries are specialized in the field, but have lower scientific impact than the world average; collaboration with Canada would help these countries to increase their ARIF;
- Armenia is specialized in earth & space science, but has a very low impact and did not collaborate with Canada in the 12 years studied; even a few collaborative projects would be beneficial to Armenia.

[10] Earth & space covers the specialties of astronomy & astrophysics, earth & planetary science, environmental science, geology, meteorology & atmospheric science and oceanography & limnology.

Figure 14 SI, ARIF and percentage of collaboration with Canada in earth & space (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.6 Engineering & technology

Figure 15 shows the specialization and expected impact of developing countries in engineering & technology relative to the world scientific output[11]. About half of the countries considered are not specialized in the field, the ones with the smallest relative effort being Nigeria and Chile with SI values of 0.46 and 0.50 respectively. The remainder have varied levels of specialization, the most specialized being Jordan (2.07), Algeria (2.01) and Saudi Arabia (2.00), all with about twice as many papers in the field as would be expected based on their share of papers in science generally. China, with a SI value of 1.81 and a number of papers bigger than Canada's over the 1992-2003 period, is also a country concentrating on work in this field.

Canada's ARIF in engineering & technology is below the world average. Argentina, Venezuela, Czech Republic, which have ARIF higher than the world's mean, and Mexico and China all have higher ARIFs than Canada. Most of the other countries have ARIFs just below the world average: no country has a really low ARIF, with Russia being the worst performing with an ARIF only 17% lower than the world.

Canada is a very important collaborator for Iran, with 10.8% of papers from Iran being co-authored with Canadian researchers. Other important collaborators for Canada are Jordan (4.5%), Morocco (4.3%), Egypt (4.3%) and Chile (4.1%). Almost all of the former Eastern Bloc countries have a weak relationship with Canada –relations with Russia, Bulgaria, Belarus, Lithuania and Ukraine being the weakest, with less than 1% of their papers being in collaboration with Canada.

The salient features of scientific output in engineering & technology are:

- Canada is not specialized in engineering & technology and has an expected impact lower than the world average; detailed knowledge about the strengths of both Canada and the developing countries would help maximize the returns from collaborative initiatives;
- China is specialized in engineering & technology, has a relatively high impact, and published more than Canada in the field in the 1992-2003 period; collaboration with China in the field is sparse and greater collaboration would benefit both countries;
- Argentina, Venezuela and Czech Republic have good scientific impact and should increase their relative efforts in this field;
- Many former Eastern Bloc countries are specialized in the field but have relatively low impact and weak relationships with Canada; collaboration with Canada would be advantageous for them.

[11] The field of engineering & technology includes: aerospace technology, chemical engineering, civil engineering, computer science, electrical engineering & electronics, general engineering, industrial engineering, library & information science, materials science, mechanical engineering, metals & metallurgy, nuclear technology and operations research.

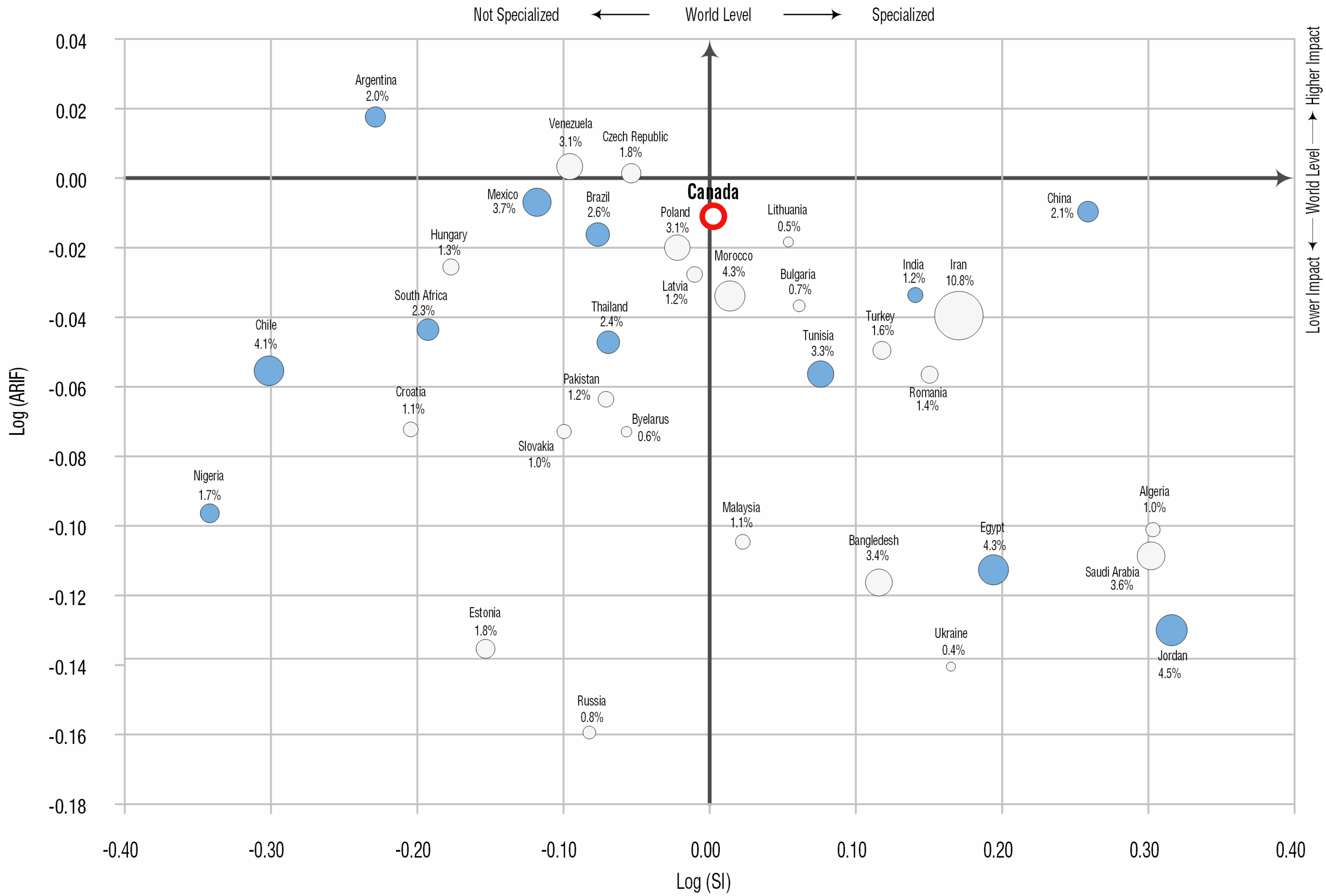


Figure 15 SI, ARIF and percentage of collaboration with Canada in engineering & technology (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.7 Mathematics

Figure 16 shows the specialization and expected impact of developing countries in mathematics relative to world scientific output[12]. Generally, the developing countries are specialized in mathematics. The most specialized is Vietnam, with a share of papers in mathematics more than 6 times higher than the average in the field. Other highly specialized countries are Tunisia, Romania and Morocco with SIs of 3.28, 3.10 and 2.70 respectively. Very few countries are not specialized in mathematics, the country with the lowest proportion of papers in mathematics being Turkey, with a SI of 0.57.

The expected impact for most countries, including Canada, is lower than the world average. Two exceptions are Brazil and Chile, with ARIF of 1.02 and 1. Argentina has an higher ARIF score than Canada's, but lower than the world average impact. The remaining countries (with the exception of Morocco (0.81), Iran (0.80), Ukraine (0.80) and Russia (0.70)) have ARIF scores between 0.86 and 0.94.

Canada is an important collaborator for South Africa (6.0%), Hungary (5.6%), India (5.1%) and Iran (5.0%). Few of the countries depicted in the figure have really low rates of collaboration with Canada, with the exception of Chile (0.6%), Vietnam (1.0%) and Tunisia (1.2%).

The salient features of scientific output in mathematics are:

- Brazil and Chile have a better expected scientific impact than Canada in mathematics and are more specialized in the field. It would clearly be beneficial for Canada to collaborate with them in mathematics; giving the actual share of their international collaboration with Canada (Brazil 3.0%, Chile 0.6%) there is still room for more and especially with Chile, which collaborates frequently with Canada in other fields.
- India and South Africa are not specialized in the field and have low impact, but Canada is an important collaborator for them; to maximize returns collaboration with these countries in other fields should probably be encouraged ;
- Vietnam and Tunisia have a strong specialization in the field, but relatively low impact and a low rate of collaboration with Canada; greater collaboration with these countries would improve the quality of their research.

[12] The field of mathematics includes applied mathematics, general mathematics and probability & statistics.

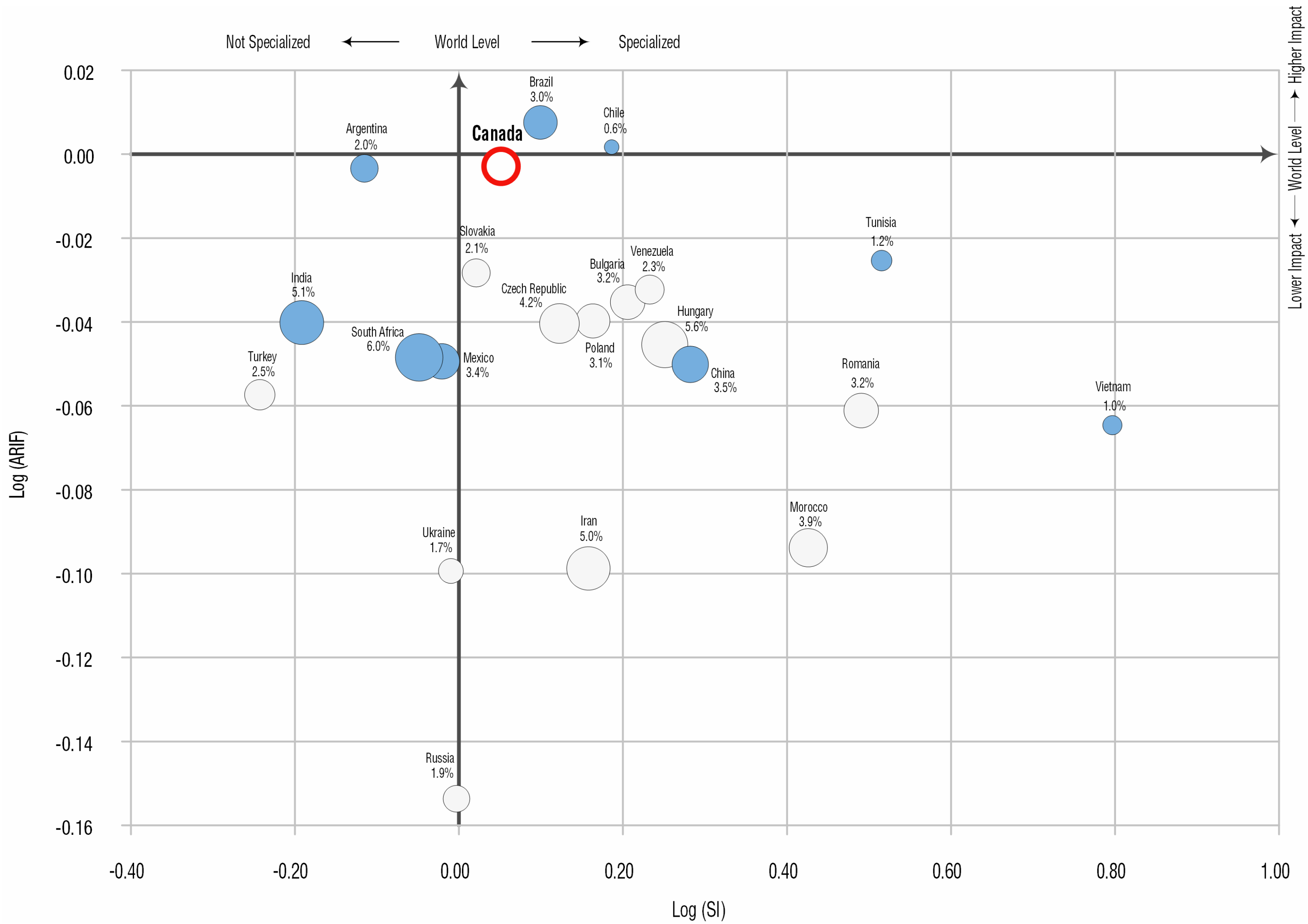


Figure 16 SI, ARIF and percentage of collaboration with Canada in mathematics (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.1.8 Physics

Figure 17 shows the specialization and expected impact of developing countries in physics relative to the world scientific output[13]. The majority of countries considered are specialized in physics with only a few, including Canada, with SI under the world average. Physics is the field where Canada's effort is lowest relative to other countries. The country with the lowest share of papers in physics is Thailand with a SI of 0.26 for a share about four times smaller than the world average. In contrast, Armenia, Georgia and Moldova are the most specialized in physics, all with more than three times more papers in the field than would be expected based on their general score in science.

Uruguay, Colombia, Argentina, Chile and Brazil, all Latin American countries, have ARIFs above the world average, while Moldova (0.61), Belarus (0.58), Ukraine (0.57), Kazakhstan (0.53), Uzbekistan (0.50) and Azerbaijan (0.44), all former USSR countries, have the lowest ARIFs in the field.

Kazakhstan has a good relationship with Canada in physics with 6.9% of its papers co-authored with Canada, a remarkable score given the relatively low share of Canada in physics papers. Other important relationships are Hungary (5.5%) and Iran (5.0%). Many countries have very low levels of collaboration with Canada in the field, particularly Malaysia and Uruguay (none over the 1992-2003 period), Georgia and Azerbaijan (1 paper), Colombia (2 papers). Many other countries have less than 1% of their papers in physics co-authored with Canada.

The salient features of scientific output in physics are:

- Uruguay, Colombia, Argentina, Chile, Brazil and Hungary all have significant scientific impact in physics and collaborating with them will lead to good quality research for both Canada and the partner country; Uruguay has the highest ARIF of all developing countries, but does not collaborate with Canada;
- Many countries, especially-USSR countries, are specialized in the field, have low impact and have low levels of collaboration with Canada., Examples include Azerbaijan, Uzbekistan, Belarus, Ukraine, Moldova, Russia, Algeria and Georgia; fostering collaboration with Canada would increase the impact of their research;
- Many countries have very low levels of collaboration with Canada, which can be explained in part by the relatively limited activity of Canada in physics.

[13] The field of physics includes acoustics, applied physics, chemical physics, fluids & plasmas, general physics, nuclear & particle physics, optics, solid state physics, and other miscellaneous physics research.

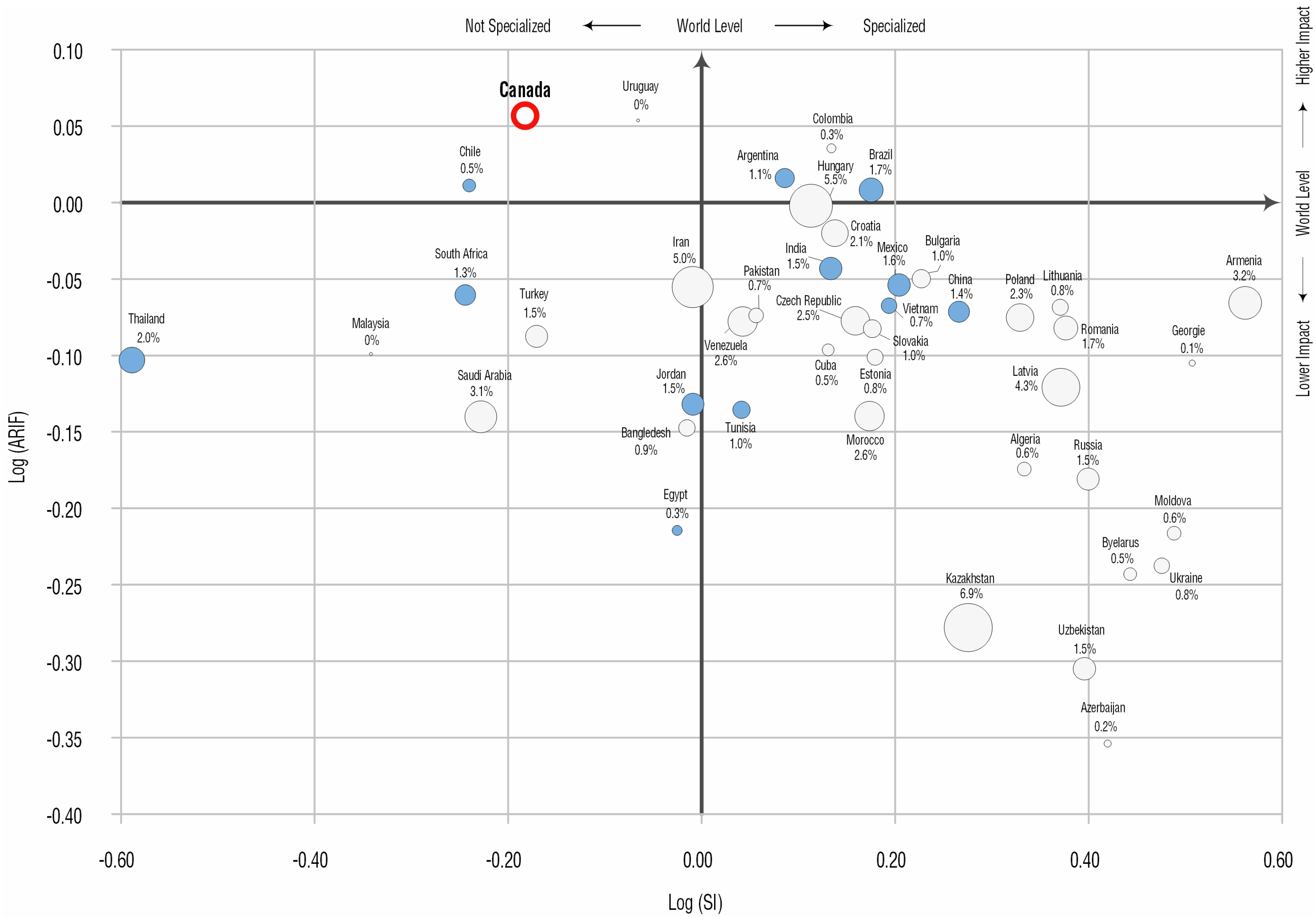


Figure 17 SI, ARIF and percentage of collaboration with Canada in physics (1992-2003)

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.2 Highlights on selected countries

This section presents close-ups of a selection of 17 developing countries (sections 4.2.1 to 4.2.17). For each country, general statistics are presented to give an idea of the importance of the country in science, its pattern of international collaboration and trends over time. Opportunities for collaboration with Canada are identified at the field and subfield levels.

4.2.1 Argentina

Argentina has a GDP per capita of US$11,200, which is just above the world average, and is the 8th richest among the developing countries. With 35,157 papers indexed in the SCI database over the 1992-2003 period, the country ranks 9th among developing countries in terms of number of publications in NSE. For number of papers per capita, Argentina ranks slightly lower in 14th place in the developing country group. Argentina's output has increased continuously over the period at an average annual rate of 8.2%, the 17th most impressive growth rate among the developing countries. However, Figure 18A shows there was a slight decrease in the number of papers for the last year shown: time will tell if this was a temporary aberration. Argentina also does well in terms of ARIF, with a score of 0.86 over the period, the 13th highest among the developing countries. However, once again, for the last year shown in Figure 18A the increase is less than for the previous five years, and it is impossible to say whether this is just an annual variation or a break in the previous growth pattern.

In SSH, Argentina scores slightly lower than in NSE at 13th for number of papers and 21st for growth. Argentina has a lower ARIF for SSH in 36th position among the selected developing countries.

Argentina has a growing share of papers co-authored with international collaborators (see Figure 18B), increasing from 31% in 1992 to 43% in 2003, a rate similar to that of Canada. Collaboration with high income countries has become less important, accounting for 81% of all collaborations in 1992, but only 74% in 2003. The share of international collaboration with Canada is just over 4% and has been stable over the period. The intensity of collaboration between Canada and Argentina is average, and is what would be expected based on Argentina's volume of publications. Collaboration is highest in clinical medicine (7.7%) and earth & space science (7.3%), and lowest in chemistry (1.4%).

Argentina's main strength is in physics with a SI of 1.22 and an ARIF of 1.04. It is one of the top four developing countries in the field. Its main speciality is solid state physics; nuclear & particle is the specialty where collaboration would likely be most beneficial. Collaboration with Canada in these two specialties is limited.

Other important fields for Argentina are biology and earth & space. The country is specialized in these fields, but the ARIF for both is below the world level. Collaboration rates with Canada in these fields are low and increasing them would boost Argentina's scientific impact. In biology, efforts should be directed towards marine biology & hydrobiology, and ecology: coincidentally, these two subfields are the weakest for Argentina and the strongest for Canada. In earth & space, Canadian excellence in astronomy & astrophysics, and in oceanography & limnology could benefit Argentina, as it is specialized in these two fields, but scientific impact is low.

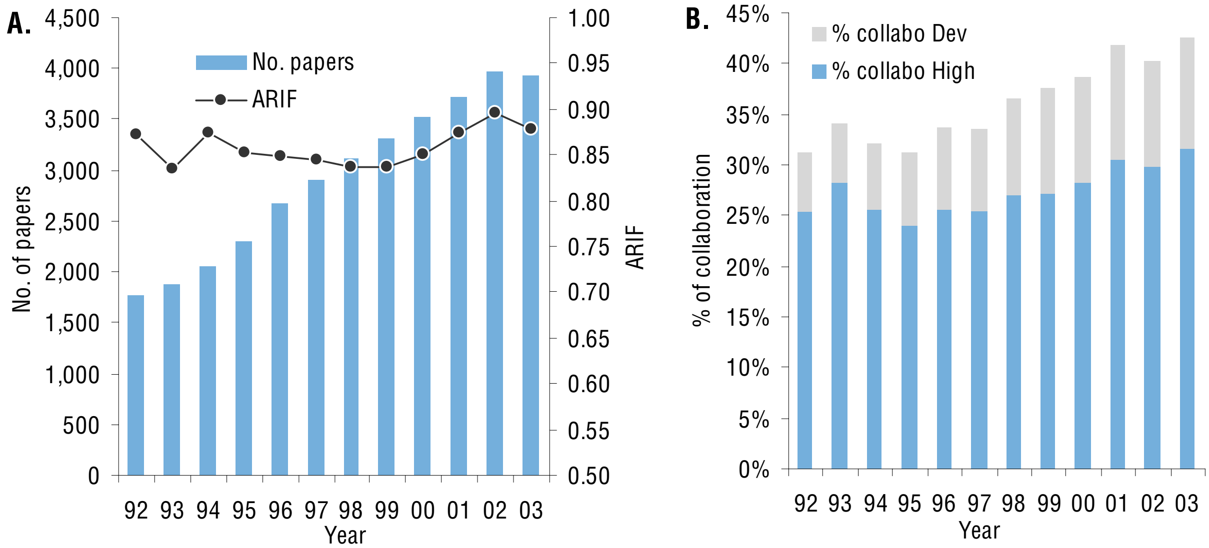


Figure 18 A. Evolution of scientific output and ARIF of Argentina, 1992-2003
B. Evolution of collaboration of Argentina, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Finally, collaboration should be encouraged in all specialties of chemistry, a field where Canada systematically has good ARIF scores while Argentina is below the world average. The benefits from collaboration in physical chemistry would be maximal for both countries. Argentina is very specialized and has an ARIF just under the world average in this area. There were only 11 papers co-authored by Argentina and Canada in these specialties in the 12 year period studied, one of the lowest rates of all the specialties.

4.2.2 Brazil

Brazil ranks 18th among selected developing countries with a GDP per capita of US$7,600. In NSE, Brazil publishes 75,466 papers and ranks 5th. This situation is somewhat mitigated when weighted by the country's population, reducing Brazil's ranking to 25th. Growth in scientific output was high in the period studied, at 11.2% per year. This puts Brazil in 12th position in terms of growth among all the countries considered, and 9th among developing countries. The number of papers published annually by Brazil continues to grow and recently passed the 10,000 mark. Brazil's ARIF score is 0.86, putting it in 15th position among developing countries.

For SSH, although Brazil ranks 5th for number of papers with 3,421, Brazil's ARIF score is only 0.63, putting the country in 42nd position among developing countries: however, this high number of papers in SSH may not continue since the growth rate between 1993 and 2002 averaged only 5.8%.

As Figure 19B shows, Brazil has a decreasing share of scientific papers co-authored with foreign collaborators which might be an indication of a growing autonomy in science as qualified researchers and research equipment are becoming more readily available locally. The share of Brazil's collaborators from high income countries in total international collaborators has slightly decreased from 84% to 77%. The share of collaborations with Canada has remained stable at nearly 6%, a score that indicates some preference for Canada. Brazil is Canada's third most frequent collaborator among developing countries. Brazil and Canada produce some 200 coauthored scientific papers per year in NSE. Collaboration is intense in every field except physics where the rate is 3.7%, a share slightly below what would be expected based on these countries' respective involvement in the field.

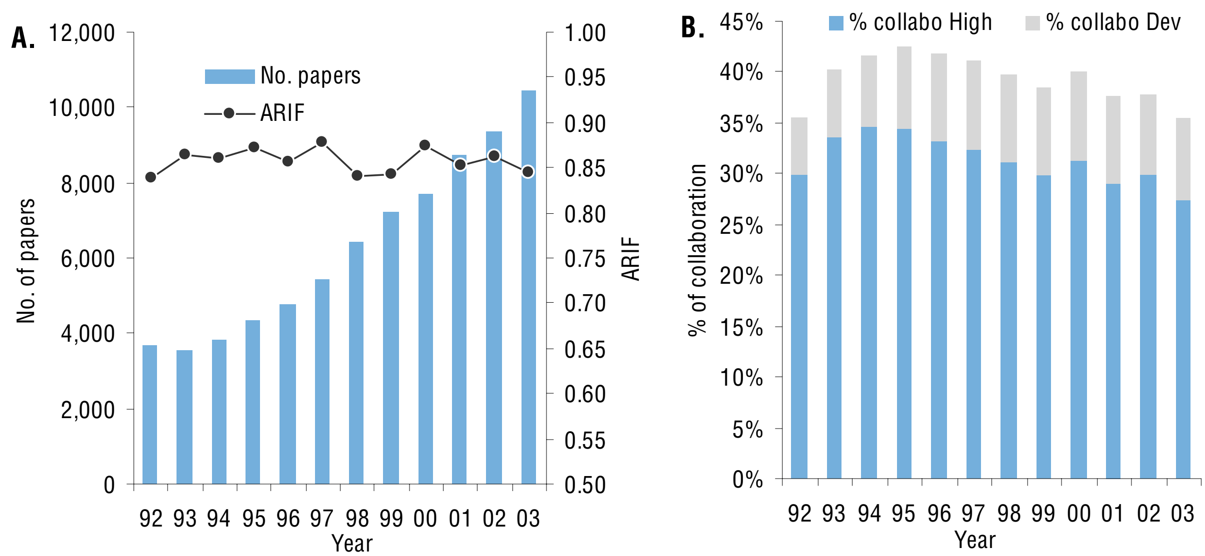


Figure 19 A. Evolution of scientific output and ARIF of Brazil, 1992-2003
B. Evolution of collaboration of Brazil, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Brazil's main strengths are in mathematics and physics; it is specialized and has an impact above the world average level in both fields. In mathematics, Brazil mainly excels in applied mathematics, one of the few subfields where collaboration between Canada and Brazil is not developed. Canada would probably benefit more than Brazil from increased collaboration as it is specialized in the field, but has a low expected impact. In physics, Brazil's performance in nuclear & particle physics and in solid state physics is outstanding - both subfields where Canada has good impact, but where it is not specialized.

Brazil is specialized in biology and in earth & space, but has ARIF scores lower than the world average in these fields. Canada is also highly specialized in these fields and has good expected scientific impact; therefore, encouraging collaboration in these fields would be beneficial for Brazil. In the field of biology, general zoology and entomology are weak areas for Brazil, but very strong for Canada. Collaboration in zoology is already significant and should be maintained, while in entomology collaboration levels are low and should be encouraged. In earth & space, astronomy & astrophysics is clearly the subfield to concentrate on, Brazil being very specialized, but with impact just below the world level whilst Canada has very high impact. Collaboration between the two countries in this specialty is not very high and should be promoted.

4.2.3 Chile

Chile has a per capita GDP of 9,900$ and ranks 13th among developing countries. Its 16,953 papers in the NSE rank it 11th among the developing countries in terms of number of papers per capita. The growth rate is 6.6% per year and the ARIF is 0.80, ranking it 25th among the developed countries (Figure 20A).

In the SSH, Chile has 845 papers for the period studied. This puts it in 15th place among developing countries. It has a high ARIF of 0.90 (9th rank). The average growth rate in number of SSH papers is 3.1%.

International collaboration for Chile increased from 38% in 1992 to 56% in 2003(Figure 20B), a rate of increase 40% higher than for Canada. The share of high income collaborators is stable at around 80%. The relationship with the US is responsible for almost half of Chile's international collaborations, and the numbers have tripled over the period. The number of collaborations with Canada has been decreasing generally, but collaboration in the field of earth & space continues to be fairly frequent.

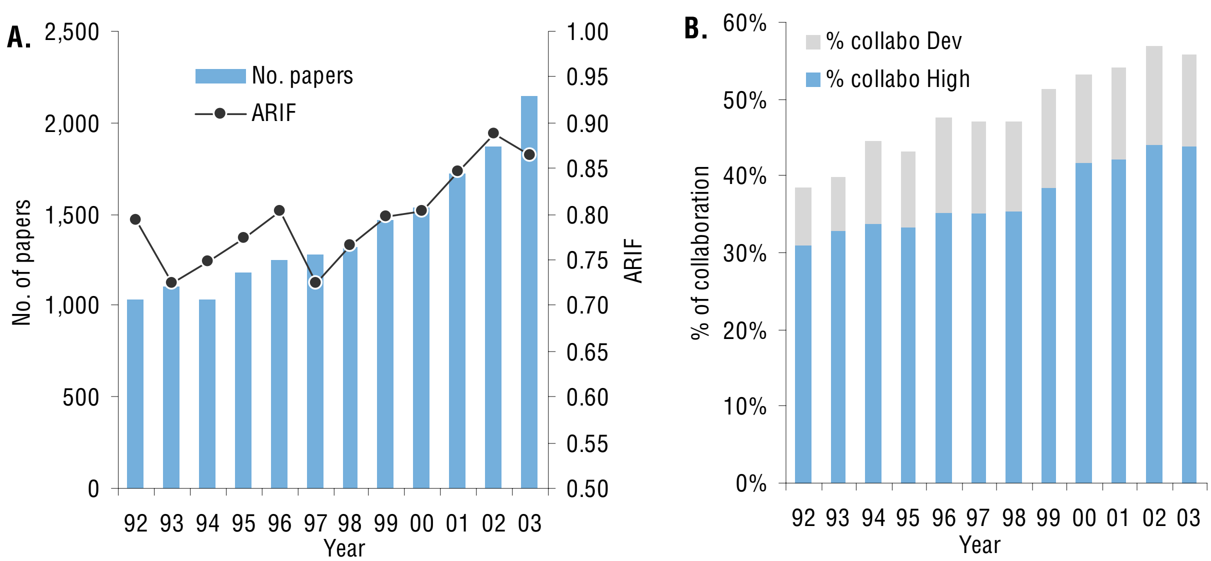


Figure 20 A. Evolution of scientific output and ARIF of Chile, 1992-2003
B. Evolution of collaboration of Chile, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Chile's main strength is in earth & space research, with a proportion of papers in this field more than 3 times higher than the world, and an ARIF score above the world level. This is mainly attributable to intense activity in astronomy & astrophysics. Chile has the clearest skies for observation of the entire southern hemisphere and thus has attracted many international space observatories: El Tololo, La Silla and the European Southern Observatory at Cerro Paranal are the most famous. Remarkably, a quarter of Chile's international collaboration is in this subfield, which for countries more generally accounts for only 1% of all the natural sciences papers. Canada has an excellent average impact factor in this subfield and maintaining its high collaboration rate with Chile (9.6%) would doubtless benefit both countries. Oceanography & limnology, and environmental science are two other subfields where Chile has made great efforts and for which scientific impact for Canada is high and thus are areas where collaboration should be encouraged to aid Chile.

Chile is performing reasonably well in mathematics with a good specialization level and an expected impact above the world average and above the level of Canada. The subfield of probability & statistics is the only one where Canada outshines Chile and thus where collaboration would most benefit Chile. However, any collaboration in mathematics would benefit both Chile and Canada, especially given their rather weak collaborative relationships.

Chile would also benefit from collaboration with Canada in biology and chemistry, two fields in which it specializes, but where it has a relatively low impact. In biology, marine biology & hydrobiology would be the areas to target, whilst in chemistry, inorganic & nuclear chemistry would be the specialty that produces the most benefit for Chile.

General & internal medicine is the second best subfield for Canada in terms of ARIF, and the worst for Chile. Only 9 coauthored papers in this subfield are indexed in the SCI database for the 12 year period studied.

4.2.4 China

China has a per capita GDP of US$5,000, ranking it 31st among developing countries. In terms of papers indexed in SCI, China is second only to Russia among the selected low income countries, with 187,083 papers; based on papers per capita China is in 39th position. The growth rate for NSE output is high, at 15.8% per year for China which puts it in 4th place for growth among developing countries, a very strong position considering the already large pool of the country's papers (Figure 21A). If the high income countries are included in the comparison, China still ranks 5th for growth. This is illustrated well in Figure 21A, which shows that output rose from about 7,000 papers in 1992 to about 32,500 papers in 2003. The country's ARIF score is 0.81, ranking it 21st among developing countries. China's ARIF has recently begun to increase slightly year-on-year, after decreasing between 1992 and 1998.

China scores even better in SSH: in terms of number of papers, China ranks second with 4,915. The difference from NSE is that China holds first position overall in terms of growth with a 24.2% annual growth rate. Its ARIF is also in the top tier, at 0.99, positioning it 3rd among developing countries. Therefore, based on quantity and quality of papers, China is the best performing of the developing countries in SSH.

China has a relatively low rate of international collaboration and this rate is decreasing. More than 90% of China's collaborations are with high income countries (Figure 21B). Collaboration with Canada decreased in the 1990s, but is now starting to increase. 6.3% of China's international collaborations are with Canada, a score almost 50% higher than would be expected based on their level of scientific output. Collaboration is highest in mathematics where Canadian researchers account for more than 10% of China's foreign collaborators.

China is specialized in chemistry, engineering & technology, mathematics, and physics. Its impact is generally low across all disciplines except engineering & technology where it is just below the world level. Therefore, this area could be considered its main strength. However, a careful look at the subfields reveals the areas where China has strengths and areas where support is needed.

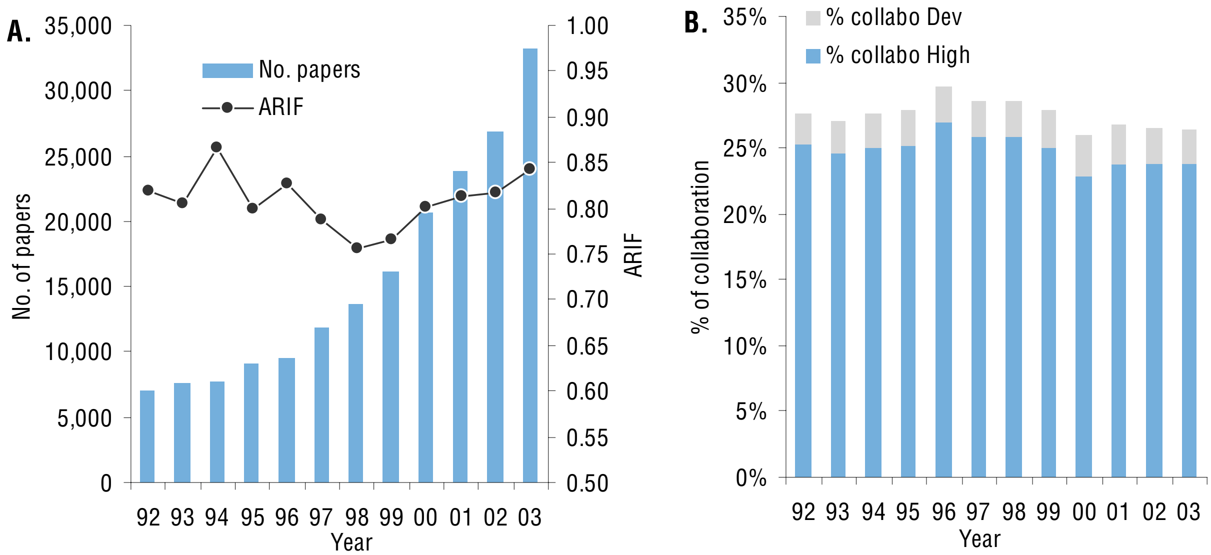


Figure 21 A. Evolution of scientific output and ARIF of China, 1992-2003
B. Evolution of collaboration of China, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

In engineering & technology, China's main strengths are in metals & metallurgy and in civil engineering, two subfields where both China and Canada are specialized. but where China really has higher expected scientific impact. For civil engineering, the subfield in which Canada is the most specialized in NSE, but where it has a very low ARIF, China has its best ARIF. In computer science, a subfield where both China and Canada specialize, but where Canada publishes in better journals, increased coauthorship could help China immensely. Collaboration rates are already quite high in all these subfields and should be maintained.

In chemistry, Canada systematically has ARIF that is far above the world average, whilst China is always well below it. Collaboration with Canada in polymer chemistry, inorganic & nuclear chemistry (where only 10 collaborations are recorded for the 12-year period), physical chemistry and analytical chemistry, where collaboration is currently low, would be most helpful for China. In mathematics, there are no particular complementarities. Collaboration in all mathematics subfields is already well developed, but generally yields papers that are published in journals with lower than average expected impact.

In physics, the situation is similar: one country's needs do not match the other's strengths. The only exception is in general physics, a subfield where Canada has a very high ARIF whilst China's is low. Collaboration between the two countries in physics is average and priority should probably be given to other areas to maximize the returns from collaboration for both countries.

Finally, China is not specialized in any of the 59 life sciences specialities (that is subfields within biology, biomedical research, clinical medicine and environmental sciences). Collaboration in subfields where China has good impact should be encouraged to enable China to develop some niches in the life sciences where it can specialize and excel. Microscopy, pharmacy and otorhinolaryngology would seem to offer the greatest promise.

4.2.5 Costa Rica

Costa Rica ranks 14th among developing countries in GDP per capita (US$9,100). Costa Rica ranks 53rd in scientific output in NSE with 1,649 papers, one of the smallest figures in the countries considered. However, it ranks 24th for papers per capita. This pool of papers is growing at an average rate of 5.6% per year (26th rank). Costa Rica's rather small output in NSE is compensated for by its quality. Indeed, the country ranks second in terms of developing countries' ARIF score (0.93).This score has varied quite dramatically over the years, limiting the predictive value of these data (Figure 22A).

In the SSH, Costa Rica again shows a very small number of publications at 121 from 1992 to 2003. Annual output is growing only very slightly at a rate of 0.7%. Looking at the ARIF, Costa Rica holds 11th position among developing countries with a score of 0.89. Because of the small number of publications which increases the risks of obtaining haphazard scores, caution is necessary when interpreting Costa Rica's SSH statistics.

International collaboration in science is very important for Costa Rica and is increasing, from 72% in 1992, to 87% in 2003 (Figure 22B), the highest percentage rise of all the countries considered. Almost 80% of these collaborations are with high income countries, a share that remains fairly constant over the period. The US is responsible for nearly half of all Costa Rica's coauthored papers. Collaboration with Canada is also important relative to its importance in science generally: 6.2% of international collaborations are with Canadian researchers. However, as Costa Rica's scientific output is very small (1,649 papers in SCI over the period ranking 54th out of the 57 developing countries selected), this represents roughly 7 papers per year co-authored with Canada in all fields. This number is very small and it is difficult to predict trends with any degree of confidence, as just one additional collaboration would increase the yearly score by 15%.

Costa Rica specializes in biology and in most biology subfields, but has systematically low ARIF scores. The subfield where collaboration with Canada would be of the greatest value is ecology, a subfield where Costa Rica specializes and where Canada has a very high impact.

Collaboration should be encouraged in two other areas of research: inorganic & nuclear chemistry, and genetics & heredity. In the first area both countries have strengths, and collaboration in this subfield could yield high impact research. The second is a subfield where both countries are specialized, but where Canada's impact is superior.

In conclusion, as Costa Rica's volume of publications is relatively small, any effort to increase research collaboration with this country could lead to significant improvement in its scientific system.

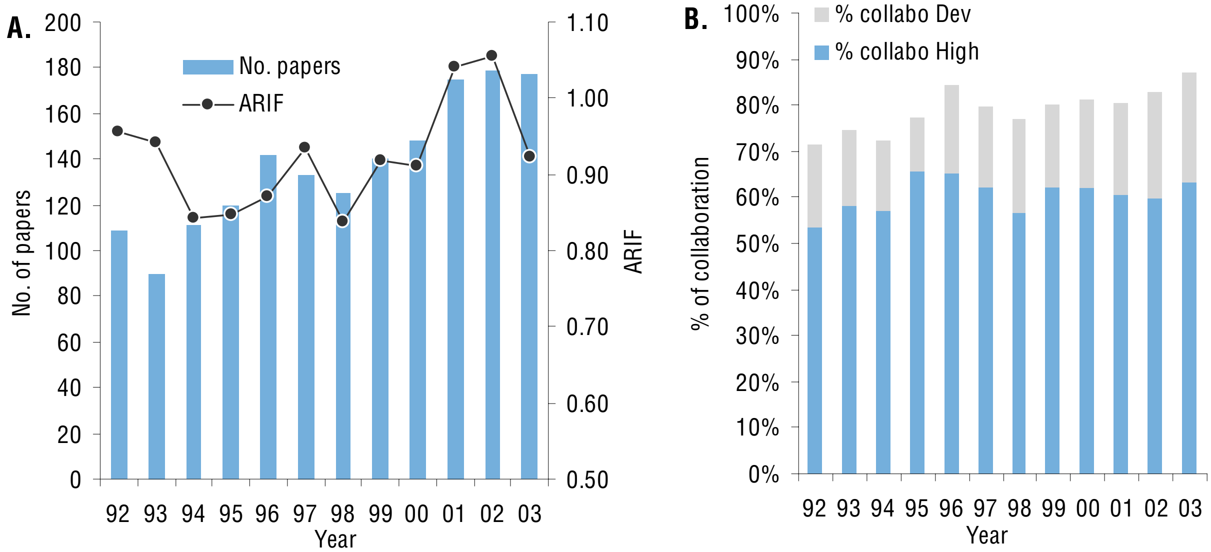


Figure 22 A. Evolution of scientific output and ARIF of Costa Rica, 1992-2003
B. Evolution of collaboration of Costa Rica, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.2.6 Egypt

Egypt is one of the poorest countries in the sample, with a GDP of US$4,000 per capita. With 19,999 papers published in the SCI from 1992 to 2003, it holds a respectable 13th rank among the developing countries. This ranking falls significantly, however, to 31st position in terms of papers per capita. With a growth rate of 2.6% (36th rank), this position is not likely to improve. In addition to Egypt's poor performance in terms of quantity of papers, it scores even worse for quality with an ARIF of 0.64, which positions it 49th among developing countries. From Figure 23A, it does not seem likely that this will improve in the near future.

In SSH, Egypt does slightly better. Number of publications is still low, with an average of 357 papers (21st rank), and output is actually decreasing with a growth rate of -0.2%, but the ARIF score is 0.93, which puts Egypt in 8th position among the developing countries.

The level of Egypt's international collaboration activity is beginning to increase and is just slightly behind that of Canada. The share of collaborators from high income countries is stable at approximately 80% of total collaborations (see Figure 23B). The share with Canada is average and is decreasing, except in the field of engineering & technology where collaboration levels are high (15.7% of all Egypt's international collaborations in the field) and has been constant over time. Collaboration in chemistry and physics is very low.

Egypt is highly specialized in chemistry, but has relatively low scientific impact in this field. Interestingly, Egypt is specialized, but has low expected impact in every specialty of chemistry whilst Canada is not specialized, but has very good impact in all areas. Collaboration should be encouraged in all the chemistry specialities, especially given the almost complete absence of collaboration in chemistry.

Egypt is specialized in engineering & technology, but with the exception of civil engineering, it has a globally low impact in the field. Canada is highly specialized in civil engineering, but has low impact. Therefore, Canada would definitely gain from collaboration in this field, while for Egypt, collaboration in computer science and chemical engineering would be beneficial. Egypt also specializes in some areas of biology, but these are areas where Canada does not excel. The only exception is entomology, where Canada has a better ARIF than Egypt.

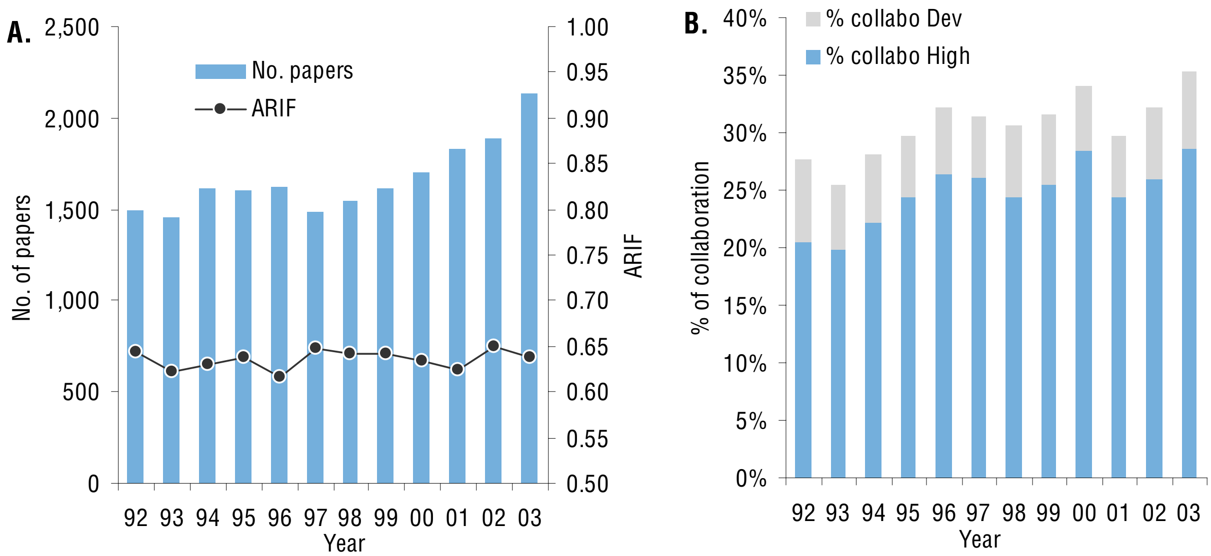


Figure 23 A. Evolution of scientific output and ARIF of Egypt, 1992-2003
B. Evolution of collaboration of Egypt, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.2.7 India

India has a per capita GDP of US$2,900, making it one of the lower tier countries in terms of wealth. With 134,627 papers in the SCI, India is the third developing country with the greatest scientific output, outdoing high income countries such as Switzerland and South Korea. The country holds only 42nd position in terms of papers per capita however, as a result of its very large population. The growth rate of its scientific output is rather small at 2.7% (35th position). The ARIF score of the country is 0.76, putting it in an average 36th position. Figure 24A shows that this factor has been constant over the period studied, reducing the likelihood of future increases.

India performs less well in the SSH. It holds 4th position with 4,275 papers, but the growth rate of this pool of papers was -4.4% for the period studied. The country's ARIF is also very low at 0.55 (45th rank).

India has a very small percentage of scientific publications co-authored with researchers from other countries, about half the percentage of Canada. But the level increased significantly over the 12-year period, from 13% in 1992 to 22% in 2003. The share of high income countries in these collaborations is high (≈82%) and fairly constant over time. Canada is a rather important collaborator for India, mainly in mathematics, for which Canada figures in 15% of its international collaborations.

India is highly specialized in chemistry. Its main strength is in applied chemistry where its ARIF is above the world average. Canada has an impressive impact in this subfield, but is not specialized. Enhanced collaboration in this area would be beneficial for both countries. India is specialized, but has low ARIF in all other specialties of chemistry whilst Canada is not specialized in any area of chemistry, but has high impact. These subfields present a good potential for mutually beneficial collaboration, which therefore should be encouraged.

India is specialized in many subfields of engineering & technology, and in physics. In engineering & technology, the benefits of collaboration would be maximal for both countries in chemical engineering, and would be optimal for Canada in civil engineering and for India in computer sciences. In physics, enhanced collaboration in solid state physics and in acoustics would be beneficial for India.

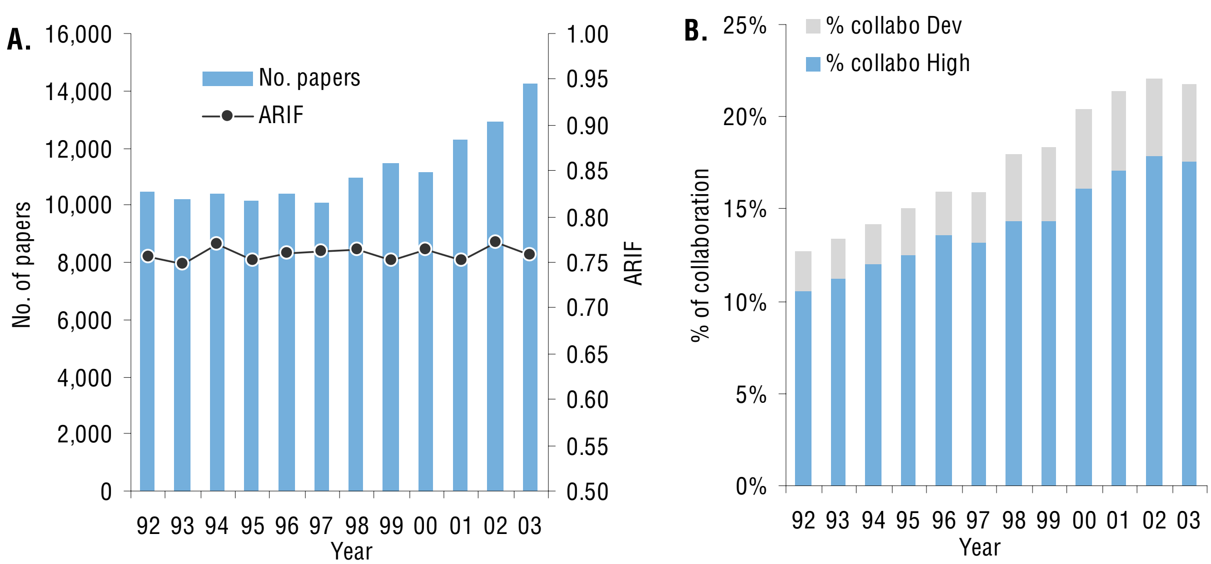


Figure 24 A. Evolution of scientific output and ARIF of India, 1992-2003
B. Evolution of collaboration of India, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

4.2.8 Indonesia

Indonesia is 41st among developing countries in terms of GDP per capita (US$3,200). The country published 3,226 NSE papers indexed in SCI giving it a rather low 36th position in absolute terms, and for number of papers per capita it ranks last among the selected countries. This situation might change however, as the country has seen a respectable growth of 8% (18th rank) in the period studied. Indonesia's low output is compensated for by an ARIF of 0.91 (Figure 25A), ranking it 3rd among the developing countries. The ARIF seems to be increasing since 1999, after a drop in the first half of the period, which bodes well for the country.

Indonesia has an all round more equilibrated score for SSH. It is in 26th position among developing countries for number of papers with 333. It has an average growth rate of 4.7% (18th position) and an ARIF of 0.86 (17th position).

Levels of collaboration for Indonesia are very high. Almost 90% of its scientific papers were co-authored with researchers from other countries, and this share is still increasing (Figure 25B). However, collaboration with Canada is minimal and is not increasing.

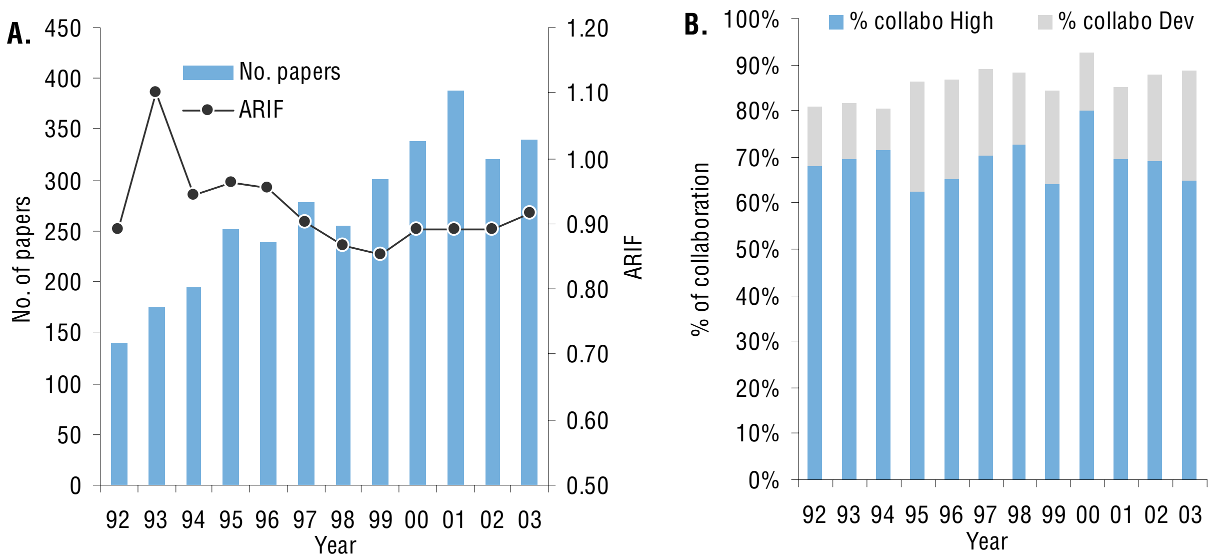


Figure 25 A. Evolution of scientific output and ARIF of Indonesia, 1992-2003
B. Evolution of collaboration of Indonesia, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Indonesia specializes in biology and in earth & space science and has ARIF scores in these fields near to the world average. In biology, specialization and impact are almost the same for each subfield and, thus, collaboration with Canada should focus on subfields where Canada has the best expected impacts: marine biology & hydrobiology, general zoology and ecology. In earth & space, astronomy & astrophysics, and meteorology & atmospheric sciences are the two subfields where Indonesia has the most to gain from collaborating with Canada. Conversely, in earth & planetary science, Canada would benefit from collaboration because Canada is highly specialized, but has a lower ARIF than Indonesia.

Indonesia excels in some specialties of clinical medicine, the most important being veterinary medicine, pharmacy and tropical medicine, subfields where the country has high impact and is specialized. In relation to Canada's strengths in the field, collaboration in veterinary medicine would be most beneficial for both countries.

4.2.9 Jordan

Jordan's GDP per capita is slightly below the average for the developing countries at US$4,300 (35th rank). With a modest 2,893 papers in the SCI, the country comes in at 20th position in terms of papers per capita. Jordan has a good growth rate and ranks 15th among developing countries and 20th overall, with a rate of 8.6%. It scores poorly on quality however, with an ARIF of 0.69 (44th rank). Figure 26A shows that with the increase in the number of papers published each year by Jordan, the

ARIF seems to be stabilizing (see the wide variations in the first five years shown in Figure 26A) and progressively increasing.

The number of SSH papers published by Jordan was 229 between 1992 and 2003, putting the country in 35th position. The growth rate in output for the SSH was -1.6%, indicating the situation is not likely to improve in this area of research. Finally, Jordan holds 25th rank in the developing countries with an ARIF of 0.78.

Jordan has an international collaboration level similar to that of Canada. Collaboration with high income countries is stable over time at 80% of all international collaborations (Figure 26B). Collaboration with Canada is also stable over time and represents 6.2% of Jordan's foreign collaborations. Collaboration in earth & space (14%) and in engineering & technology (12%) is the most important, but this is calculated on very small numbers (14 collaborations in 12 years in earth & space and 24 in engineering & technology).

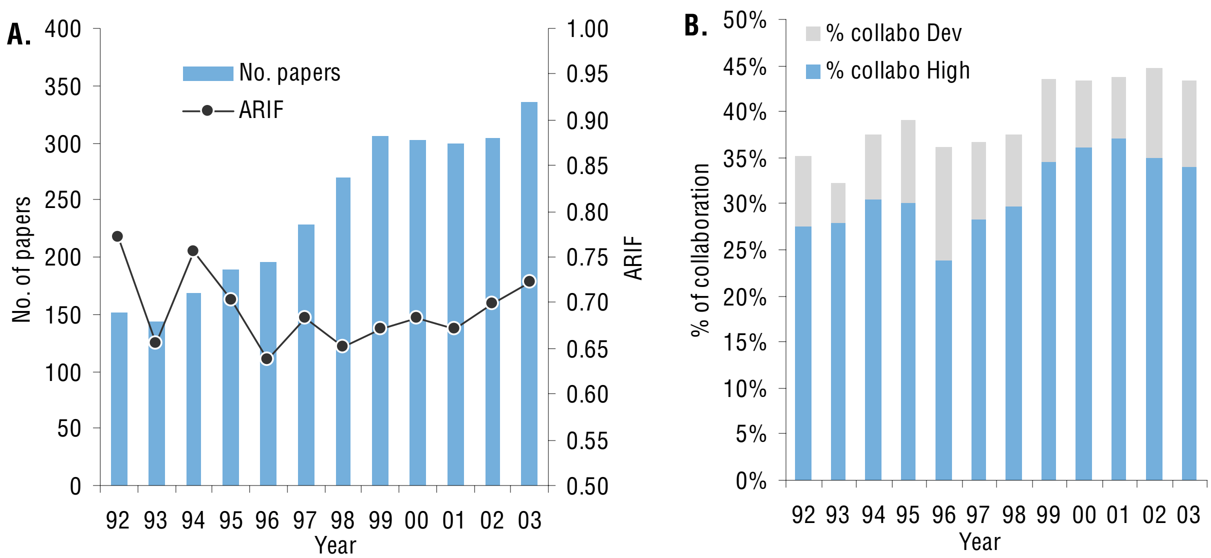


Figure 26 A. Evolution of scientific output and ARIF of Jordan, 1992-2003
B. Evolution of collaboration of Jordan, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Jordan is highly specialized in engineering & technology, the most specialized of all countries considered, but has a very low ARIF in the field, the 4th lowest of all countries considered. Collaborating with countries that excel in engineering & technology is undoubtedly the best way for Jordan to build better capacity in this field. Subfields where collaboration with Canada would be most helpful are chemical engineering and computer science.

Chemistry and biology are two more fields where collaboration would help increase the scientific impact of Jordan. In chemistry, Canadian strengths complement Jordan's relative weaknesses, particularly in inorganic & nuclear chemistry and in applied chemistry, but also in polymer science and organic chemistry. In biology, Canada can mainly help in ecology.

4.2.10 Kenya

Kenya is the fourth poorest country in the sample, with a per capita GDP of US$1,000. It published 4,949 papers in the SCI from 1992 to 2003, putting it in 27th position among the developing countries. When weighted by population, Kenya position goes down to 35th. The country shows very low although positive growth for the period at 0.4%, making it one of the lower ranking countries in that respect (45th position). Kenya scores quite well for the quality of its research, with an ARIF of 0.89 (Figure 27A) putting it in 8th position among the developing countries. This figure has been rather inconsistent over the years however, so it is difficult to make predictions.

Kenya performs well in SSH. With 415 papers, it holds 18th position among the developing countries. The number of SSH papers produced annually is increasing at a rate of 4.8% for the period (17th rank). Kenya has a high ARIF score of 0.94, putting it in 7th rank in this respect.

Kenya's international collaboration has been increasing rapidly and is now quite substantial, with 84% of its papers co-authored with foreign researchers (Figure 27B). The UK is by far its most frequent collaborator (considering these countries' importance in science generally). One Kenyan scientific paper in four is co-authored with a British researcher. Canada also has numerous collaborations with Kenya. Kenya is the 14th most important developing country in terms of collaboration with Canada whilst it is 27th in terms of volume of publications generally. Collaboration is particularly important in clinical medicine, with a net majority of papers on AIDS.

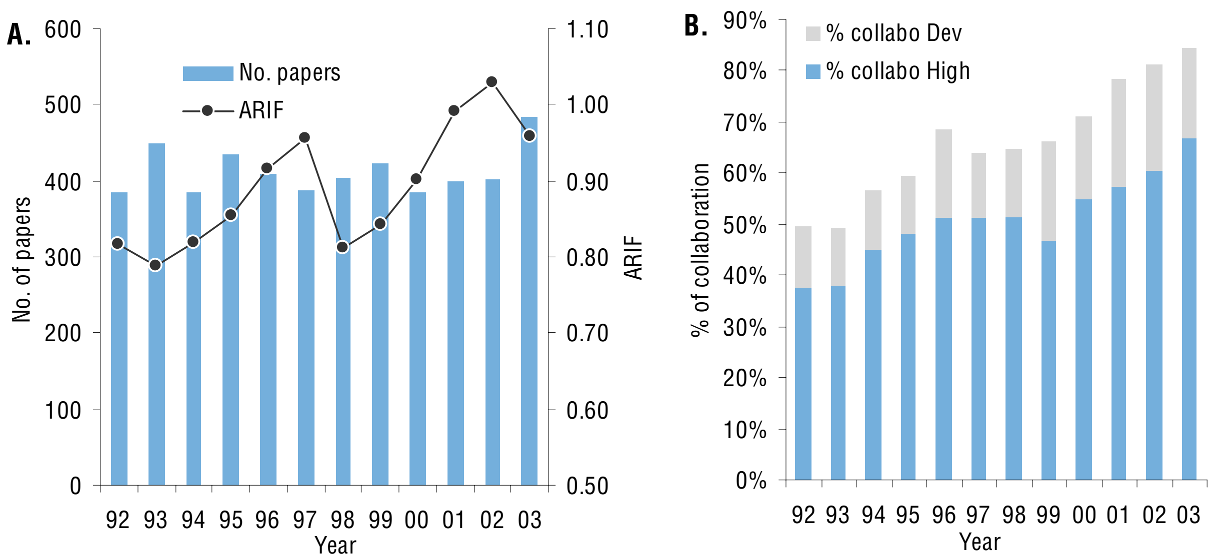


Figure 27 A. Evolution of scientific output and ARIF of Kenya, 1992-2003
B. Evolution of collaboration of Kenya, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

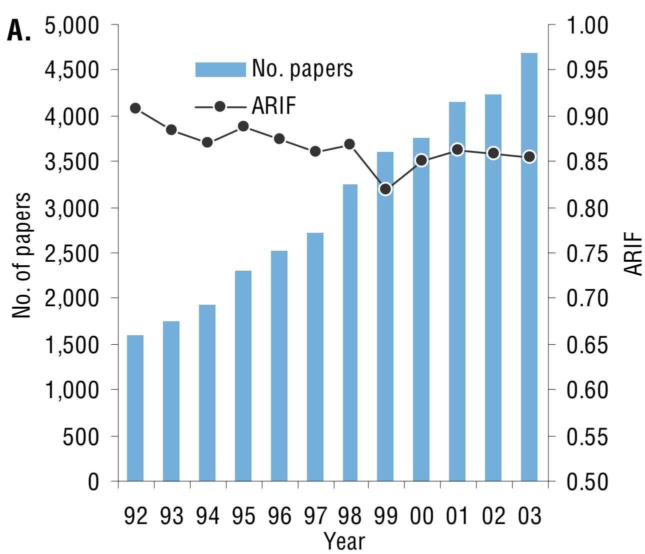
Kenya is specialized in biology and in clinical medicine, but has ARIF scores below the world level in these two fields. In biology, Kenya's main strength is zoology, for which it has an ARIF above the world and Canadian levels. This encompasses work on baboons, the tilapia fish and malaria carrying insects. Kenya is also specialized in marine biology & hydrobiology, and in ecology, but would benefit from collaboration with Canada in terms of higher impact in these subfields. In clinical medicine, there are no clear complementarities, but collaboration would benefit Kenya in general & internal medicine and in immunology, two subfields where both Kenya and Canada already collaborate actively, mainly on AIDS.

4.2.11 Mexico

Mexico has a balanced performance in the NSE. Its weakness is in terms of papers per capita, where it ranks 28th. It ranks 8th in absolute numbers of papers for the developing countries, with 36,501 papers, has a growth rate of 10.6% (11th position for developing countries and 14th overall) and an ARIF of 0.86 (12th position for developing countries). The effect of these good results is somewhat damped by a clear downward trend in the country's ARIF over the period studied, as shown in Figure 28A.

For SSH research, Mexico does not rank as high as in the NSE. It still publishes a good number of papers at 3,143 (6th in the developing countries) and shows a good growth rate (11th in the developing countries). Mexico's ARIF, however, is only 0.55, ranking it 46th among developing countries.

Mexico's share of papers with foreign collaborators increased until 2000, but since then has been decreasing. The proportion of these collaborations with high income countries is also diminishing. Spain is Mexico's most frequent collaborator and this relationship has strengthened over time. Canada also collaborated strongly with Mexico in the past, but levels are rapidly decreasing. Collaboration between Canada and Mexico is average or higher in every field except physics, where it is underdeveloped.



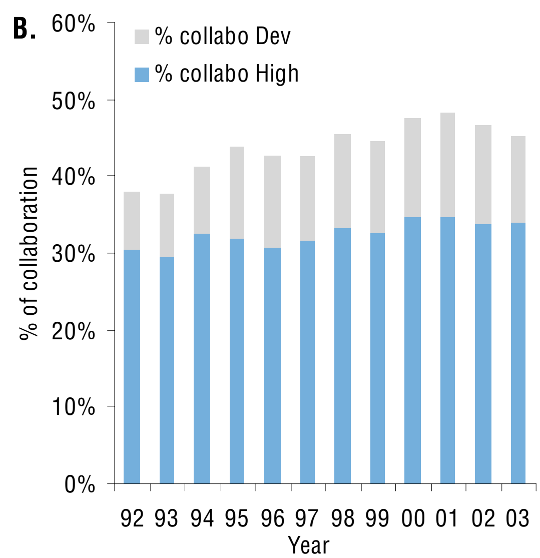


Figure 28 A. Evolution of scientific output and ARIF of Mexico, 1992-2003
B. Evolution of collaboration of Mexico, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Brazil specializes in biology, earth & space and physics, three fields where globally it has low impact. In the area of biology, Mexico has a really good ARIF score in general zoology, a subfield in which it is not specialized. Canada has good impact in this subfield and collaboration between the two nations should be encouraged to increase Mexico's activity and yield high quality research. In most other subfields of biology, Mexico needs to collaborate with researchers who do high quality research. As Canada does extremely well in marine biology & hydrobiology and in ecology, collaboration with Mexico could be oriented towards these areas.

In earth & space science Mexico needs to boost its impact in most subfields. Collaboration with Canada would be optimal in oceanography & limnology, astronomy & astrophysics and in environmental science. In physics, the only interesting complementarity is in solid state physics where Canada does high quality research, but is not specialized, while Mexico does a lot of research, but has relatively low impact.

4.2.12 Nigeria

Nigeria has a per capita GDP of US$900. This makes it the third poorest of the countries considered. The number of NSE publications associated with this country is 5,940, ranking it 26th for absolute number of papers in the developing countries. Its position drops to 51 when this number is weighted by population. The number of NSE papers published by Nigerian researchers fell between 1992 and 2003 as can be seen from Figure 29A, producing a growth rate of -3.4%. Nigeria also has one of the lowest ARIF scores at 0.62, and ranks 50th among developing countries in this respect. Figure 29A indicates that the ARIF although uneven, is increasing.

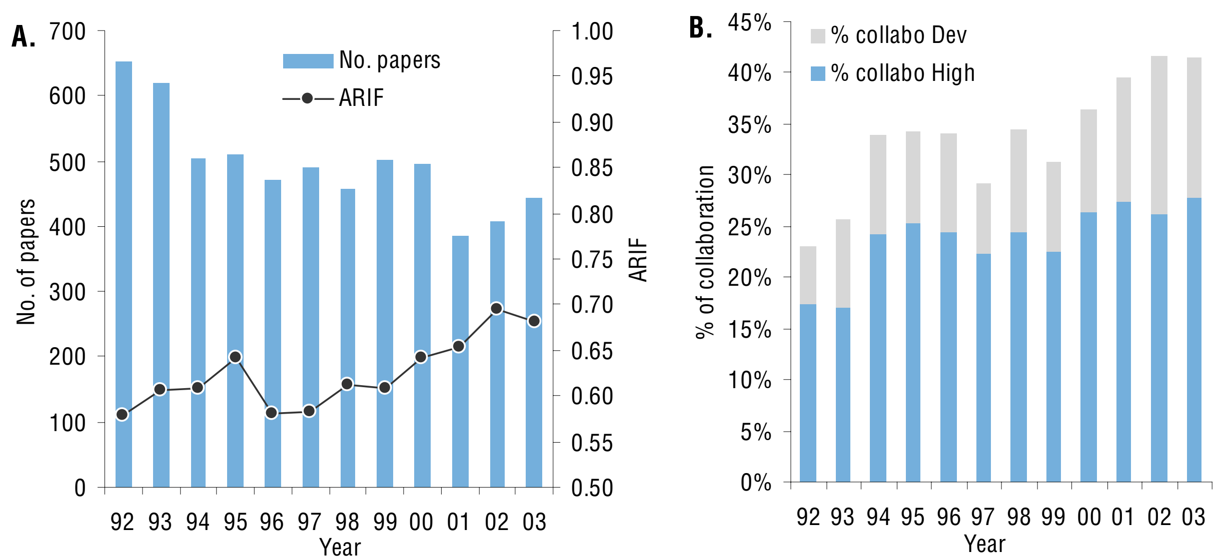


Figure 29 A. Evolution of scientific output and ARIF of Nigeria, 1992-2003
B. Evolution of collaboration of Nigeria, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Nigeria shows similar patterns for SSH. Number of publications is quite high at 923 and 14^{th} position. The ARIF is respectable at 0.81 (21^{st} position among developing countries). The growth in output however is lower than for the NSE and is the lowest for all the countries at -8.1%.

The share of scientific papers with foreign collaborators is increasing (Figure 29B). The share of collaborators from developing countries is also increasing. However, the number of collaborations with Canada is decreasing and is extremely low (only 3 papers in 2003).

Nigeria is specialized in biology, but has one of the lowest impacts in this field of all the countries considered. Thus, in this field, any collaboration would be beneficial for Nigeria, and ecology is the subfield where Nigeria would gain the most from greater collaboration with Canada. There are some subfields of clinical medicine where Nigeria would profit from collaboration with Canada. The most important are pharmacology, obstetrics & gynaecology, and general & internal medicine.

4.2.13 Senegal

Senegal also belongs to the lower tier in terms of wealth. With a per capita GDP of US$1,600, it is ranked 53^{rd} among the developing countries. It has the second lowest number of papers in the SCI, 1,278 units. When weighted by population, this ranking rises to 43^{rd}. Senegal compensates for this weakness in quantity with an ARIF of 0.89, positioning it 9^{th} among the developing countries. It is not possible to calculate a reliable growth rate for the period: however, it would seem from Figure 30A, that Senegal seems to experience random growth. If 2003 is taken as a reference point, the number of yearly publications could increase in the years to come.

In SSH, Senegal has a few publications with a relatively high ARIF. Its 81 papers place it in 49^{th} position among the developing countries, while an ARIF of 0.83 puts it in 19^{th} position.

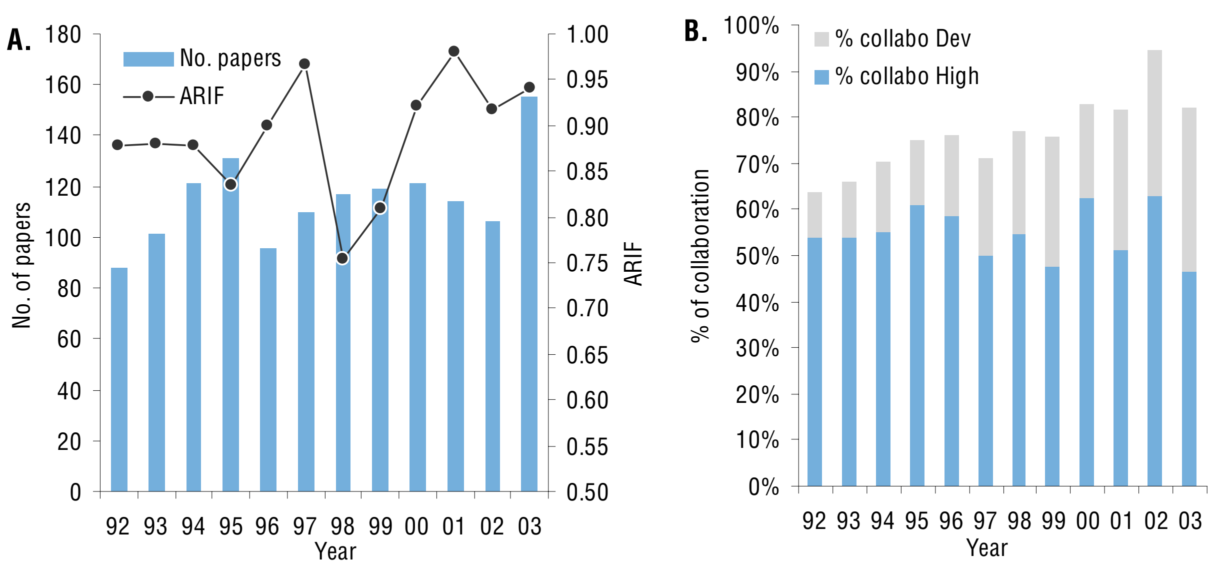


Figure 30 A. Evolution of scientific output and ARIF of Senegal, 1992-2003
B. Evolution of collaboration of Senegal, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Senegal collaborates intensively with other nations, and with the exception of the last year presented, this trend has continued to grow. A large and continuously increasing share of these collaborations is with developing countries. The share was almost 50% in 2003, the largest of all countries presented. Interestingly, Senegal collaborates with other Africa countries more than with Canada (only 16 papers in 12 years with Canada), a pattern that is unusual given these countries' microscopic share of scientific publications. Senegal's collaborators are, in order of importance, Cameroon, Burkina-Faso, Gambia, Ivory Coast, Niger, Mali, Mauritania and Benin. This list will get longer, as collaboration with Canada in the last few years has virtually ceased. The most important collaborator from all perspectives is France, with Senegal having co-authored almost 50% of its scientific papers with this country. Here too, though, the share is diminishing. Generally, Senegal has a clear preference for French-speaking countries. It is not surprising then that the majority of collaborations with Canada are with researchers from Quebec, but collaboration is still well below the level that could be expected. More than 80% of Senegal's collaborations are in the life sciences, with a dominant proportion of papers on infectious diseases.

Senegal's main strength is clinical medicine. The main subfields are general & internal medicine, tropical medicine, and environmental & occupational health, in which the country is specialized and has ARIFs above the world average[14]. It is also specialized in immunology, veterinary medicine, dermatology & venereal disease, and paediatrics, but would benefit from collaborating with leaders in these subfields to increase its scientific impact.

Senegal is also specialized in biology, but the only subfield in which the number of papers is reasonably high and in which it is specialized is agriculture & food science, a subfield in which Canada generally publishes in lower-impact journals than Senegal.

4.2.14 South Africa

South Africa is ranked 10th among the developing countries with a per capita GDP of US$10,700. It holds 16th position in terms of SCI papers per capita, slightly below the 12th position it achieves in absolute terms for its 31,066 papers. These relatively high positions however are accompanied by a low overall growth rate of 1.4% (41st rank). Figure 31A shows that this low figure is attributable more to the first part of the period studied since growth has increased in recent years. South Africa's ARIF is average for a developing country at 0.79 and 28th rank.

The country has the third highest number of publications in SSH with 4,662 papers. Growth is 1.3% in this case (29th position). The ARIF of South Africa is 0.80 for SSH, giving it a respectable 22nd position.

South Africa's share of papers in international collaboration is increasing very fast and has more than doubled over the period studied (Figure 31B). The country is also giving growing importance to collaboration with other developing countries. South Africa has a clear preference toward

[14] Senegal is one of the few African countries that have controlled the AIDS pandemic, with a vast concerted public health program.

collaborating with Australia. It also collaborate more with Canada than might be expected considering Canada's regular share. However, this relationship is slowly losing importance in all fields, apart from earth & space, and mathematics, two fields where South Africa's and level of collaboration with Canada is relatively high.

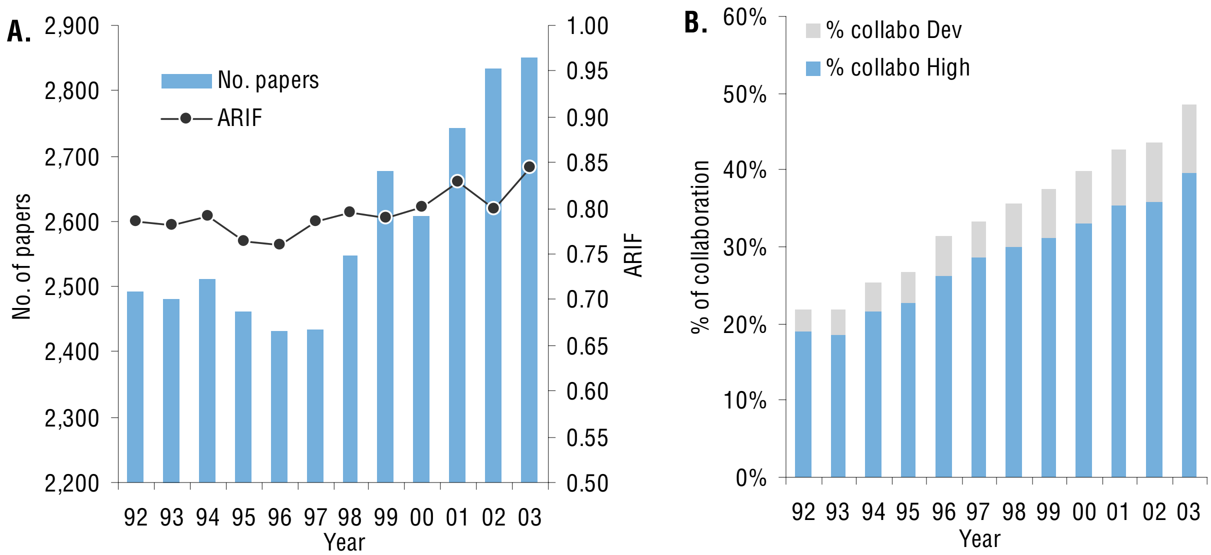


Figure 31 A. Evolution of scientific output and ARIF of South Africa, 1992-2003
B. Evolution of collaboration of South Africa, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

South Africa's main forte is earth & space, in which it is one of the most specialized countries in the world and where its impact is good compared with other developing countries. Canada and South Africa have many interesting complementarities in this field: where one shines in terms of number of papers, the other stands out in terms of quality of its research. Both countries excel in astronomy & astrophysics and geology, two areas where collaborating could be mutually beneficial. In oceanography & limnology as well as in environmental science, South Africa would definitely benefit from Canada's high-quality research, whereas Canada would gain most from greater collaboration in earth & planetary science.

Biology is also a field in which South Africa is relatively active. Generally, Canada is conducting research of higher quality in this field than South Africa, and, thus, enhanced collaboration would be helpful to the latter. In terms of subfields, the country should concentrate on zoology.

4.2.15 Thailand

Thailand is in 20th place among the developing countries in terms of per capita GDP at US$7,400. In NSE, the country shows an average number of papers with 9,399 publications, and is in 19th position among developing countries. This position changes significantly when weighted by the country's population, taking Thailand down to 38th position. Growth in scientific output has been high for the period studied at 11.8% per year. This puts Thailand in 10th place with the highest growth in all the countries, or 7th when considering only developing countries. Thailand's ARIF is 0.87, putting it in 11th position among developing countries. The ARIF score has been following a downward trend however, as illustrated in Figure 32A.

Thailand is strong in SSH. It has an average to high number of publications with 528 papers, putting it in 17th position. Growth rate is also average at 4.9%, or 16th. Thailand's ARIF is 0.90, which puts Thailand in 10th place for SSH.

Thailand's ratio of papers with foreign collaborators is quite high, but is decreasing. English-speaking countries are usually favoured by Thailand, and, accordingly, the US, the UK, Australia and Canada are the most prefered collaborators. China and Japan are also favoured collaborators.

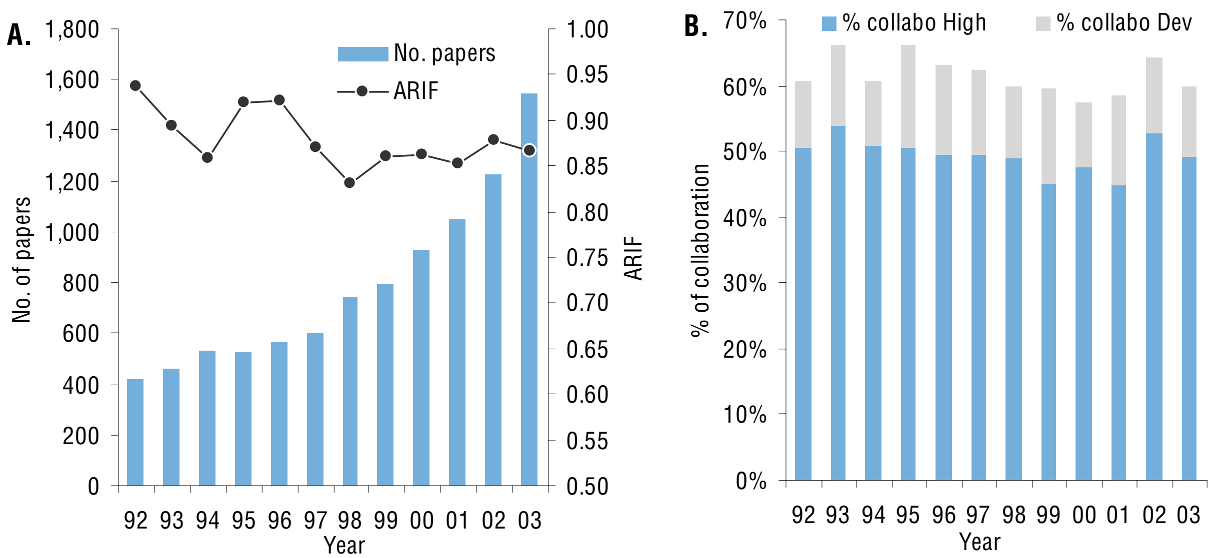


Figure 32 A. Evolution of scientific output and ARIF of Thailand, 1992-2003
B. Evolution of collaboration of Thailand, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Thailand, similar to many other developing countries, specializes in biology. Collaborating with countries that have better scientific impacts is generally be a recipe for success in all subfields, and Canada is very well positioned to help Thailand in zoology and marine biology & hydrobiology.

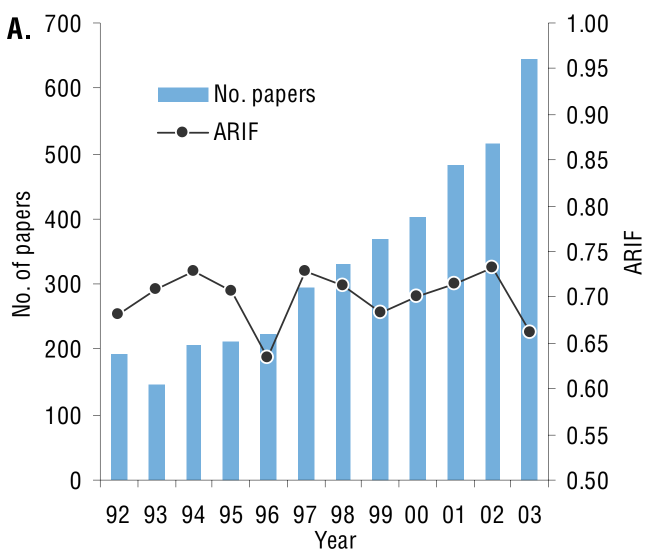
Thailand also specializes in clinical medicine, a field in which it has an ARIF close to the world average. Its best subfield is environmental & occupational health, a subfield in which it generally publishes in more highly cited journals than does Canada. It also excels in tropical medicine, a field of lesser importance to Canada. Thailand is relatively active in pharmacology, dentistry, pharmacy, dermatology & venereal disease, immunology, haematology, obstetrics & gynaecology, fertility, and veterinary medicine, all subfields where Canada's research is of better quality and thus scientific collaboration could help Thailand. Thailand's level of activity in physics is low, and its researchers publish their results in journals that are, on average, less often cited. Given this, collaboration should probably be encouraged in other disciplines, unless an effort is made to identify more potent research groups and/or research subjects.

4.2.16 Tunisia

Tunisia ranked 23rd in the developing countries in terms of per capita GDP which is US$6,900. It has an average to low number of papers in NSE with 4,015 publications (32nd rank). Tunisia ranks 26th for number of papers per capita, a noticeable increase over the rank obtained for the absolute number of papers. Tunisia is one of the countries with the highest growth rate for all countries in number of papers. It ranks 8th overall and 5th among developing countries with a growth rate of 13.2%. It must be remembered that it is easier to achieve a high growth rate from a low starting point, as is the case here (see Figure 33A). The country has a low ARIF of 0.70 (43rd rank for developing countries), indicating a weakness in terms of quality.

Tunisia ranks 48th for its 90 papers in the SSH. The country should soon improve on this low number of publications, since its growth rate for the period is 13.4% (7th rank). The caveat about a low starting point again applies. Tunisia has a low ARIF, of 0.70 for SSH (35th rank).

Tunisia has a stable rate of international collaboration close to 55%, a little higher than that for most high-income countries, but lower than that for many developing economies. 80% of its international collaborations are with France. This leaves very little room for other collaborators and, accordingly, collaboration with Canada is very limited.



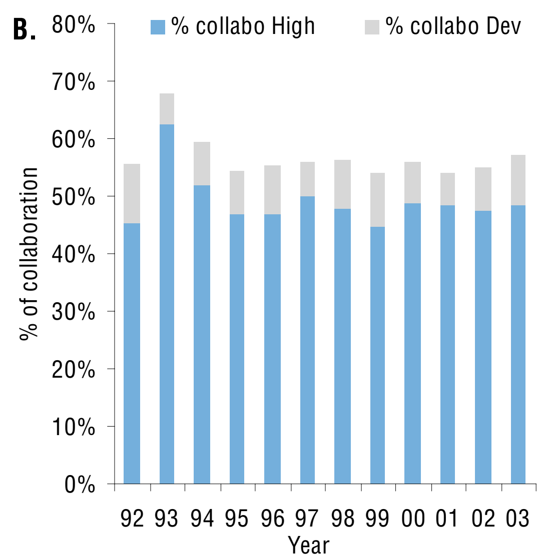


Figure 33 A. Evolution of scientific output and ARIF of Tunisia, 1992-2003
B. Evolution of collaboration of Tunisia, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

Tunisia specializes in chemistry, mathematics, engineering & technology, and physics. Conversely, its level of activity in the life sciences is generally very low. In chemistry, Tunisia would benefit greatly from collaboration in the organic chemistry and physical chemistry subfields. In mathematics, there is no specific subfield where collaboration would yield better returns than in others. In engineering & technology, Tunisia is doing far better than Canada in the subfield of metals & metallurgy, but would gain greatly from more collaboration in chemical engineering. Finally, in physics, the subfield of solid state physics would be a good area for collaboration as Tunisia is very specialized and Canada has very high impact. Also noteworthy is that both countries' excel in genetics & heredity. Both are very active in this specialty and both publish their research results in high-impact journals, especially Tunisia, which has one of the highest ARIFs of all countries.

4.2.17 Vietnam

With a GDP per capita of US$2,500, Vietnam ranks 44th among developing countries. It has a small number of papers in the SCI with 2,443 publications, putting it in 42nd place. In terms of papers per capita Vietnam ranks fourth lowest at 54. It shows a good growth rate of 11.4% (8th among the developing countries and 11th overall). Finally, it has one the best ARIF of developing countries at 0.91, for a 5th position. Figure 34A shows that the ARIF is rather uneven, which argues for caution in interpreting this value.

With 117 papers in the SSCI and AHCI, Vietnam has a rather small pool of SSH publications (43rd position). Here again, Vietnam shows a high growth rate with 14%, a 6th position among the developing countries and 8th position overall. The ARIF for SSH is 0.72, 33rd position.

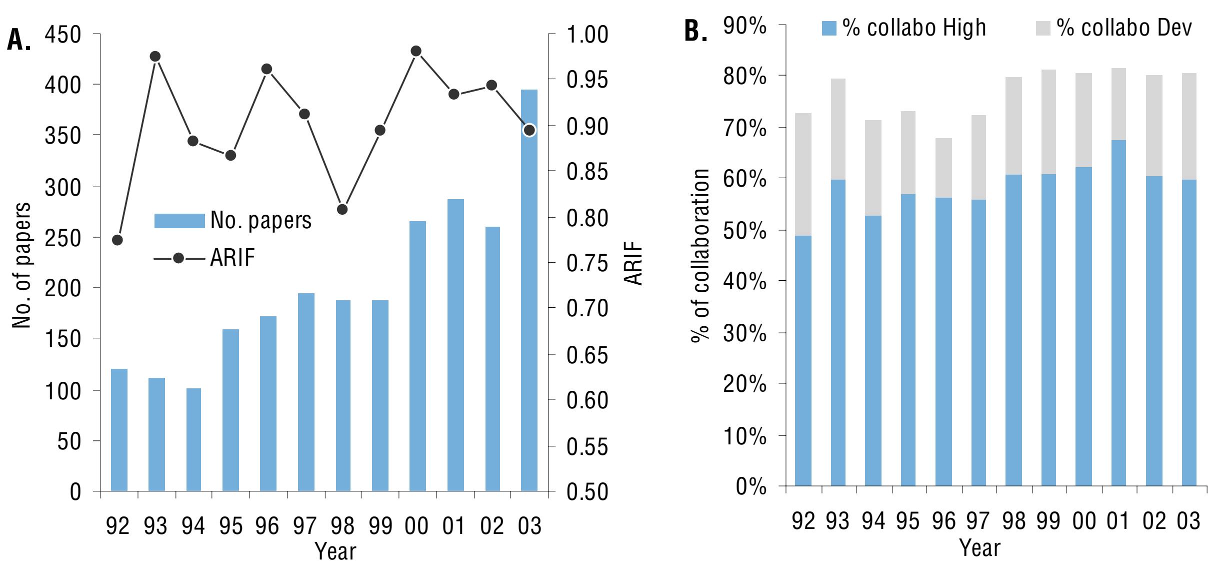


Figure 34 A. Evolution of scientific output and ARIF of Vietnam, 1992-2003
B. Evolution of collaboration of Vietnam, 1992-2003

Source: Compiled by Science-Metrix from data prepared by OST from SCI (Thomson ISI)

The percentage of Vietnamese papers co-authored with foreign collaborators is high and appears to have remained constant over a few years. The share of Vietnam's collaborators from other developing countries (25%) is among the highest for all countries presented. Its strong relationship with Thailand, Russia, China, South Korea, India and Indonesia, all developing countries that collaborate more with Vietnam than Canada, explains this. In fact, all G7 countries, with the exception of France, play a relatively minor role here. Canada accounts for only three collaborations a year with Vietnam and receives the lowest relative attention from this country.

Vietnam is highly focused on mathematics. It has by far the highest specialization index value in this field of all the countries presented, with a share of papers in mathematics six times higher than the world average. However, Vietnam has a relatively low ARIF in mathematics, even when compared to that of other developing countries. Effort is concentrated in general and applied mathematics, while over the 12-year period only one paper has been published in probability & statistics, the only mathematics subfield where Canada performs relatively well. Canada should probably support collaboration in other scientific fields if the goal is to maximize returns to Vietnam. Vietnam is also specialized, but to a lesser extent, in biology and physics. In biology, there is no subfield where collaboration would be mutually beneficial, while in physics, collaboration with Canada support would be most useful in solid state physics.

5 Conclusion

This report provides original data and analyses on the fields and subfields that would be most promising for collaborative research between Canada and developing countries. Proper characterization of each country's current state of scientific development in NSE and SSH, and its relative strengths and weaknesses, was lacking. And, despite the fact that scientific collaboration between developed and developing countries is increasing, relationships are often damaged by neo-colonialist attitudes, where ideas and money come from the richer countries and little consideration is given to the views and priorities of the developing countries.

Collaboration with developing countries must be developed along mutually beneficial lines.Inevitably, Canada will often be in the position of having a stronger science base, and more money, but there are areas of research where developing countries outshine Canada. Also, many topics like AIDS, pollution and food shortage are crucial to poorer countries, but are also very important for all countries.

The information presented in this report is particularly useful given Canada's goal of investing in a relatively new form of aid to developing nations through increased scientific collaboration, and given the relatively small involvement of Canada in this area compared to the other OECD countries. Canada's minor involvement in scientific collaboration in the developing world might be attributable to its history, and the scarcity of common institutions. The development of common institutions, or of strong relationships between institutions, is surely a determining factor in the long term sustainability of our international relationships.

Effective planning starts from the recognition that the developing world is not uniform. Countries with significant growth rates in the number of scientific publications are often also countries where the scientific system is developing rapidly, and this momentum offers an excellent opportunity for Canada to act as a catalyst in this development process. Conversely, some countries, such as Tanzania which is one of the poorest countries studied, have very shaky science bases and very few institutions with which to engage in durable collaboration.

Some lower income countries already have a publication level similar to that of Canada, for example Russia, China and India. But those relatively high publication levels do not mean that these countries cannot be helped. Some of these countries have strong scientific institutions and have developed some areas of excellence, but they are often concentrated in the larger urban areas while many regions continue to have no electricity supply and other amenities required for modern scientific undertakings. Thus, more detailed information on scientific development at the regional level should definitely be factored into Canadian strategies for collaboration with the less industrialized countries.

Biology is a generally fertile ground for mutually beneficial collaboration between Canada and many developing economies. The level of collaboration in several biology subfields is already quite high and should be strengthened further. This field includes important applied research endeavours in agriculture and food, as well as more fundamental research on the natural environment. Chemistry and physics are also relatively strong in developing countries, but are not among Canada's strongest fields. Conversely, biomedical research and clinical medicine are fields generally neglected by developing countries, even though disease is one of the most stringent problems for poorer countries. Additional efforts should be made to foster collaboration particularly regarding infectious diseases and tropical medicine, which are two domains of relatively less importance to the North, but vital to the South.

In earth & space, astronomy & astrophysics is the strongest subfield in the developing countries, whilst the environmental science subfield is generally very weak. It has been argued in the literature that astronomy requires international collaboration and is often perceived by governments as an "easy" way to gain S&T visibility (Jasentuliyana, 1995). It is also generally argued that space science is a good tool for the promotion of a scientific culture. Underlying this thought is that developing such a culture is necessary to reap the benefits of science in the longer run, including increased technological development. However, others argue that the linear model of science in which fundamental research is transcendentally producing helpful technologies, should not be applied to developing economies and that more emphasis is needed in the development of practical solutions to directly address the needs of people in their everyday lives (Goldemberg, 1998). Given this view, help would probably be more useful in developing solutions to environmental problems such as deforestation, desertification and water pollution. This type of consideration about the utility of research applies to every field of science and must take account of local circumstances and the development stages of each country. As a general rule, in really underdeveloped countries knowledge of local needs should be the main focus, whilst in more advanced countries, knowledge of areas where they peform significantly better than their competitors is probably more decisive.

It is important to remember that it is not the responsibility of the richest countries to decide which areas of science should be supported. The approach proposed in this report suggests a policy that builds upon the strengths that developing countries have already developed, and provides help to strengthen these areas further in a relationship that is mutually beneficial rather than an imposition of the ideologies of the North, whether they be towards favouring popular culture or pragmatic development.

For this reason, the social sciences are central to the development of nations and work in this area usually requires only small investments. Unfortunately, the bibliometric methods used in this report are not adequate to identify the strengths and weaknesses of developing countries in SSH because, as it have been said earlier, topics in SSH are more local and therefore there is little motivation to publish in international journals. Other tools should be used to overcome these limitations and provide in-depth portraits of SSH in the developing countries, which could be used to help developing countries strengthen the areas they have elected to focus on.

It is obvious that the problems of the developing world cannot be resolved by good intentions: scientific collaboration is only part of the solution. Identifying promising avenues for collaboration is undoubtedly useful, but much more needs to be done to support scientific and technological development. Science first has to be perceived by the governments and policy makes of the poorest countries as a legitimate and useful endeavour.

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Appendix: Methods Used in Scientometric Analyses

Dataset

This scientometric study is based on the use of the Thomson ISI Science Citation Index, Social Science Citation Index and the Art & Humanities Citation Index databases (SCI, SSCI and AHCI). The statistics are drawn from three document types that are considered to be original contributions to scientific knowledge: articles, notes and reviews. The tables presented in this report refer to these three document types as "papers."

SCI provide the most effective coverage of high-quality scientific research in natural sciences and engineering in indexing approximately 5,900 of the world's leading scholarly science and technical journals in more than 150 disciplines[15]. SSCI indexes 1,760 journals in social sciences while the AHCI indexes nearly 1,130 arts & humanities journals. These journals are considered to be the most important peer-reviewed journals in their respective fields. They reflect significant scientific achievements and are the most widely cited journals in the world (over 80% of the world's citations). The choice of ISI indexes over other databases (e.g. Biological Abstract, Agricola) is also advantageous because it traditionally includes the addresses of every author listed in scientific papers. Therefore, it allows the collaboration rate between countries to be analysed.

Indicators

The resulting datasets were used to produce detailed statistics based on the following indicators:

Number of papers - Number of scientific papers written by authors located in a given geographic, sectoral, organizational or individual entity (e.g.: countries, cities or institutions).

Growth rate - The growth rate is calculated using the percentage (%) of annual growth of the exponential model that best fits the experimental points. Put simply, this means that the indicator is the percentage of annual growth that would be calculated if the percentage of growth was the same for every year of the period. For example, the number of papers in 2004 should be the number of papers in 2003 multiplied by the growth rate and then added to the number of papers in 2003. Countries' effective growth never follows exactly an exponential growth, but an approximation is usually sufficient for a descriptive statistic. In cases where the model does not fit the experimental points, the statistic is not computed.

International collaboration rate - This is an indicator of the relative importance of international collaboration. The rate is computed by dividing the number of papers of an entity with at least one foreign country in their address fields, by the entity's total number of papers.

Average relative impact factor - This indicator is a proxy for the quality of the journals in which an entity publishes. Each journal has an annual impact factor (IF), based on the number of citations it received, relative to its number of papers. Then the journal's IF is ascribed to its papers. Each paper's

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[15] Data derived from information prepared by the Institute for Scientific Information, Inc. (ISI, Philadelphia, Pennsylvania, USA). Copyright Institute for Scientific Information. All rights reserved.

IF is divided by the average IF of all papers in its subfield to obtain a Relative Impact Factor (RIF). The average relative impact factor (ARIF) of a given entity is computed using the average RIF of each paper belonging to it. When the ARIF is above 1, it means that an entity scores better than the world average for a given field; when it is below 1, this means that on average, an entity publishes in journals that are not cited as often as the world average.

Specialization index - This is an indicator of the intensity of research of a given geographic or organizational entity (e.g.: country) in a given research area (domain, field) relative to the intensity of the reference entity (e.g.: world) in the same research area. The specialization index can be formulated as follows:

$$SI = \frac{(X_S / X_T)}{(N_S / N_T)}$$

X_S = Papers from entity X in a given research area (e.g.: Canada in physics)

X_T = Papers from entity X in a reference set of papers (e.g.: Canada in the whole database)

N_S = Papers from the reference entity N in a given research area (e.g.: world in physics)

N_T = Papers from the reference entity N in a reference set of papers (e.g.: world in the whole database).

An index above 1 means that a given entity is specialized relative to the reference entity. Conversely, a score below 1 means that the given entity is not specialized relative to the reference entity.