Science for Local Needs?
Research and Policy Implications of National and International Malaria Efforts

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Abstract

Countries are unlikely to solve a particular problem unless they have some level of research invested in the effort. The approach in this paper is to use malaria research as a proxy for effective exploitation of local scientific knowledge. We study the malaria-related research output in two countries, Brazil and India, with among the most advanced science and pharmaceutical capabilities in the developing world. We assess local relevance of science and also its integration with international research by looking at almost 60 years of scientific publications on malaria between 1945-2003. While scientific publications are only one measure of scientific output, they are an important one. This research confirms previous findings of underrepresentation of developing countries in international science and its databases. In addition, we use a variety of indicators to demonstrate that while both countries together show substantial scientific output relative to their combined global share of malaria incidence, each shows low local relevance of malaria-related science using country and journal comparisons, relatively low rates of increase in published outputs and insignificant private sector effort. Finally, both show practically no collaboration with each other, while each is more likely to collaborate with a few advanced industrialised countries. The findings raise questions for both national and international scientific programs aimed at stimulating research for malaria and other neglected diseases.

Keywords:

Brazil, India, Research and Development (R&D), malaria, neglected diseases, science policy

JEL: O31, O32, O38, L65
JPL: 22-1, 16-1, 14-7

Introduction

How relevant is local science for local needs? The tropical disease burden worldwide is immense. Annual malaria morbidity alone is 300-500 million people and has a conservative mortality estimate of 700,000- 2.7 million lives. It affects over 40% of the world's population and over 75% of the mortality figures are from deaths of African children alone. (MIM, 2001) Brazil and India are two of the remaining nine countries outside sub-Saharan Africa where the incidence of malaria is high. The two countries combined have 9.37% of total world malaria cases (25,195,018) in 2001, Brazil with 1.54% and India with 7.83% (WHO Global Atlas for Infectious Diseases). In Brazil, although malaria incidence is low compared to India, it continues to be a sizeable problem in absolute figures, since the estimated number of malaria cases in 2001 was 338,658, a considerable increase in relation to the estimated 50,000 cases in 1970 (Cavasini et al. 2000; WHO Global Atlas for Infectious Diseases).

In India, a significant population, 973.1 million in 2000, was vulnerable in so-called malarious areas, with 20,000 estimated deaths and 1,971,586 estimated cases in 2001, with P. Falciparum being responsible for a great proportion of these cases (WHO, 2003; WHO Global Atlas for Infectious Diseases). Besides the immense misery through high morbidity and mortality alike that malaria brings about, it's economic burden is equally huge. An intricate cause-effect relationship between poor health and economic growth is now documented. Studies suggest that countries with large malaria burdens are poorer, grow at a much-reduced rate relative to those without malaria, and upon malaria eradication, economic growth appears to accelerate substantially Per capita income growth from 1965 to 1990 for countries with severe malaria transmission was 0.4% per year, while corresponding growth for countries with fewer malaria infections was more than 5 times higher, at 2.3% per year.(Gallup and Sachs, 2001, MIM, 2001). Despite its obvious negative impact, to say that malaria is difficult to eradicate is an understatement, in part because insecticide-resistant mosquitoes and drug-resistant parasites have caused a diminishing number of methods to be available and diffusion of existing technologies is challenging for various institutional reasons. Correspondingly, many international initiatives have been launched, for example, the Multilateral Malaria Initiative (MIM), focused on international scientific collaborations, and The "Roll Back Malaria" initiative at the World Health Organization (WHO), launched in May 1998, targeting a 50% reduction in malaria deaths by 2010 and various vaccine-targeting initiatives.

How can these diseases, which overburden many developing countries, be dealt with? How can local scientific research investments be exploited for these local needs? There has been a significant rise in the profile of development of drugs and vaccines for neglected disease research in the past 10 years. Notable contributions have called for reform in how this development is conducted and draw from the logic that more R&D is needed for such diseases (for example, Mrazek and Mossialos, 2003), that better managed public-private partnerships are needed (Widdus, 2003 and Ridley, 2001 and others) or that more funding is necessary (Lewison, Lipworth, de Francisco, 2002, for example). There is an acknowledgement that gaps exist between research and products. Undoubtedly both are required. However, we need more studies that assess local knowledge acquisition and existing research efforts of leading developing countries to address local diseases. Some studies have focused on indigenous capabilities in the private sector of developing countries for neglected diseases (Kettler and Modi, 2001, Cockburn and Henderson, 2001). Disparity in published outputs from developing

countries have been addressed before, aggregated into 'neglected diseases' or 'tropical medicine' (see most recently, Keiser et al. 2004) or even in malaria research (Wellcome Trust, 1996).

However, to link research output to S&T policy choices, this paper returns the attention of the reader to assessing past scientific investments by developing countries for studying malaria, through both public and private organizations. The approach is to use malaria research as a proxy for effective use of local scientific and technological efforts. Malaria calls for a variety of strategies, from bed nets to vaccines, from draining stagnant water to insecticides and many of these strategies work together. In general, countries are unlikely to create products for malaria unless they have some level of research invested in the effort. Moreover, when international efforts are underway to tackle diseases with local relevance, the level of integration of local science with this international research also contributes to its local relevance. Clearly countries which are affected by malaria must also have some local research strategies to cope with this disease.

This paper assesses efforts invested in local strategies along two dimensions: (a) scientific output and (b) international research engagement. Moreover, countries which have scientific capabilities may not always be able to translate these into product development capabilities. By addressing a single disease and two specific countries, we are able to assess to some extent the intensity and type of output arising from leading developing countries. This allows more specific research and policy responses both for national S&T and health policies as well as international malaria research efforts.

Assessing local relevance:

In both countries, past industrial policies have dictated to some degree the nature of innovation and the institutions that invest in these capabilities. Furthermore, geography also influences scientific and technological capabilities (de Solla Price, 1966; Coe and Helpman, 1995), life science and pharmaceutical priorities and production output (Mariani, 2000). Both countries have also invested public and some private efforts in pharmaceutical research and production (For recent analyses on the two countries studied here, see de Hasenclever et al., 2002; Fialho et al., 2003 on Brazil and Ramani, 2002, Srinivas, 2004 on India). Since knowledge production is concentrated in developed countries, it would be important that these countries be engaged in international collaboration. But as observed in other studies, knowledge production is highly influenced by geographical proximity, and this is also observed in respect to collaboration among researchers located in Brazil or India and researchers located in foreign countries. Collaborations, when they exist, is generally north-south collaboration, but since these two countries are among those developing countries with greater scientific and technological capabilities, south-south collaboration should be also stimulated. Our research is guided by the following hypothesis, which is tested:

Since tropical research has been an important framework upon which research institutes in Brazil and India have been built; those countries would be more involved in scientific research relevant to local needs compared to countries with less of a tropical disease burden.

Methdology

Since scientific capabilities evolve over time, we studied a longitudinal sample of publication (article) data from both countries from 1945 to 2003, almost 60 years of scientific articles in peer-reviewed journals.

Different measures have been used to characterize technological efforts such as public and private expenses in research and development, scientific and technological infra-structure in universities and research institutes; number of patent applications and patent grants; number of scientists and engineers (OECD, 1996).We argue that patent studies are highly limiting and have been fuelled in large part because of attempts to homogenize intellectual property regimes through initiatives such as the World Trade Organization's TRIPS. Patents cannot capture scientific capabilities accurately at the best of times, and certainly when significant gaps in commercialization exist. Furthermore, institutionally, both countries have used patents sparingly, showing the uneven geographic utility of such indicators.

Besides, such measures pose several limitations especially for developing countries since they imply that low indicators equal little or no knowledge production in those countries, which we know not to be the case from other studies and methods. Therefore, other measures are necessary not only to analyze the relative participation of developing countries but also to explain performance which certain quantitative measures may hide. Among the alternative measures would be the number of papers published in peer-reviewed scientific journals (so called bibliometric indicators) as well as qualitative analysis of interactions among universities and industry.[1]

National scientific output can be measured in large part by articles published. While this is not the only measure of scientific effort, it is an important one, particularly in a field with so international a face and a wide variety of publishing countries. Certainly, developing countries face particular disadvantages in publishing which are well known, some of which are availability of laboratory materials, quality inconsistencies in inputs and outputs, and the need for expensive equipment, and the language barrier since most international journals are published in English. It is also important to observe that health research spending is concentrated in developed countries, and that developing countries face great obstacles in draining scarce financial resources to science and technology efforts, which has been mainly accomplished in public funded institutions. Nevertheless, leading malaria laboratories in both countries are not without resources, due to specific and historical reasons[2]. Scientific articles of course, only test newer advances, and do not assess the extent to which the country might already be utilizing older methods for eradication/prevention of malaria, specially those related to traditional knowledge and concerning sanitation and behavioral practices.

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[1] For an appraisal of caveats in science and technology indicators, especially bibliometric studies see Leydesdorff (1991) and Okubo (1997).

[2] For example, in Brazil, Fundação Oswaldo Cruz is one of the most important health research institutions, founded in the early twentieth century and has focused on tropical diseases since its inception. The Malaria Research Centre (MRC), established in 1977 and the National Institute of Communicable Diseases.in New Delhi, fulfil a similar role. Also prominent since the 1980s is the International Centre for Genetic Engineering and Biotechnology (ICGEB) established by UNIDO.

In order to test the hypothesis above, we searched articles related to malaria research using the Science Citation Index. The Science Citation Index was chose basically because it covers scientific journals that are considered as influential by the scientific community; and it is available on-line. Nevertheless, the SCI has limitations common to other bibliometric databases. One of these limitations is related to the "citation" criteria to select the journals covered by the SCI. Such criteria does not take into account that the there are no *a priori* explanation for the behavior of scientist to cite each other, and this may not necessarily be correlated to originality, importance or quality. Thus the number of citations depends on how many readers can a paper be exposed to, sometimes because of the "authority argument" in order to support citing eminent scientists[3]. Another important aspect is that citations can be positive or negative, and bibliometric databases do not make any distinction between these two. There are also other limitations regarding "self-citation" and that a large number of papers are "uncited" for several reasons. Another limitation of the SCI is related to the problem of language since most SCI journals are in English, and thus non-English speaking authors may be underrepresented and less likely to be cited, relative to databases such as Medline.[4] In fact, there is evidence that Indian journals have seen a decline in SCI in number as well from 36 in 1980 to 10 in 2000 (Gupta and Garg, 2002) [5]In addition, it has been observed that in the SCI some disciplines (chemistry, physics and biomedicine) are better represented in relation to others (geosciences, biological field research, engineering and technology, mathematics and, to a certain extent, clinical medicine).[6]

Despite these limitations, this database is a publicly available source covering a large number of international journals, edited in many different countries, although English speaking countries account for the majority of them. And, however controversial, this might be, the scientific community is mostly evaluated by number of papers published in international indexed journals, like those covered by the SCI. It is important to observe also that we are not making any inference on quality of work or the effectiveness of the outputs on mitigation of malaria.

We used a five-step process:

1. First, we used a set of keyword searches in all journals of the SCI;
2. Second, we used communications with experts and secondary data to isolate a set of leading journals in the field;
3. Third, we identified all authors and locations and created a tag for whether the paper was written in collaboration and if so, with whom ("south" or "north");
4. Fourth, we tagged public domain and private, for-profit research organisations in each of the two countries;

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[3] Some papers must be cited frequently if they refers to a specific method (Okubo, 1997).

[4] This problem may be even greater in certain fields of science (Okubo, 1997). However, Medline has its own limitations, such as only listing the address of the first author which would have severely limited the scope the study.

[5] Although this decline of domestic journals in international databases itself is an issue that affects malaria (and other) research, we do not explore it here. Efforts such as IndMED, a database to include many peer-reviewed Indian biomedical journals not covered in MEDLINE, deserve further study.

[6] The most likely explanation would be that in certain disciplines communication is concentrated in a few core specialised international journals and that certain journals have a narrower "influence" (Okubo, 1997).

5. Fifth, we characterised a Rest of World (RoW) profile, for all countries excluding Brazil and India. We did this last step for, for all scientific publications, those for malaria, as well as those within the leading tropical disease journals and those within leading malaria journals. We describe the main steps below.

In order to assess the relative share of Brazilian and Indian efforts in malarial research we compiled data retrieved from the Science Citation Index from 1945 to 2003, where 1945 represents the start of database records. We used the key words "malaria*", "plasmodium falciparum" "anoph*", as representative key words according to specialists and other studies[7], and tracked authors whose address is India or Brazil at the time of writing or publishing.[8] P. malariae is selected for under malaria*. Although four types of potential plasmodia might appear to be relevant keyword searches in themselves: *Plasmodium falciparum, Plasmodium vivax, Plasmodium ovale and Plasmodium malaria*, and two types of mosquitoes, Anopheles and Culex, the search was conducted using the word malaria* which should represent all articles with any pertinence to this subject, the root and strings. The additional "OR" Boolean keyword choices of falciparum and anoph* (and related strings) were to cover all other possibilities.

It is important to observe that the address informed in the SCI is not necessarily referred to the author's nationality, so that articles whose authors informed India or Brazil in their addresses are not necessarily Brazilian or Indian citizens. Since citations alone do not necessarily indicate relevance of scientific production, we used the number of articles as an indicator of scientific output. This relative simplified measure can be a proxy of the quantity of work produced either by a given scientist, research group, university, institute, company or country. In our case we decided to focus on the country level. Since we used key words as search method, the number of journals in which those articles were published was very high, and due to limitation of resources available for this research, we were not able to distinguish whether a given journal was most likely to publish "basic" research findings or "applied" research results. Besides, categorization articles and scientific and technology efforts as basic or applied is itself a problem. The longitudinal sample here is large, with almost 60 years of data tracked. It is important to observe that our results make no distinction about participation or relative importance of author and co-authors, since this is difficult to address and is immaterial to our hypotheses.

Scientific articles can also provide some measure of private sector efforts. They do not reflect attempts to produce or use more mature techniques for prevention/eradication such as antimalarials or insecticide production, but are intended to capture scientific research in diverse areas such as gene sequencing, vaccines, diffusion/diffusion studies, demographic variations

[7] Experts on malaria, lifescience and pharmaceutical capabilities were contacted for discussions while a list of relevant ournals was drawn up. The lists of leading journals used were also compared to journal lists appearing as outputs from leading malaria researchers and institutes worldwide. We also used comparable recent studies to whet the journals.

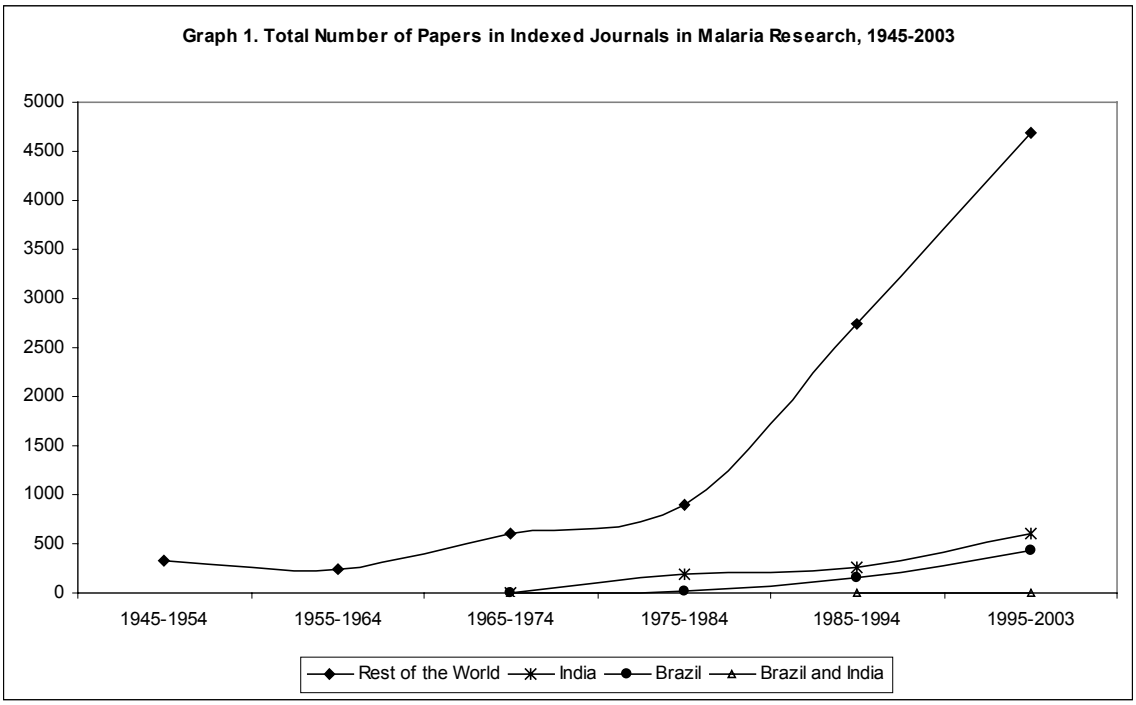
[8] Additonal searches with the keyword "falciparum", yielded a 0.48% difference. We excluded this because of low statistical relevance.

etc. that may have potential profitability. They may also capture efforts to put mature technologies to novel use or test them under different models.[9]

Overall, we use the following indicators of local effort and to test relevance: (a) total percentage output of both countries' malaria-related articles relative to their total fraction of global malaria incidence and the rates of increase of this output (b) percentage of malaria output relative to total scientific output of India and Brazil compared to the rest of the world (RoW) (c) relative output in leading scientific journals publishing on malaria research (d) relative outputs in journals with higher numbers of malaria-related articles (e) share of malaria-related papers in tropical research journals in terms of world publication and the two-case countries.

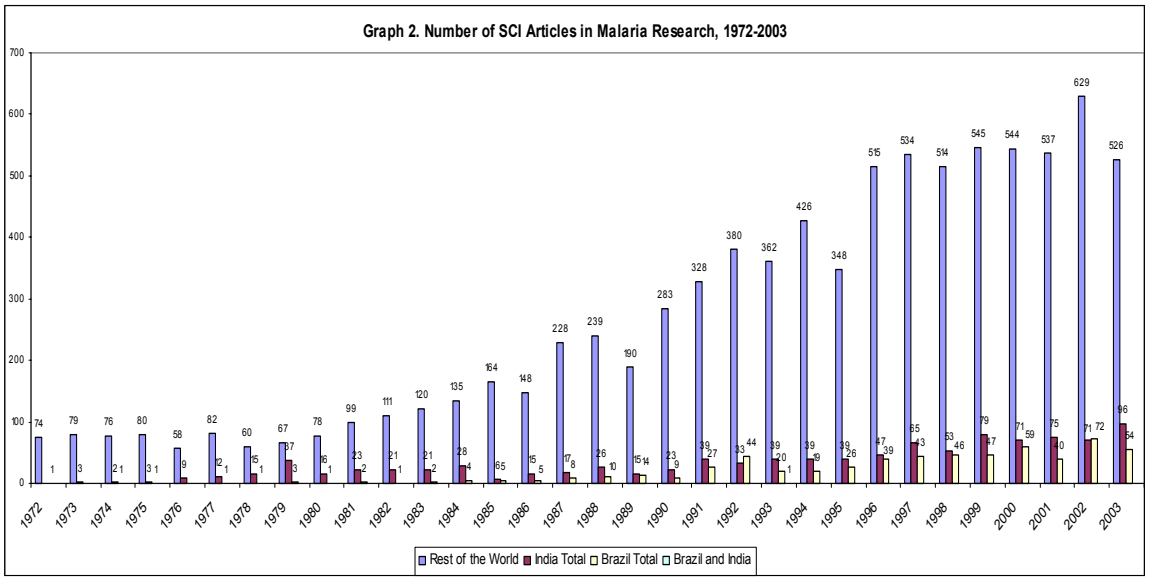
Findings

From 1945 to 2003 we found more than 11,000 papers written on malaria, however neither of our two case countries has any publications until 1972 and show a total of 1,644 articles (~16%) . In addition, as the graph below shows, both countries experienced a much smaller rate of increase of malaria-related publications compared to the rest of the world, most significantly represented by the advanced industrialized countries.

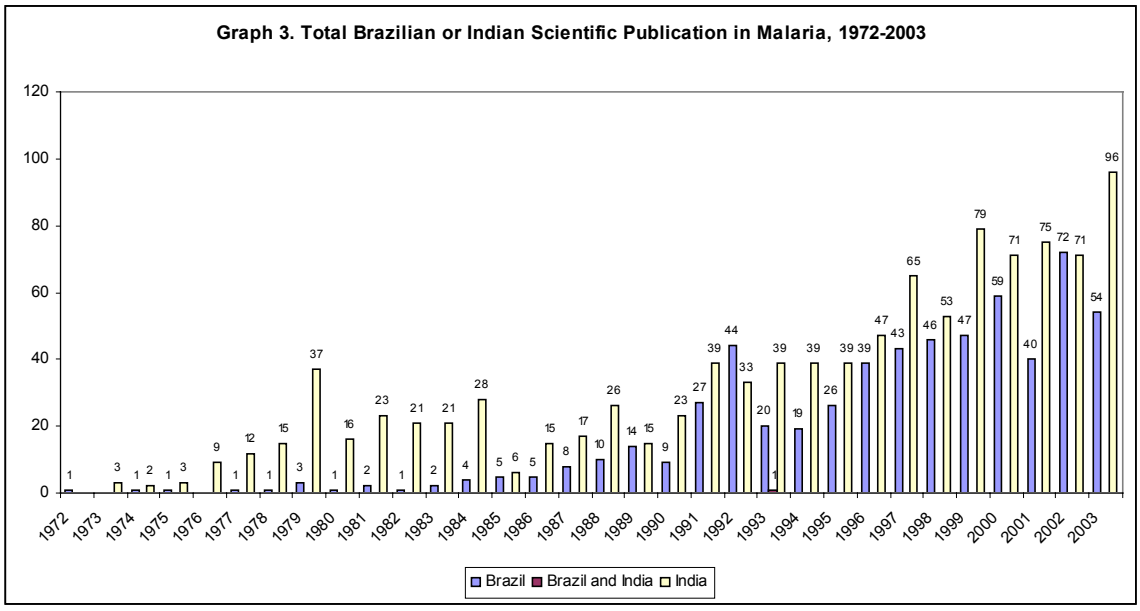


Between, 1972 and 2003, we found 10,203 articles (91.15% of the total), of which 1,644 were written by researchers located either in India or Brazil: 1,038 by researchers located in India, 605 by researchers located in Brazil, and 1 by researchers located in Brazil and India.

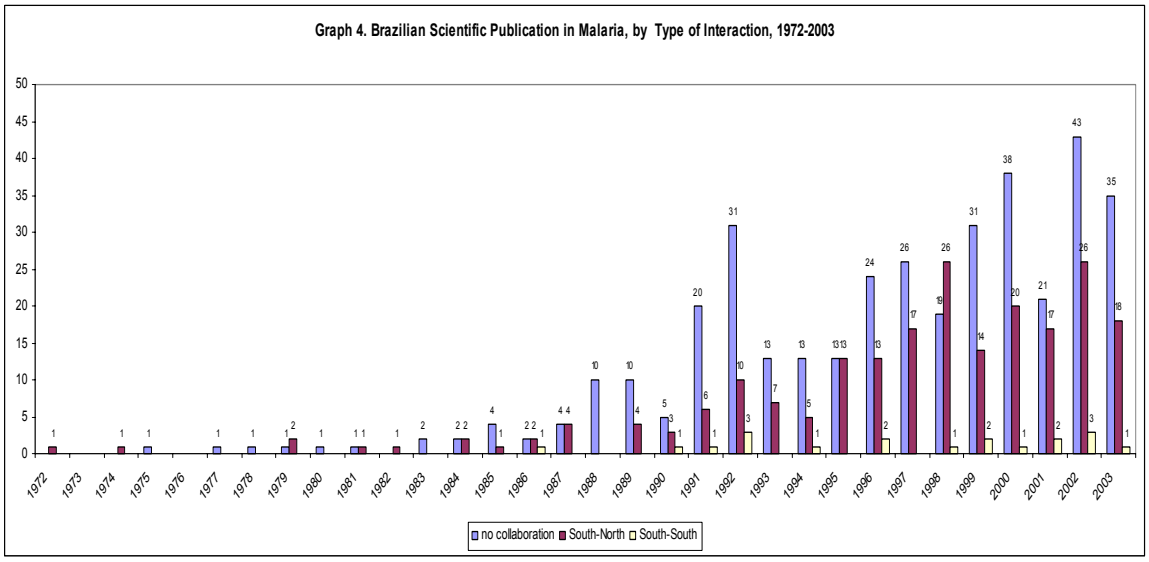
[9] Note that a different methodology would be needed to test the link between scientific output and private money invested in the malaria effort. Our aim is simply to show the presence, if any, of private actors as part of the national effort to address the malaria challenge.



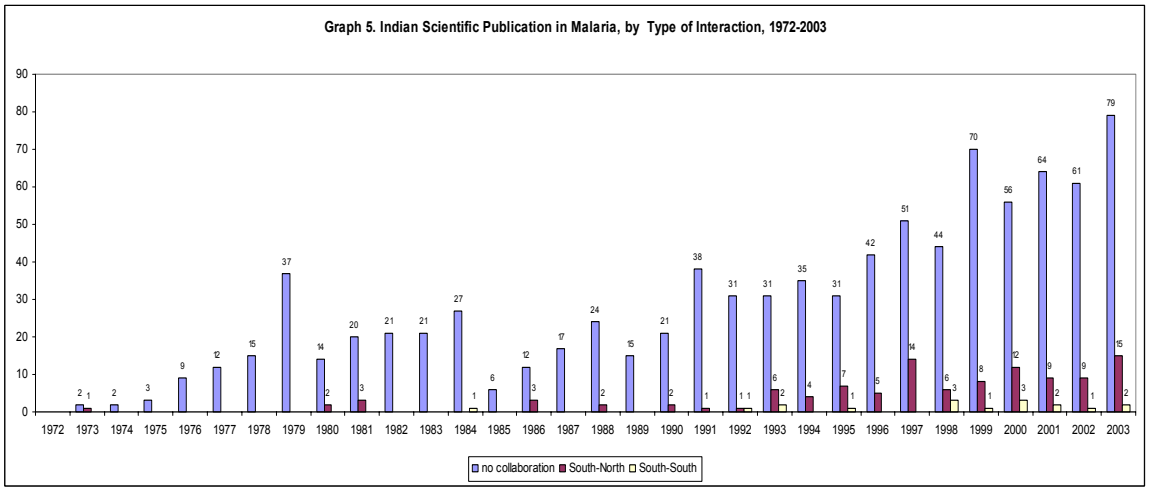
In respect to patterns of interaction of the "Brazilian" and "Indian" articles we observed that most articles were produced through collaboration among researchers within these countries, 911 from authors located in India, 372 from authors located in Brazil. Only 360 involved partnerships with researchers located in other countries, 127 between authors located in India and in other countries, 233 between authors located in Brazil and in other countries, and, as already mentioned, 1 with authors located in India, Brazil and the United States.



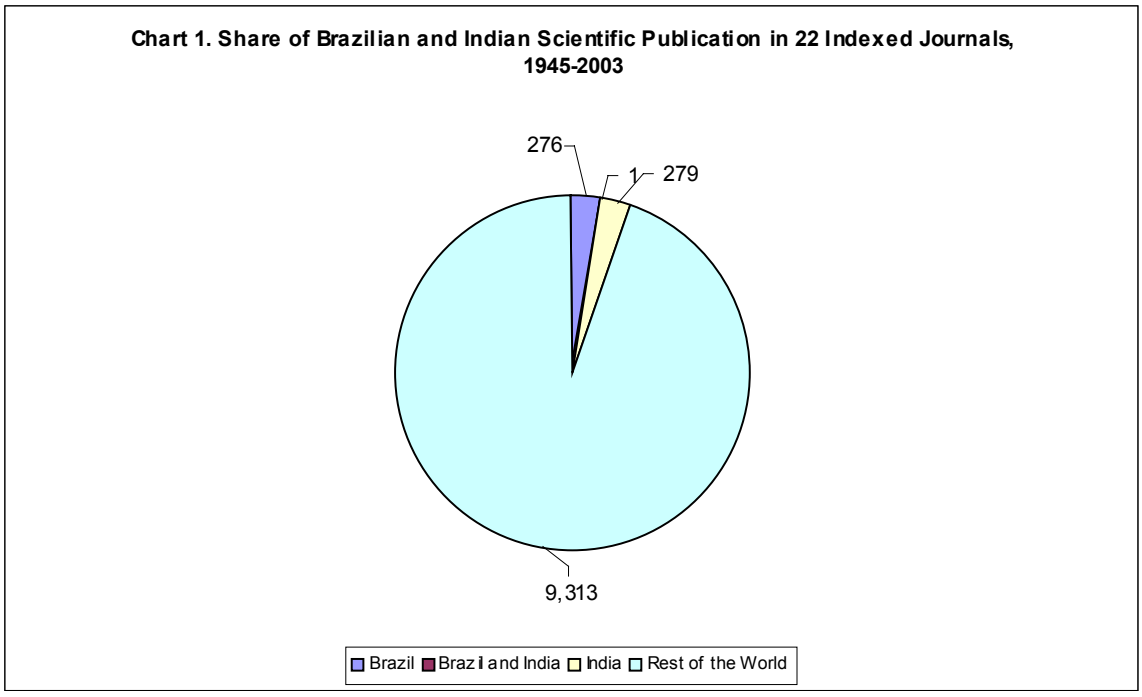
We also looked for the pattern of interaction in terms of south-south and north-south collaboration. In this regard, both India and Brazil interact more with "northern" researchers than with "southern" researchers. But as we observed from the graphs below, Brazil interacts more with "southern" researchers than India.



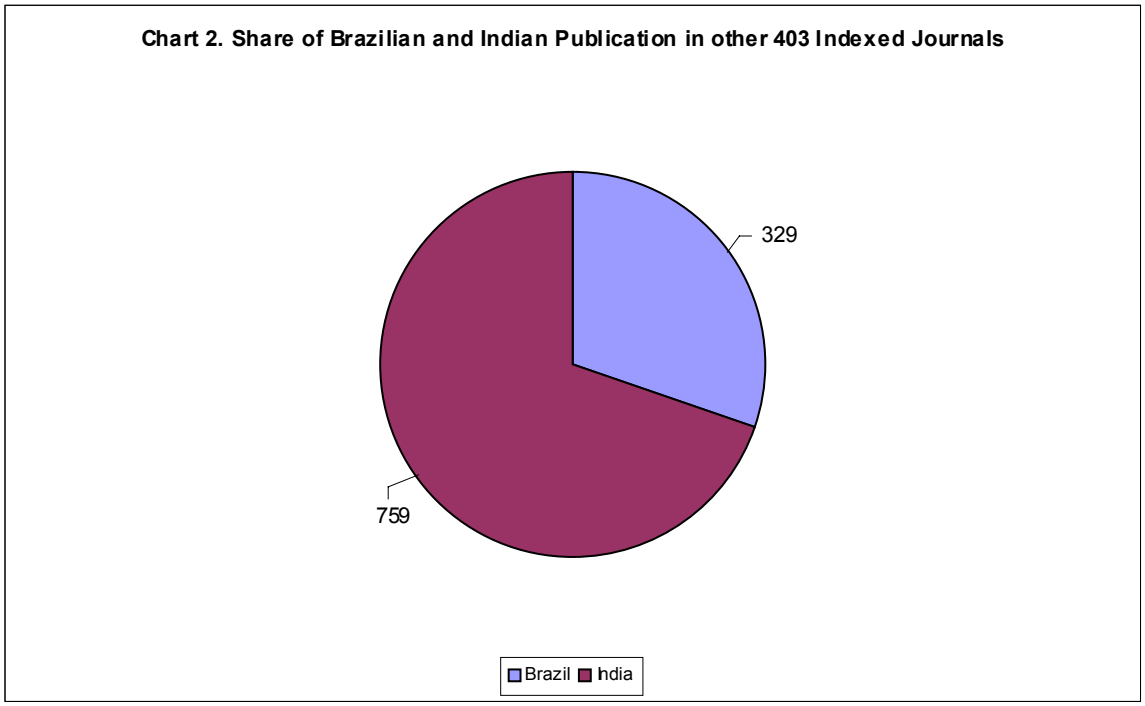
Another interesting result is that in the case of relative share of number of articles without collaboration and number of articles indicating collaboration, Indian authors seem to be less collaborative than Brazilian authors.



In addition, in order to assess the relative share of India and Brazil in the world scientific context in malaria research we counted the total number of articles published in the main international indexed journals reviewed by specialists we contacted. This list comprises a total of 22 journals with 9,869 articles (88.53% of the total 11.148 articles found) published by authors from all countries (including India and Brazil) between 1945-2003.



Besides the "leading" 22 journals, we also studied Brazilian and Indian articles published in 403 other journals, in which we found 1,279 articles related to malaria between 1972-2003, of which 759 were published by researchers located in India, 329 by researchers located in Brazil.



Other studies have shown that India had the 5th highest number of malaria publications worldwide between 1984 and 1994, for 3 sample years[10] (Wellcome Trust, 1996). However, our data shows that this number is less promising if one assigns relative weights to the journals where more and less malaria articles appear. This is an area for further research.

The table below indicates a 30-year representation of these two countries for malaria publications in terms of a leading set of 22 international journals from 1945 to 2003.

Table 1. Top International Indexed Journals in terms of the RoW Scientific Output on malaria, , 1945-2003

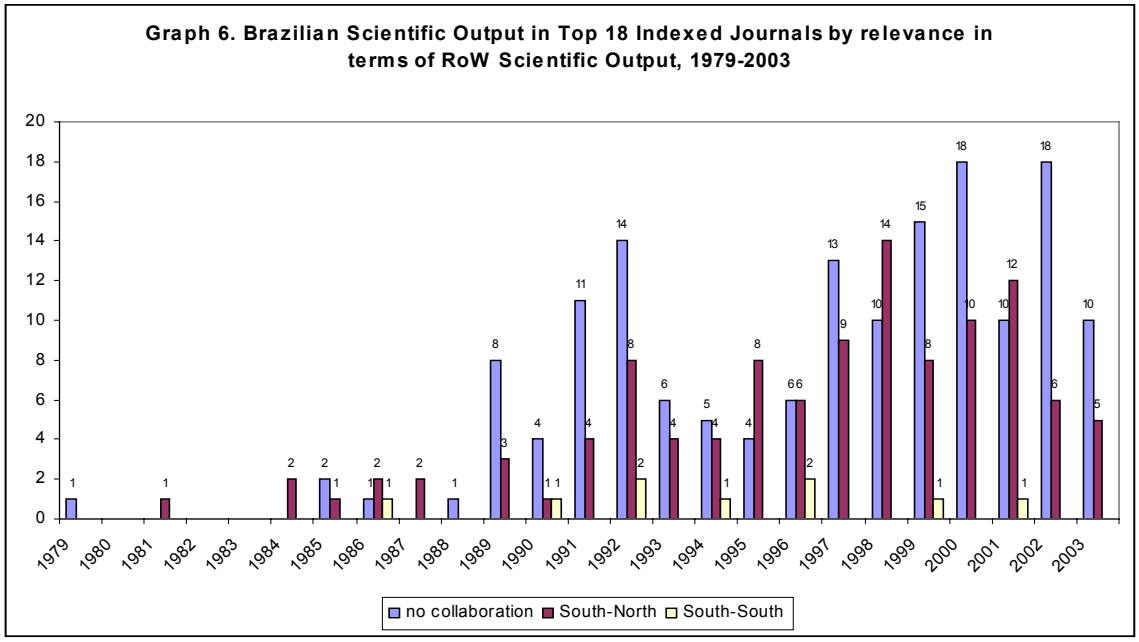
Journal Title	Total Journal	RoW	RoW (% of Total Journal)	India or Brazil Total	India or Brazil (% of Total Journal)
Acta Tropica	242	218	90.08	24	9.92
American Journal of Tropical Medicine and Hygiene	1,718	1,642	95.58	76	4.42
Annals of Tropical Medicine and Parasitology	687	634	92.29	53	7.71
British Medical Journal	189	187	98.94	2	1.06
Bulletin of the World Health Organization	492	480	97.56	12	2.44
Experimental Parasitology	509	482	94.70	27	5.30
Infection and Immunity	593	569	95.95	24	4.05
International Journal for Parasitology	200	188	94.00	12	6.00
Journal of Biological Chemistry	263	247	93.92	16	6.08
Journal of Infectious Diseases	280	270	96.43	10	3.57
Journal of Medical Entomology	334	316	94.61	18	5.39
Journal of the American Mosquito Control Association	403	357	88.59	46	11.41
Journal of Tropical Medicine and Hygiene	205	194	94.63	11	5.37
Medical and Veterinary Entomology	237	223	94.09	14	5.91
Memorias do Instituto Oswaldo Cruz	202	116	57.43	86	42.57
Molecular and Biochemical Parasitology	954	914	95.81	40	4.19
Nature	201	198	98.51	3	1.49
Parasite Immunology	213	202	94.84	11	5.16
Science	185	181	97.84	4	2.16
Transactions of the Royal Society of Tropical Medicine and Hygiene	1,252	1,210	96.65	42	3.35
Tropical Medicine & International Health	339	325	95.87	14	4.13
Vaccine	171	160	93.57	11	6.43
Top International Journals	9,869	9,313	94.37	556	5.63

Relative to the RoW, Brazilian or Indian articles comprise on average less than 6% of the total, ranging from 1% to 43% in the unusual case of the journal, *Memorias do Instituto Oswaldo Cruz*, published in Brazil. But it is worth noting that in *Acta Tropica*, the two countries jointly comprise almost 10% of total output. The product-oriented vaccine research in *Vaccine* shows 6.4% from the two countries. This may indicate that both are directing part of their scientific efforts to more applied research, a worthwhile endeavor given their pharmaceutical capabilities. But how far this knowledge is being transferred or used by domestic companies for product development is doubtful since these companies invest very little in R&D, and neglected diseases are less likely to attract overall pharmaceutical R&D investments.

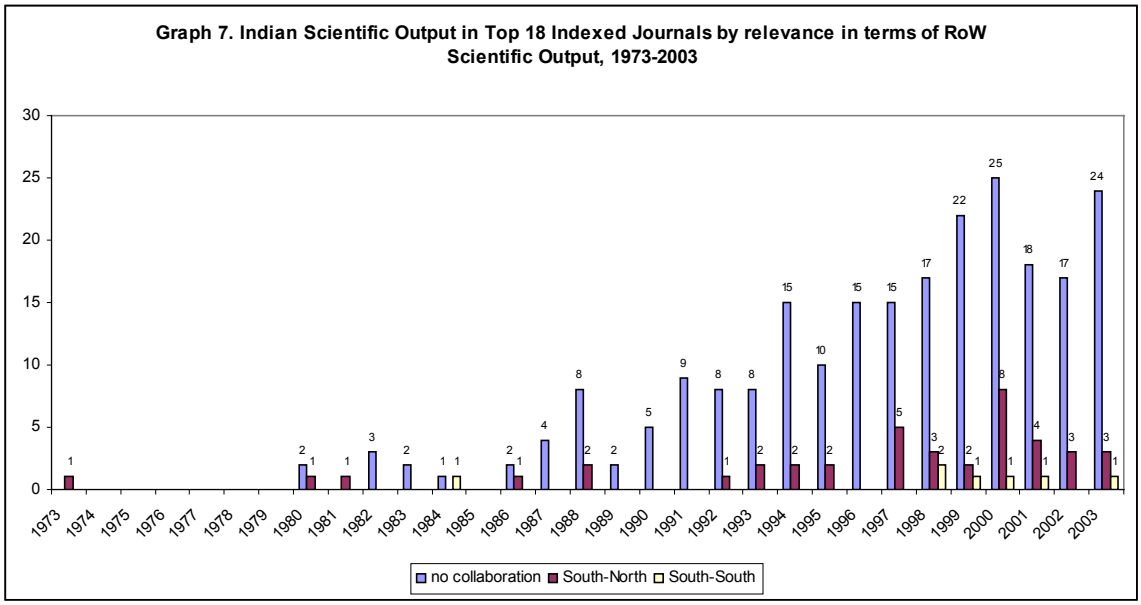
To study the extent of Brazilian and Indian science with international research relevant to local needs, we then studied the integration with international research, which is indicated in the graph below. To do this, we used 425 journals with any mention within articles, of Brazilian or Indian address, to conduct the search. With respect to the relative share of "Brazilian" articles in terms of "rest of the world" publication in the 22 specialist-indicated "lead" journal list, we

[10] A different measure of publications was used for that study: articles, notes and reviews. We consider articles to represent the most consistent form of novelty relative to the other two types, even if every article considered is not truly novel. The more encouraging numbers for publications from India, Thailand and Kenya, the 3 developing countries in the leading ten elsewhere over a more limited perriod may emanate from this difference.

found 187 articles (31% of total "Brazilian" articles), of which 93 (50%) did not involve collaboration and 94 (51%) involved collaboration with foreign authors, 86 was a "south-north" collaboration (46%) and only 8 was a "south-south" collaboration (5%).



In the case of India, we found 257 articles (25 % of total "Indian" articles), of which 215 (84%) did not involve collaboration with authors located in other countries, and 42 (16%) involved collaboration with authors located in other countries, 35(14%) papers "south-north" collaboration and 7 (2%) papers "south-south" collaboration.



In addition to the 22 journals with higher percentages of Brazilian and Indian malaria publications, we provide a contrast between malaria and tropical disease journals by using the journal list for tropical diseases from Keiser et al. (2004). Data from 1945-2003 is analyzed and shown in the table below. Within these, if we study publications relevant to malaria, we see that for the leading tropical disease journals there are comparable figures relative to the previous table of 9.9% from India and Brazil and 7.7% in *Annals of Tropical Medicine and Parasitology.* The table also shows an expected high percentage in *Memorias do Instituto Oswaldo Cruz.* Four other journals, *Annals of Tropical Paediatrics, Journal of Tropical Pediatrics and Leprosy Review* and *Tropical Doctor* show particularly high percentages from India and Brazil and these two countries alone contribute the very small number of malaria-related publications in these journals.

Table 2. Top International Indexed Journals in Tropical Medicine Research, 1945-2003

	Rest of the World				Brazil or India			
Journal Title	Total	% World Total	Malaria	% Malaria Total by Journal	Total	% World Total	Malaria	% Malaria Total by Journal
Acta Tropica	1,466	87.89	218	90.08	202	12.11	24	9.92
American Journal of Tropical Medicine and Hygiene	8,453	94.13	1,642	95.58	527	5.87	76	4.42
Annals of Tropical Medicine and Parasitology	3,268	93.13	634	92.29	241	6.87	53	7.71
Annals of Tropical Paediatrics	911	88.53	-	-	118	11.47	4	100
Journal of Tropical Pediatrics	1,078	68.27	-	-	501	31.73	1	100
Leprosy Review	707	68.38	-	-	327	31.62	1	100
Memorias do Instituto Oswaldo Cruz	900	33.15	116	57.43	1815	66.85	86	42.57
Transactions of the Royal Society of Tropical Medicine and Hygiene	5,350	91.03	1,210	96.65	527	8.97	42	3.35
Tropical Doctor	1,292	85.56	-	-	218	14.44	3	100
Tropical Medicine & International Health	1,008	90.81	325	95.87	102	9.19	14	4.13
Grand Total	2,4433	84.22	4,145	93.17	4578	15.78	304	6.83

Furthermore, despite malaria itself being a significant tropical disease killer, leading tropical disease journals are themselves less representative of malaria research, and publish more heavily on other tropical disease topics. For example, in Acta Tropica, a leading tropical disease journal where we saw in Table 1 that both countries had almost 10% of total publications, malaria is only 16.5% of all publications in Acta Tropica. Moreover, despite the fact that one of the leading pediatric killer diseases is malaria, it accounts for only 0.09% in the *Journal of Tropical Pediatrics* (i.e. 1 publication, and that from one of our case countries). Only in two journals on tropical medicine do malaria publications comprise a much higher 22.6% (*Transactions of the Royal Society of Tropical Medicine and Hygiene*) and 19.4% (the *American Journal of Tropical Medicine and Hygiene*).

Discussion

Returning to our hypothesis, the data shows that while both countries, which have significant efforts invested in locally relevant malaria research, they represented only 0% between 1945-1971, and 16% of the world's total published output for 1972-2003[11]. The relative share of

[11] Note that the absence of any articles 1945-'71 may also reflect the underrepresentation of journals from these countries in the SCI database during this period.

Brazil and India in scientific output related to malaria research is noteworthy, especially if one takes into account that these two countries combined have 9.37% of total world malaria cases (25,195,018) in 2001, Brazil with 1.54% and India with 7.83% (WHO Global Atlas for Infectious Diseases). Nevertheless, the relative impact of malaria within the economies leads us to different conclusions about the efforts invested in malaria research.

While the 0-16% increase over the latter 30 years is an encouraging sign of effort, the relative importance of malaria within the local population also acts as a guide in assessing relevance. We used an indirect measure of this. Our calculations show that Brazil and India combined have 1.37% articles addressing malaria from within their *total* scientific output, while the rest of the world (RoW) has 4% of their total scientific effort dedicated to malaria research. While the RoW includes countries that do have higher malaria incidence (such as countries in sub-Sharan Africa), the publication analysis shows the overwhelming number of malaria publications arising from countries with little or no malaria incidence.[12] This gauge indicates that scientific research efforts in India and Brazil are less relevant to local problems such as malaria relative to the efforts of countries for which malaria is less of a burden.[13] Other authors studying malaria research output find that over 37% of the entire world publication output on malaria have at least one author from the US, a low malaria incidence country (Wellcome Trust, 1996). This would support our findings.

From an institutional map, we see that the efforts in both countries are overwhelmingly from public research efforts. It is worthy to mention that the data shows a total of 9 Indian published papers, and none for Brazil from the private sector. In the Indian case, most are from the Astra Research Centre, a non-profit research foundation, or affiliated to the company Astra Zeneca R&D in Bangalore, India. No Brazilian private involvement exists. It would be useful to contrast this with some other countries which are leading malaria publishers to understand under what conditions and what specific types of research, research on malaria could be initiated in the private sector.

The science policy implications arising from the full dataset are two-fold. As the data shows, for 30 years between 1972 and 2003, the trend in malaria publications from both countries is clearly increasing at the same time that malaria-resistance of various kinds has also increased. It would be useful for future policy research to study whether the increase in research over this period has been largely behavioral, studying patterns of incidence and uptake of common prescriptions such as bed nets, use of insecticides etc. or of the "laboratory" variety e.g. vaccine research or drug development.

Of those journals with a higher concentration of malaria publications, India and Brazil share almost identical percentages (3 % in average each). For those publications with a smaller number of malaria-related publications, both India and Brazil show significant percentages.

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[12] It is important to observe that although these countries have less of a tropical disease burden today, some had one in the past. Furthermore, many countries with higher tropical disease burdens today have allocated resources elsewhere, and may need to devote energy towards both new research as well as application of existing knowledge for tropical diseases.

[13] Brazil, relative to India, has a lower share of global incidence, but a comparable level of scientific output. This in itself, is inconclusive for a contrast of respective national strategies since we need more data on relative emphases within the malaria effort and per capita spending on the disease, among other variables.

Overall, this is an encouraging showing, but suggests that both countries do better at publishing outside the malaria "heavyweight" journals and a two-tiered system becomes evident for these two countries.

However, for the journals with higher publications on malaria, the situation needs further analysis. Only one publication (out of 557 written by "Brazilian" or "Indian" authors) consists of collaborators from both India and Brazil. Nevertheless, this too is one with a US partner. The extraordinarily small share of collaboration in research between India and Brazil on malaria raises two issues: (a) first, international and national ventures should be doing more to bring together existing capabilities within "southern" countries (b) WHO-driven or other donor driven initiatives for malaria research may run the risk of isolating critical masses of researchers by pursuing a purely geographic distribution of research through regional offices. Although malaria and other vector-driven research can indeed be geographically specific, there are other risks to be weighed in separating those developing countries with scientific and pharmaceutical capabilities capable of making advances on both the science and the development of new drugs or vaccines.

Understanding when international collaboration occurs is an interesting phenomenon in itself. The two countries are dramatically different in their collaborative profiles. In the case of Brazil, collaboration with the "north" has been increasing steadily since the early 1980s, much earlier than in the Indian case. Furthermore, collaborations are a substantial portion of overall Brazilian malaria-related publications. However, we show that for India, the 1990s onwards herald some substantial increase in international collaboration, suggesting that (a) economic liberalization begun in the 1980s and (b) changes in international patterns of funding may have resulted in some later openness on the science side to international research. However, collaboration is still a small (and not continuously increasing) function of overall publication from Indian scientists, which has increased more rapidly over the same period. In both countries, geopolitical considerations-Brazil's longstanding relationship with the US economy and links to Europe, and for India, historical legacy from Britain may be strong influences on collaboration patterns.[14]

While international collaboration appears to be fairly robust for both countries in the 1990s and 2000s, this is primarily Brazil-North, India-North collaborative types. The extent to which both countries collaborate with other developing countries is significantly smaller in the case of Brazil, and slightly smaller in the case of India, which collaborates less overall in absolute numbers. This suggests that truly international collaborations (of which the Human Genome project was an example) for gene sequencing efforts, or other types of malaria-eradication measures for which networks of scientists and institutions have already been developed may result in sidelining countries such as India.

[14] Our research makes no statement on whether collaboration is the better option for these countries. Thus the fact that Brazil's collaborations have increased faster than India's over the same period provides no hints on quality of science, efficacy of findings or even broader relevance to other malaria-efforts other than those for which the collaboration occurred. They may have significant institutional impact, however, linking research efforts and changing patterns of financing for scientific R&D..

When we showcase collaborations within top indexed journal publications, however, we find a slightly different tale. Overall malaria publications show a gentle increase, peak and decrease over the 1997-2003 period, but Brazil-North collaborations show a seemingly randomized pattern during this period (contrasted with the steady increase in Brazil for *all* collaborations in malaria that we saw earlier). For all publications, the highest number of South-North collaborations is 26. Not surprisingly, if we track the leading journals, we see that the highest number of collaborations is only 12 since Brazilian (and Indian) publications in the leading journals are fewer. The South-South collaboration in the leading journals, however is very small, 1-2 papers in any year, and almost constant. This indicates that at least from a scientific standpoint, international malaria collaborations have thus far had limited impact in advancing institutional development for the South. Assuming that leading journals are a proxy for capability (although in rapidly developing biological sub-fields, established journals are being challenged by large numbers of new publications), this suggests that junior researchers may need more reorientation in their publishing records and that institutional efforts are necessary to redesign the advisory and editorial boards of journals. National science policy must also address how to increase the visibility for developing country researchers in the ”breakthrough” journals, such as *Science* and *Nature,* for example, which have showcased malaria advances from other countries (RoW), but have low rates of overall publishing from Brazil or India. There is the additional challenge of addressing the low number of developing country journals that are accepted into SCI databases. Our ongoing research into the more detailed institutional characteristics of malaria research from Brazil and India will undoubtedly shed more light on international and intra-national disparities in science and technology. Despite research capabilities, prior research indicates that both countries have significant gaps in capability in translating this research into new treatments. Both countries have invested considerable resources in malaria research, but some tentative evidence from our ongoing research suggests that leading institutions for tropical medicine research in these countries is skewed in favor of other tropical diseases and less on malaria.

Furthermore, our data shows that leading tropical disease journals themselves compound this problem by under representing malaria in overall articles published.

Finally, studies must take into consideration the varied nature of malaria-related research, particularly since developing countries may be depending on more mature technologies and products to address the problem.

Conclusions

Although scientific publications cannot be the only criteria to evaluate the relevance and robustness of local science, they provide an insightful dimension into the broad trends of this research and some institutional characteristics of publication and collaboration. Both India and Brazil have 1,644 articles on malaria in the last sixty years, the first thirty of which were without any representation in the SCI database.. While this research confirms previous findings of underrepresentation of developing countries in international science, it underscores that two countries with significant promise in both science and pharmaceutical research in the developing world show low local relevance of science for malaria research, almost no collaboration with each other, relatively low rates of increase in published outputs, insignificant private sector activity and appear to primarily collaborate with a few advanced

industrialised countries. Their science appears to be less relevant to local needs when compared to the extent of publications on malaria from regions that are less affected by the disease and as shown by profiles of publication in tropical disease journals. The relationship between per capita spending and epidemiological relevance of malaria relative to other diseases, for example, could provide further guides to fine-tuning scientific research efforts.

Furthermore, they have not increased published articles on malaria, international collaborations or publications in leading international journals at the same rates as the rest of the world. In addition, South-South collaborations with either an Indian or Brazilian involved, have shown low scientific output, and are poorly represented in leading journals with few exceptions. Given that both India and Brazil have among the most sophisticated science establishments as well as pharmaceutical industries in the developing world, the research indicates that more can be done to establish institutional links within the respective countries and with useful worldwide collaborators. The research also holds lessons for international malaria initiatives. To the extent that global health policy advances can also be underscored by better linking existing investments in science, and for encouraging private actvity, such worldwide programs should give more thought to how to invite these countries into broader collaborative patterns, as well as to link advanced capabilities within these two countries with others in the developing South.

Since many malaria interventions may be behavioral, infrastructural or institutional (with respect to uptake and diffusion), more collaboration (and studies in contrast) with other developing countries may be a worthwhile investment. This research also highlights the secondary status in numbers of malaria articles even in leading tropical disease journals where malaria publications are a small percentage of the total. This suggests both supply and demand problems for science research on this disease.

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[15] (MIM partners include The Centers for Disease Control and Prevention, GlaxoSmithKline, The National Institutes of Health (USA) the Rockefeller Foundation, The United Kingdom Medical Research Council, The United Nations Foundation, the United States Agency for International Development (USAID), The Wellcome Trust, and the World Health Organization.)

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