
Health biotechnology publishing takes-off in developing countries

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Abstract: To gain insights into the potentials and characteristics of health biotechnology in developing countries, we carried out an analysis of health biotechnology publications in developing nations that have had some successes in this field. We analysed the patterns of health biotechnology publications of authors from seven developing countries from 1991 to 2002. Our results showed a significant growth in health biotechnology publications in developing countries. Their growth in the field was larger than the growth in industrialised countries, but the visibility of their research was limited. Universities were found to be the strongest producers of health biotechnology papers in the countries we studied. This study showed further that international research collaboration of these countries was extensive and domestic knowledge flows between their institutions seems to be increasing. Contrary to other work on health research in developing countries, this study suggested that developing countries' research was focused on local health needs.

Keywords: publications; biotechnology; developing countries; scientometric analysis; citations; collaboration; research focus; Brazil; China; Cuba; Egypt; India; South Africa; South Korea; innovation; technological change; South-South.

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1 Introduction

The potential value of biotechnology for improving health, quality of life and for economic gains has been stressed by many policy makers in recent decades (CBC, 1998; EC, 2002; OECD, 2004). A key to the development of this sector has been to promote science that will eventually result in improved products and services. Lately, there has been an increasing recognition that biotechnology has not only a potential role in developed countries but could be applicable to developing countries' problems as well to improve their quality of life and increase their wealth (Daar et al., 2002; Juma and Lee, 2005; UNDP, 2001).

Case study research has shown that several developing nations have actively promoted health biotechnology in their countries, which has resulted in new and often more affordable health products for their populations (Thorsteinsdóttir et al., 2004a). For example, as Cuba had capacity in health biotechnology it could respond to a meningitis outbreak in the country by producing the world first's meningitis B vaccine; firms in India have been able to produce genetically engineered vaccines for hepatitis B at a fraction of the cost of the vaccine in other markets; and a Brazilian firm has, in cooperation with a university, developed and patented a process for recombinant human insulin that can be used to address the mounting incidences of diabetes that many developing countries suffer from (Ferrer et al., 2004; Kumar et al., 2004; Thorsteinsdóttir et al., 2004b). The health biotechnology innovation systems in those countries have varied features and their governments have relied upon diverse policy measures to promote the development of the field. These include developing biotechnology strategies, encouraging linkages and attempting to reverse brain drain. Case studies have provided valuable insights into the development of the health biotechnology sectors in the countries studied. However, a study of health biotechnology publications would provide a more quantifiable approach to study the development of these sectors in developing countries and allow further comparisons between the countries.

A substantial proportion of health biotechnology publications in general is produced by researchers at universities and public research institutes (Faulkner and Senker, 1995; Powell and Owen-Smith, 1998; Zucker et al., 1998). These institutes typically emphasise publishing in peer-reviewed journals and therefore examining patterns of health biotechnology publications can give valuable insights into the development of the sectors. We can, for example, estimate if health biotechnology sectors are growing in specific countries by examining the publishing outputs of those countries in the peer-reviewed literature. We can gauge the impacts of the research produced by a country and how the knowledge from those countries is flowing by examining how often the papers are cited in the literature and who is citing them. Knowledge flow from academia to industry has, for example, been mapped by examining the citations of academic papers in patent applications (Meyer, 2002; Narin, 1994). Both domestic and international linkages can further be studied by examining the extent and patterns of papers that include several co-authors.

Studying publication patterns of scientific papers written by authors from developing countries has been carried out for a few decades. Frame et al. (1977) were amongst the first to examine empirically the extent of scientific publishing in the world by examining the level of publications of developing and industrialised countries and they pointed out the limited role of developing countries played in the production of scientific papers. Until now many authors have focused either on science publishing in developing

countries in general (Garfield, 1983; Osareh and Wilson, 1997) or on particular continents or developing countries (Arunachalam, 2002; Arunachalam and Doss, 2000; Narvaez-Berhelemot, 1995; Russell, 1995; Zhou and Leydesdorff, 2005). In a recent paper on scientific impacts of nations, King (2004) included several developing countries in his analysis.

Despite many examples of studies focusing on publication patterns in developing countries, no study has so far examined publication patterns in the health biotechnology sectors in developing countries. As was highlighted above, the health biotechnology research can play a significant role in the development of new and needed health products in developing countries so a quantitative analysis of publication patterns in this sector can provide a more profound understanding of the status and the processes involved. In this paper, we will therefore examine the pattern of health biotechnology publications in seven developing countries that have demonstrated some successes in this sector. They are Brazil, China, Cuba, Egypt, India, South Africa and South Korea and all have significant scientific capacity in health biotechnology. These countries represent different parts of the world and present significant differences in income levels and population size. South Korea does not, however, fit the developing country classification and is now an OECD country. We included it in the study for a comparison with a country that is relatively newly industrialised. By including seven countries in this study, the scale of this project is relatively large which offers expanded potentials for comparisons of the publications' patterns and enlarges the contribution of this paper.

We will examine the level of scientific output in the health biotechnology sector for each of the seven countries and we will estimate their growth in publications over the 1991–2002 period. We compare the performance amongst the seven countries and also to some leading countries in the world in knowledge production in health biotechnology. This will give us an indication of how promising the health biotechnology sectors are in these countries and allow us to examine whether the changes in the output can be associated with major policy changes in those countries. We will also assess the visibility and the impact of their health biotechnology publications by looking at their citation rates. Further, we will determine who are the countries' most active contributors to health biotechnology by examining which sectors (i.e. government, university, industry, etc.) the authors of the papers represent. We will also examine domestic and international collaboration as reflected in copublications. Active collaboration and knowledge flow are essential for health biotechnology development and analysis of copublications offers an approach to map these flows. Finally, we will determine the focus of health biotechnology research in the seven countries and evaluate how well the focus of research is aligned with local health needs.

2 Methods

The scientometric analysis is based on the data extracted from Thomson ISI's Science Citation Index Expanded database (SCI Expanded), which contains papers from about 6000 journals that are considered to be the world's most important peer-reviewed scientific journals. For this study, we counted contributions from four types of documents that are considered as original contributions to knowledge: articles, notes, reviews and

conference proceedings. The data set was built using keywords in title searches¹ with a view to operationalise the OECD definition of biotechnology, that is:

“The application of scientific and engineering principles to the processing of organic and inorganic materials by biological agents to provide goods and services” (OECD, 1998).

As biological agents, we included both biological organisms and biological substances; for goods and services, we focused on goods and services for the health sector. This definition covers biotechnology in the fields of clinical medicine and biomedical research. The database of health biotechnology was built up by selecting only those papers published in journals that were classified as clinical medicine and biomedical research.

The health biotechnology papers that were published during 1991–2002 and that had at least one author with an address in Brazil, China, Cuba, Egypt, India, South Africa and South Korea were extracted from the SCI Expanded database. The papers published in Hong Kong were not included for the data set on China. The addresses from these papers were standardised according to country and city and they were classified into sectors, that is, university, government, clinics and hospitals, company and other.

It has been noted by several scholars that the coverage of developing countries' journals in the Thomson ISI databases is more inclined to include journals published in English than in other languages (Arunachalam, 1988; Arunachalam and Manorama, 1988; Archambault and Vignola-Gagné, 2004; Bordons and Fernández, 2002; Osareh and Wilson, 1997). SCI Expanded has a more extensive coverage of journals than the basic SCI database – it indexes papers in about 2000 additional journals. However, even though SCI Expanded has an improved coverage, it is likely to ignore many important journals in the countries we focus on that are not published in English. Hence, for non-English speaking countries (every country in this set except for India and South Africa), only the most international part of their scientific output is accounted for in this study. For life sciences in general, Arunachalam and Rino (2003) have shown that 55% of Indian papers are published in Indian journals. According to them many of these papers are of low quality. In this study, we are therefore likely to cover the most international and high quality proportion of the health biotechnology papers in the countries we studied.

3 Results and discussion

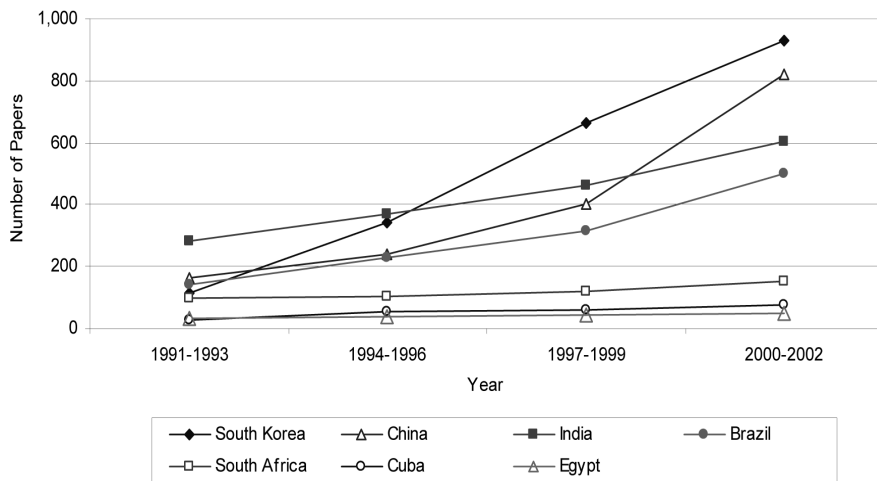
3.1 Level of publishing in health biotechnology

The total number of health biotechnology papers published in the world has been relatively stable during the period covered in this paper, increasing from about 10,000 in 1991 to about 12,000 in 2002. Thus, the proportion of health biotechnology papers in the SCI Expanded database dropped slightly during the period, that is, from 1.8% in 1991 to 1.6% of total papers in 2002. This fits with work on genomics that indicates a slowing down in genomics publishing when analysing papers in the BIOSIS database (Nightingale and Martin, 2004).

Figure 1 presents the number of papers in health biotechnology by the seven developing countries. In the early 1990s, the production of health biotechnology papers

was very small in all the countries and only India produced more than 200 papers for the three-year period 1991–1993. This reflects India's early prioritisation of biotechnology, for example, in its sixth five-year plan, 1980–1985, as a tool to address its development needs and to improve the health of its population (Kumar et al., 2004). Thus, India had an early start in supporting research in the field.

Figure 1 Number of papers in health biotechnology by countries, 1991–2002



Source: Science-Metrix (data from Science Citation Index Expanded, ©Thomson ISI).

Around the mid-1990s, health biotechnology seemed to be taking off in several of the countries with South Korea, India, China and Brazil all showing a considerable increase in the number of papers published. South Korea's performance has been most impressive. Its publications increased over eightfold and by the end of the period it had become the clear leader among these seven countries. South Korea has considerably increased its R&D outlays during the period and, as a result, had one of the largest growths in R&D expenditure as a percentage of GDP in the world. By 2001, R&D spending was 3.06% of its GDP and surpassed, for example, the 2.82% of GDP spent on R&D in the USA (OECD, 2003). South Korea is a relative latecomer to the field of biotechnology but in 1994 seven government ministries signed a plan to transform South Korea into one of the world's top seven biotechnology producing countries by 2010. They allocated significant resources to the sector and from 2000 to 2007 the government will have invested over US\$ 4.4 billion in biotechnology (Wong et al., 2004).

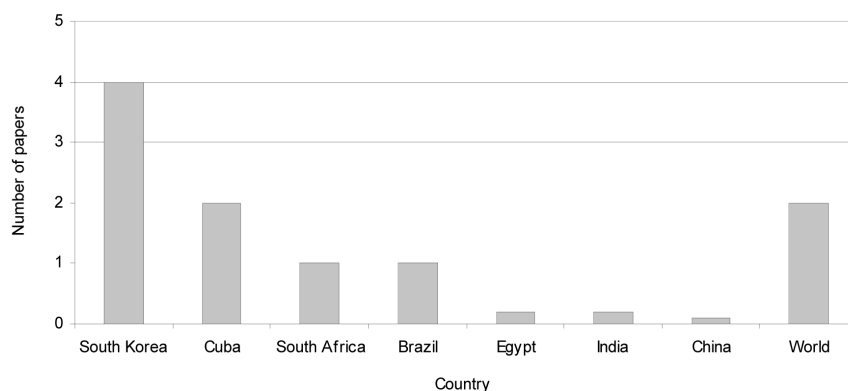
China increased its number of papers in health biotechnology from 1991 to 2002 almost fivefold. From 1997 to 2002, China showed an especially steep increase in its health biotechnology publications and surpassed India's output in the field. These results are confirmed by other research that shows that China's publication output in new biology has been increasing faster than India's for the period 1992–2001 (Arunachalam and Rino, 2003). After the Cultural Revolution had passed, the Chinese government launched programmes that prioritised health biotechnology research (Zhenzhen et al., 2004). The increased funding and capacity building in health biotechnology resulting

from these programmes and the opening up to Western science are likely reflected in this increase in the health biotechnology output of the country. For science in general, Zhou and Leydesdorff (2005) have also shown that the Chinese growth in publications is exponential (Zhou and Leydesdorff, 2005).

Brazil and Cuba also significantly increased their output in the health biotechnology papers from 1991 to 2001. Brazil's increase was 3.5-fold and Cuba's was 2.6-fold. Neither Egypt nor South Africa managed to double their output in health biotechnology papers during the period we studied. Egypt's increase was 1.6-fold and South Africa's 1.5-fold. It is noteworthy that a trade embargo by the USA against Cuba has been in effect since 1961 and has discouraged US journals from accepting Cuban papers. It was unclear to the editors of journals if they were allowed to accept papers from embargoed countries and further if they were allowed to edit them as altering their work could constitute provision of services to those countries. Early in 2004, it was clarified that accepting and editing publications from embargoed countries would not constitute a violation of the embargo even though collaboration and co-authorship would be considered as prohibited exportation of services (Mitka, 2004). The USA generally dominates the field of health biotechnology and a large number of journals in this field are based in the USA. As a result, it is likely that Cuba's performance in health biotechnology is underestimated in this analysis of data from SCI Expanded.

In Figure 2, we present data that accounts for the differences in population sizes between the countries. The figure presents data on the number of health biotechnology papers these countries produced per million inhabitants from 1991 to 2002. Even when accounting for population size, South Korea clearly published more in health biotechnology than every other country studied here. At the beginning of the period, it published only one health biotechnology paper per million inhabitants but by the 2000–2002 period it was publishing seven papers per million inhabitants thus significantly surpassing the world average of two papers per million inhabitants. Cuba is the only other country in our study that has reached the world average by publishing two health biotechnology papers per million inhabitants. This indicator is useful to examine the production of smaller countries but it does not provide an accurate representation of the health biotechnology potential of countries such as China and India, which have a very high proportion of the world's population.

Figure 2 Number of papers per million inhabitants, 1991–2002



Source: Science-Metrix (data from Science Citation Index Expanded, ©Thomson ISI).

3.2 Comparisons with leaders in health biotechnology

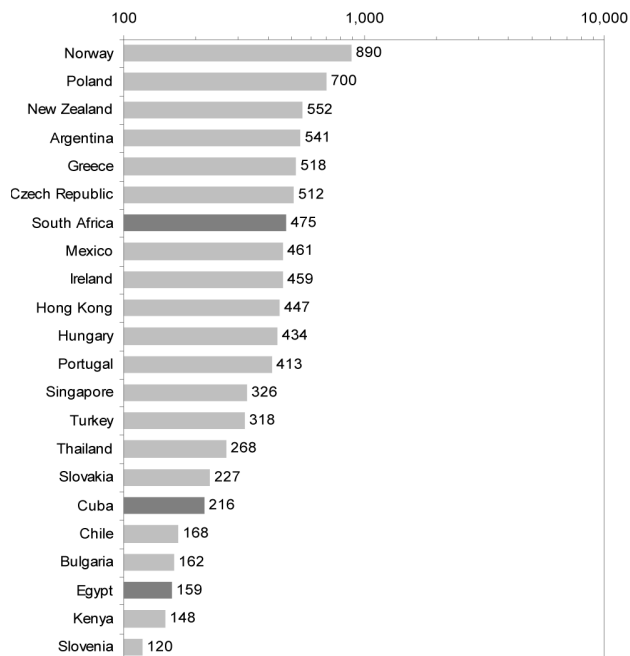
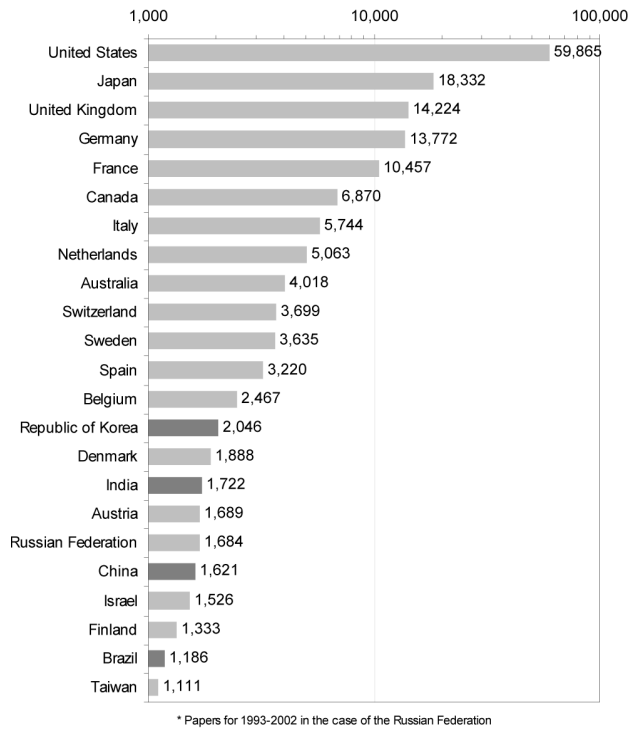
Figure 3 presents the top 45 countries that publish papers in health biotechnology in the world. Compared to the leading countries in the world, the contribution of the countries in our study is very limited. Figure 3 shows, however, that some of the developing countries in this study are approaching and/or surpassing smaller developed countries in their health biotechnology publications for the entire period. The USA has a clearly dominant position in this field.

As can be seen in Table 1, the growth rate in health biotechnology publication is much greater in the developing countries we studied than in the developed ones. The gap between the number of papers in the countries is therefore decreasing and some of the most active developing countries are poised to be amongst the strongest knowledge producers in this field in a few years' time. China's growth rate is particularly impressive. As indicated in Figure 1, its publication level in health biotechnology was surging ahead of India and approaching that of South Korea. The negative growth rate for Egypt does not suggest that the country is likely to significantly strengthen its position in the field of health biotechnology publications.

Table 1 Average yearly growth of papers in health biotechnology in selected countries, 1999–2002

<i>Country</i>	<i>Average growth (%)</i>
Cuba	25.2
China	19.6
South Africa	12.5
South Korea	11.8
India	10.8
Brazil	10.4
Italy	−1.8
Austria	−1.9
Sweden	−2.1
Germany	−2.5
Spain	−3.3
Israel	−3.3
USA	−3.3
The Netherlands	−3.3
Japan	−3.8
Australia	−4.5
Denmark	−4.5
Canada	−4.6
France	−5.1
Egypt	−5.9
Switzerland	−7.1
UK	−7.8

Figure 3 Top 45 countries by the number of papers in health biotechnology (log scale), 1991–2002



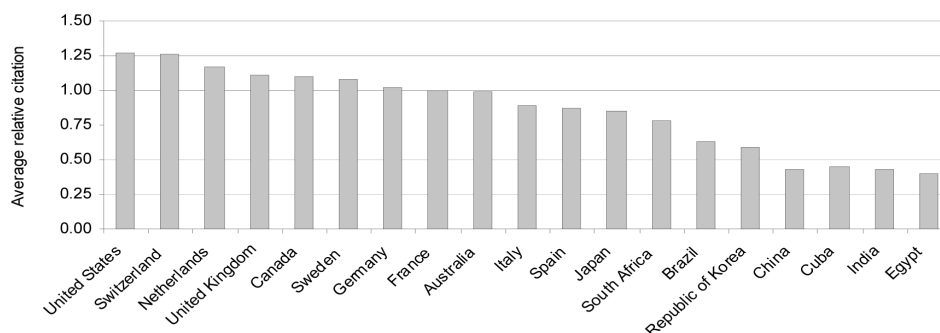
Source: Science-Metrix (data from Science Citation Index Expanded, ©Thomson ISI).

3.3 Citations of health biotechnology papers

The number of papers the countries publish in health biotechnology is only one indicator of the countries' standing in the health biotechnology field. Another perspective is to examine the citations received by publications. This is useful to determine the visibility and impact of the research by these countries, in the global peer-reviewed literature. The numbers of citations for each of these papers were counted for the year in which they were published and for the two subsequent years. For example, for papers published in 1991, citations made to the paper during 1991, 1992 and 1993 were counted. The years 2001 and 2002 were however exceptions as data were yet not available for a three-year citation window. The citation count was then divided by the average count of all papers published in health biotechnology in the SCI Expanded database to obtain a relative citation count. The Average Relative Citations (ARCs) were computed using the ARC count of each paper (Figure 4). When the ARC is greater than 1, it means that the paper from a particular country scores better than the world average in this field. By contrast, when the ARC is less than 1, the citations of a country's paper have not reached the world average.

Although the countries in our study are publishing actively in the health biotechnology field and approaching the level of some of the leading countries in this field, their publications are still not cited to the same extent. In fact, none of the countries in our study reached the world average ARC levels. Furthermore, some of the leading countries in terms of publication output such as South Korea and China have a relatively low citation rate while South Africa, which is a more modest producer of health biotechnology papers, has the highest ARC of the countries considered in this paper. These results confirm that, for science in general, the most cited publications come from only a few leading countries and developing countries' science is infrequently cited (Arunachalam and Manorama, 1988; King, 2004; Osareh and Wilson, 1997; Velho, 1986). Thus, while the contribution of developing countries' scientists is increasing in the health biotechnology field their visibility still has to be improved to be on par with scientists from industrially advanced countries. There are some signs that indicate that the visibility of at least some developing countries is increasing. Both King (2004) and Zhou and Leydesdorff (2005) have revealed that the citations of the publications from China and South Korea, are increasing considerably, even though the levels are still very low.

Figure 4 ARC of selected countries in health biotechnology, 1991–2002



Source: Science-Matrix (data from Science Citation Index Expanded, ©Thomson ISI).

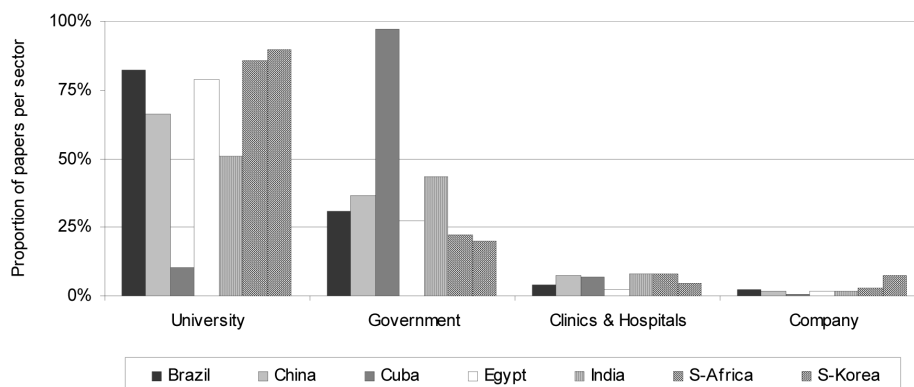
3.4 Sectors of health biotechnology publications

The health biotechnology papers in each country were classified according to the sectors of the authors to find out where the main activities in health biotechnology are located. Figure 5 shows that, in almost all the countries, universities are the main producers of health biotechnology papers. The governments in these countries have actively promoted health biotechnology by promoting university research in this field. This agrees with analyses in many developed countries, where universities have been strong knowledge producers in this sector (Krimsky et al., 1991; Powell and Owen-Smith, 1998; Zucker et al., 1998).

In some of the seven countries, the dominance of universities has increased over time. For example, in China in 1990, universities published around 54% of the health biotechnology papers but by 2002 they were publishing around 76%. The increased role of universities in health biotechnology research was a part of a move away from the Soviet research model that China had previously adopted. Under that system, universities had predominantly a training role and most of the research activities were performed in public research institutions. From Figure 5, it can be seen that Cuba adopted this system and universities play a relatively small role in research in the health biotechnology field with most of the papers produced by public research institutes (labelled as government in Figure 5). In India, the roles of universities and government are more even than in any of the other countries and both are very strong knowledge producers in this field.

It is noteworthy in Figure 5, how small the role of clinics and hospitals is in health biotechnology of the countries under study and only in India and South Africa does their contribution reach 8% for the whole period. Their scientific output is smaller than has been the case in industrially advanced countries such as Britain, where around 20% of papers are from the hospital sector (Hicks and Katz, 1996a,b). Furthermore, the private sector does not have a significant role in publishing papers in the countries we studied. It is the largest in South Korea, where it is 7.2% for the period 1991–2002. Companies such as LG Chem Ltd. and Hanhyo Institute of Technology are actively publishing. Increasing publishing by firms has been observed more generally in developed countries and in other industrial sectors such as in the chemical and communications sectors (Hicks and Katz, 1997, 2000).

Figure 5 Percentage of papers in health biotechnology per sector, 1991–2002



Source: Science-Metrix (data from Science Citation Index Expanded, ©Thomson ISI).

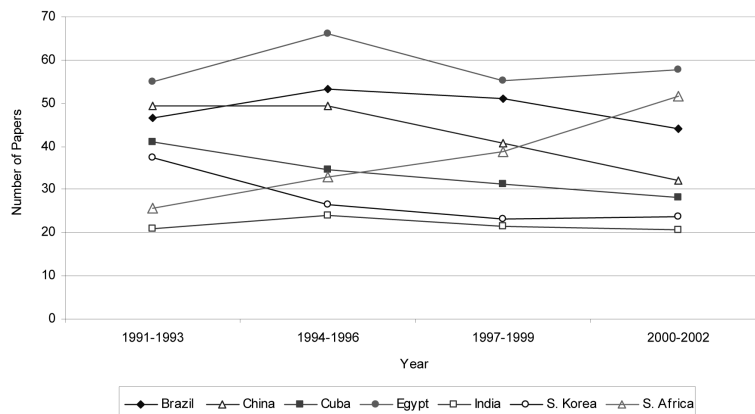
In several of the countries, health biotechnology has been concentrated in special regions or clusters. In some cases, the governments of territories or states within the country have been actively promoting health biotechnology. In Brazil, for example, the State of Sao Paulo has played a pivotal role in building up health biotechnology (Ferrer et al., 2004) and over one-third (36%) of the health biotechnology papers were produced in Sao Paulo. In general, the South East part of the country is very strong in health biotechnology and researchers in Rio de Janeiro, another city in South East Brazil, published 23% of the Brazilian papers. Governments have also promoted clusters of health biotechnology. In Cuba, the government established the West Havana Scientific Pole in the early 1990s that has been very active in this field with almost all (98%) of the Cuban papers being produced in Havana. In South Korea, most of the health biotechnology papers are produced in two cities, Seoul (56%) and Taejon (28%), which incorporates a biocluster in its Daedok Science Town. In India, health biotechnology research seems to be spread more evenly throughout the country. Delhi, with just under a quarter of the Indian papers, and Bangalore, with 10% of the papers, have the highest proportion of the Indian publications. The same applies to South Africa, where the highest activity levels are in Johannesburg with 15% and Cape Town with 14% of health biotechnology papers. In Egypt, Cairo has the highest concentration of health biotechnology papers with over 57% of the papers. There have been attempts to build up a cluster just west of Alexandria, the so-called Mubarak City for Scientific Research and Technology Applications (MUCSAT) but so far Alexandria has less than 13% of the papers in the field.

3.5 Health biotechnology collaboration

3.5.1 International collaboration

To evaluate the extent of international collaboration in health biotechnology research, we examined the proportion of health biotechnology papers produced by researchers in the seven developing countries that had co-authors in other countries. Figure 6 shows the ratio of health biotechnology papers that involve at least one foreign country in their address fields to the total number of papers in the field.

Figure 6 Rate of international collaboration in health biotechnology, 1991–2002



Source: Science-Matrix (data from Science Citation Index Expanded, ©Thomson ISI).

There it can be seen that Egypt is most involved in international collaboration with well over half of its papers produced with external collaborators. India, on the other hand, has the lowest international collaboration rate with around 20% of their papers produced with international co-authors. Furthermore, the international collaboration rate in India remains steady for the whole period. China has a relatively high international collaboration rate but it seems to be diminishing over time. The same applies for Cuba and South Korea. It is of interest to note that at the same time that China and South Korea have emphasised strengthening their health biotechnology sectors and significantly increased their research in this field, they rely less and less on international collaboration. In Cuba, that may also be the case but the financial difficulties following the collapse of the Soviet Union and tightened embargo by the USA may also hinder Cubans from participating in international collaboration. South Africa on the other hand shows a steady increase in international collaboration from the early 1990s, which can be a reflection of the opening up of the country after the abolition of the apartheid regime. Brazil remains fairly heavily involved in international collaboration with around 50% of its papers involving international co-authorship throughout the period.

The main collaborators of the researchers in health biotechnology in the seven countries are listed in Table 2. The USA is the main collaborator of almost every country, which reflects the dominant status of this country in health biotechnology. It is only in Cuba, where the main international collaborators are not from the USA but are rather from Sweden and Spain. Considering that the physical distance between Cuba and the USA is very small, the low collaboration rate is likely to be a direct result of the US embargo imposed on Cuba. The other leading health biotechnology countries are all heavily involved in research collaboration with the seven developing countries we studied. It is notable, how centrally Japan features as a collaborator with researchers in South Korea and China and is their second most common collaborator after the USA.

Table 2 Main countries that collaborate with selected developing countries in health biotechnology, 1991–2002

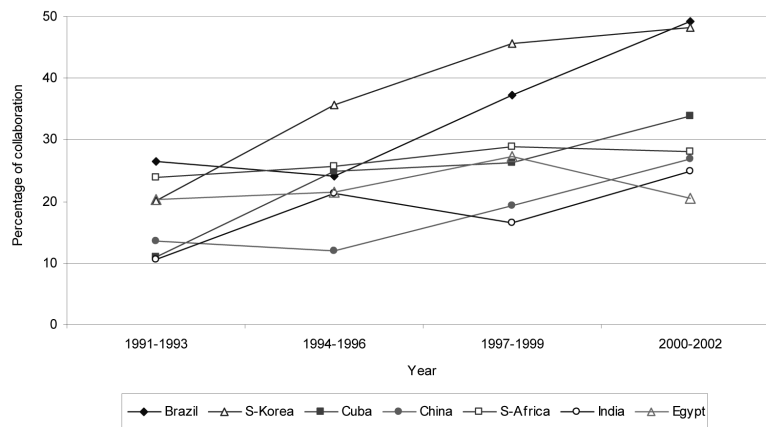
<i>Country</i>	<i>Brazil</i>	<i>China</i>	<i>Cuba</i>	<i>Egypt</i>	<i>India</i>	<i>South Korea</i>	<i>South Africa</i>
USA	46.0%	36.6%	10.3%	60.6%	43.3%	64.9%	43.2%
UK	15.3%	8.8%	7.4%	6.4%	18.8%	3.6%	25.4%
Japan	4.4%	17.5%	0.0%	6.4%	8.3%	20.7%	2.2%
Germany	6.5%	9.1%	13.2%	9.6%	12.6%	4.2%	11.4%
France	11.6%	7.5%	10.3%	5.3%	5.6%	2.0%	10.8%
Canada	4.0%	4.4%	1.5%	1.1%	4.3%	5.4%	4.3%
Australia	3.3%	5.5%	0.0%	0.0%	2.2%	2.8%	4.9%
Italy	4.7%	2.9%	8.8%	4.3%	0.8%	1.0%	5.4%
Sweden	1.8%	3.2%	20.6%	0.0%	2.7%	1.2%	4.9%
The Netherlands	4.2%	1.5%	2.9%	6.4%	2.4%	1.4%	6.5%
Hong Kong	0.0%	9.6%	0.0%	0.0%	0.3%	0.4%	0.0%
Belgium	4.2%	1.0%	0.0%	1.1%	1.6%	0.2%	7.6%
Denmark	1.4%	1.0%	4.4%	1.1%	2.2%	0.6%	3.2%
Spain	2.1%	0.5%	19.1%	1.1%	0.3%	0.2%	1.6%
Switzerland	1.8%	0.6%	0.0%	1.1%	3.0%	0.2%	3.8%
Israel	0.2%	1.3%	1.5%	6.4%	1.3%	0.8%	0.5%
Argentina	3.0%	0.2%	2.9%	0.0%	0.5%	0%	0%
Total collaboration (<i>n</i>)	569	617	68	94	372	498	185

The rest of the countries have a stronger tendency to collaborate with European researchers. Argentina is the only developing country that is amongst the main collaborators of the countries we studied. Both Brazil and Cuba have around 3% of their papers co-authored with Argentinean scientists. That is a relatively low number for intra-regional collaboration and does not signify a vibrant South-to-South collaboration in health biotechnology.

3.5.2 Domestic collaboration

We evaluated domestic collaboration by examining the extent of inter-institutional co-authorship within the countries. To this end, the proportion of health biotechnology papers that had co-authors from more than one domestic institution to all the papers published in health biotechnology in the country were computed. Figure 7 shows the domestic collaboration rates for the seven countries in our study. All the countries except for South Africa and Egypt have increased their domestic collaboration in this field during the study period.

Figure 7 Rate of domestic collaboration in health biotechnology, 1991–2002



Source: Science-Matrix (data from Science Citation Index Expanded, ©Thomson ISI).

Brazil and South Korea have the highest degree of domestic collaboration of the countries we have studied. Brazil shows a steep increase in its collaboration after it initiated policies to encourage domestic collaboration, which included a ‘virtual genomics institute’ that linked genomics researchers across the country. The collaboration between research institutions and universities flourishes in Brazil but linkages with private sector firms are more limited (Ferrer et al., 2004). Cuba shows a steady increase in domestic collaboration during the period. China shows, however, a modest but increasing domestic collaboration. Lack of collaboration amongst Chinese institutions has characterised and limited the growth of the sector in China. For example, China missed the opportunity to be first in the world to map the genomics sequence of the SARS virus due to lack of domestic collaboration (Zhenzhen et al., 2004). Recent years have shown more intensive collaboration in China that can again be linked to governmental policies to increase domestic linkages. Both India and Egypt also have relatively small domestic collaboration in their health biotechnology fields. Egypt’s

limited domestic collaboration is in stark contrast to its extensive international collaboration shown in Figure 6. This paints a picture of Egyptian health biotechnology researchers having limited linkages with each other but relying more on international cooperation to complete their research. This reflects limited resources for health biotechnology in the country, hence Egyptian researchers have to rely on international collaboration to finish research projects but it also reflects a lack of trust between its researchers (Abdelgafar et al., 2004).

3.6 Research focus of the health biotechnology sectors

It is of interest to explore to what extent the countries we are examining focus on local health needs as opposed to the needs of the handful of developed countries that dominate the health biotechnology field. To thoroughly investigate, this relationship would require detailed information on the specific health needs of these countries and their correlation with a keyword analysis of the health biotechnology papers they are publishing. It is beyond the scope of this paper to do such an analysis but an examination of the specialisation indices in the different subfields of health biotechnology can give rough indications of the focus of the health biotechnology sectors. The specialisation index is an indicator that expresses the intensity of research in a specific field that a country publishes in, relative to the intensity of publications in that field by the rest of the world. A specialisation index of 1 means that a country publishes proportionally as much in a specific field as the world does. In Table 3, we present the subfields of health biotechnology that the countries are relatively specialised in.

Table 3 Subfields of health biotechnology with specialisations indices > 1

	Country						
	Brazil	China	Cuba	Egypt	India	South Korea	South Africa
Biochemical and Molecular Biology	1.02						1.12
Biomedical Engineering	1.5	1.8	3.75	2.1	3.2	2.26	3.92
Genetics and Heredity						1.02	
General Biomedical Research		3.3			2.11	1.3	
Immunology			2.05				
Microbiology	1.67			2.51	1.39	2.03	2.44
Miscellaneous Biomedical Research		1			2.27		
Nutrition and Dietition					1.69		
Parasitology	6.69				1.49		
Virology					1.03	2.13	
Dentistry	2.85						
Dermatology and Venereal Diseases					1.53		1.37
Fertility					1.27		
General and Internal Medicine	2.9	4.5	1.99		1.25	1.54	
Ophthalmology					1.95		
Pharmacology		1.9					
Tropical Medicine	11.68	2.2		31.12	2.3		
Veterinary Medicine	1.76				3.3	2.44	

Table 3 reveals that the largest specialisation indices are in tropical medicine. Four of the countries in this study, Egypt, Brazil, India and China, publish proportionally more papers in tropical medicine than other countries in the world do. Tropical medicine is a subfield of health biotechnology that relates to the immediate health needs of developing countries located in the tropics. A relatively large emphasis on tropical medicine suggests that the focus of the health biotechnology sectors in those countries is related to local health needs rather than the needs of industrially advanced countries. Parasitology is another related field that Brazil and India emphasise which relates specifically to developing countries' needs.

It is also noteworthy that all the countries have relatively high publication intensity in biomedical engineering. It is difficult to argue that it is a field that is specifically aligned to health needs in developing countries but it is likely to be a field of importance for developing technology and products based on health biotechnology research. It is worthy of future research to examine if the biomedical engineering sectors in these countries are specifically oriented towards applied problems of their health biotechnology development. Microbiology is also a subfield emphasised by the countries in the study that may or may not be closely related to the health needs in developing countries. Expertise in microbiology is, however, a necessary prerequisite of health biotechnology endeavours so publication intensity in this subfield does not imply that those countries are more focused on needs of developed countries than their own needs. Five of the countries in this study publish relatively intensively in general and internal medicine. The highest specialisation indices of China are in general and internal medicine and general biomedical research. As these fields are very general, it is difficult to determine whether or not the research is especially aligned to Chinese health needs.

The data above suggest that the countries we studied have relatively high publication intensity in the subfields that are likely to be of value for meeting the health needs of their populations. This is encouraging as it increases the likelihood that the countries we studied are able to produce health biotechnology products that are aligned to local health needs. This in turn encourages innovation in the sector as integration with the health system is a source of innovative ideas for the research system (Thorsteinsdóttir et al., 2004b). It is of interest to note that Arunachalam and Gunasekaran (2002a,b) have revealed opposing results from their study on publications from China and India and they argued that there is a gap between the disease burden and the share of research performed in these countries. They did not examine health biotechnology per se but rather research on specific diseases such as tuberculosis and diabetes. Arunachalam and Gunasekaran did not use the same approach as the current study of calculating specialisation indices but they mapped the research efforts by using various approaches such as proportion of these countries' contribution to the world research on these diseases and calculated the ratio of research (in papers) versus the prevalence of diseases. It would be of interest to carry out further research to see if differences between the findings of the research reported here and the previous research on disease burden and share of research efforts in China and India is due to health biotechnology being more aligned to the health needs in these countries than research more generally on prevalent diseases or is due to the different approaches being used in these various studies. More detailed research is, therefore needed to confirm the results that the focus of the research in health biotechnology is aligned with local health needs.

4 Conclusions

This analysis demonstrates, firstly, that there is a significant growth in developing countries in the health biotechnology sector. All the countries we studied have considerably increased their levels of publishing in health biotechnology. Furthermore, most of these countries have much larger growth rates in the field than industrially advanced countries, which indicates that the gap between these developing countries and the leading countries in the field is diminishing, even though for most of the countries in this study the gap is still substantial. As we chose countries that have demonstrated some successes in this sector, the results cannot be generalised to all developing countries. The countries we focused on have placed emphasis on building up capacity in the field with governments setting up programmes and allocating funding to support health biotechnology research. These investments are paying off in terms of increased scientific output in the field. A heavy investment by a latecomer such as South Korea seems to be quickly reflected in a steep increase in papers in the field. The increase has been so fast that South Korea already publishes more papers than a small industrialised country such as Denmark.

Secondly, this study shows that despite an impressive increase in the number of papers that these countries publish, they do not seem to be much noted by the international scientific community: all of the countries we studied have ARC rates well below the world average citation rate in health biotechnology. Even active knowledge producers in this field such as China, India and South Korea are not cited frequently. Research on science in general has indicated that citations of research from China and South Korea are, however, increasing at an impressive rate (King, 2004; Zhou and Leydesdorff, 2005). Further research could gauge whether citations to health biotechnology research is generally increasing in developing countries. It is also important to stress that researchers in developing countries need to publish in high impact journals in order to increase citations and visibility of their research.

Thirdly, this paper shows that universities are predominantly the strongest producers of health biotechnology papers in the countries we studied. This is, however, not a universal rule and both Cuba and India had strong public sector research carried out in specific research institutes. Case studies have shown that both of these countries have successful health biotechnology sectors that have produced relatively affordable health products for their populations (Kumar et al., 2004; Thorsteinsdóttir et al., 2004b). Further research would be of interest to examine what is the more promising strategy in developing countries to structure their public sector health biotechnology research around universities or public research institutes. This research should gain insights into the factors and conditions that shape the successes of these strategies.

The fourth main finding of this study is that the health biotechnology sectors in all the countries studied are characterised by high rates of collaborations. Most of the countries, we studied were shown to have increased domestic collaboration between their institutions. It is important for knowledge flow in the innovation system to have a close domestic collaboration and this is likely to strengthen the innovation potentials of these countries. The countries we studied have also relatively high international collaboration rates and as a result are not likely to be isolated in their fields. In order to increase the impact of the health biotechnology research in developing countries and to encourage that the knowledge to be put to use where needed, it would be advisable that developing countries increase the levels of collaboration amongst themselves, that is, South-to-South

collaboration. We are not recommending that they replace North-to-South collaboration with South-to-South collaborations, as both types are likely to be of value to these countries. But developing countries often share common interests in this field as they frequently have similar health research needs. Malaria is, for example, not a disease in temperate climates anymore but is common in many developing countries. HIV-1-C Subtype is also a much more common strain of HIV/AIDS in developing countries than in industrialised countries. Preventative healthcare strategies are also commonly relied upon in developing countries, as prevention is typically more cost effective than therapeutics. This calls, for example, for a shared emphasis on vaccine research. To join efforts in different countries could push forward solutions to these persistent problems. South-to-South collaboration could, therefore, both be beneficial for nations' health biotechnology development and also increase the impact of their research.

Finally, this study highlights that the research in health biotechnology in the countries we studied has relatively high publication intensity in subfields that are likely to be of value for meeting the health needs of the populations in developing countries. Thus research efforts seem to be focused on areas needed for addressing local health problems which increases the likelihood that the research will encourage innovative solutions to their problems as integration with a health system has been suggested to be a source of innovative ideas for the research system (Thorsteinsdóttir et al., 2004b). There is, however, need to carry out more detailed research on how well developing countries' health research in general is aligned to local health needs as previous studies and common perceptions suggest the opposite (Arunachalam and Gunasekaran, 2002a,b; CHRD, 1990; WHO, 1996). This can have important implications for developing countries. If proven to be the case that their research is focused on local health needs, a promising strategy both of local governments in developing countries and of international organisations is to support health research both by and for developing countries researchers to increase global health equity.

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Note

- ¹The keywords were selected as follows: first papers were randomly selected from journals specialised in biotechnology; keywords and keyword combinations were then chosen from the titles of these papers in order to retrieve other papers in the field of biotechnology. Afterwards, the biotechnology keyword set was validated using the SCI Expanded database with a goal of selecting papers specific to the domain of health biotechnology.