Jointly published by Akadémiai Kiadó, Budapest
and Kluwer Academic Publishers, Dordrecht

Scientometrics,
Vol. 55, No. 3 (2002) 383–391

Scientific and technological development in Brazil. The widening gap

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This article examines the contrast between Brazil's impressive scientific development over the last 25 years and its lagging innovative capacity. As the world's eighth largest economy, an evaluation of this link offers insights, not only for Brazil, but also for parallel developments in other emerging countries. The growth rate of Brazilian scientific production has exceeded the international average, showing a six-fold increase in the last twenty-five years. However, Brazil's innovation capability is still unsatisfactory and, in contrast to its scientific production, is failing to grow significantly. This hiatus between the generation of science and innovation is also typical of other emergent countries. A possible remedy is suggested: interaction with universities and research centers is particularly necessary for Brazilian companies – far more so than in industrialized countries.

Brazilian scientific production

Brazil's scientific production indicators show significant developments over the last 25 years. Several anecdotes offer examples of the recent world-class achievements of Brazilian science. In only three years, a virtual network of some 65 laboratories completed genomic maps of sugar cane and four plant pathogens, (see, e.g., Ref. 1), placing Brazil squarely in the worldwide scenario of genomics research.

Journal articles are another indicator of scientific production. We compiled a table (Appendix) that indicates the share of ISI papers of the 39 most prolific countries (with over 2,000 papers in the year 2000). The G7 tops the list of contributors to our understanding of nature. Brazil ranks 17th, up from its 1975 ranking of 28th.

Figure 1 illustrates the growth of Brazilian participation in all the sciences, medicine and engineering, revealing a six-fold increase over the last twenty-five years in the relative number of articles by Brazilian authors that the ISI – Institute of Scientific Information - catalogued electronically. (The ISI catalogs approximately 5% of the world's leading journals). Points marked by squares in Figure 1 show Brazil's 1.3% contribution to the worldwide scientific production indexed by the ISI in 2000, up from

0138–9130/2002/US $ 15.00

0.2% in 1975. This performance would be even more impressive were we able to include Brazilian authored high quality articles "buried" in conference proceedings and in some 300 national journals not registered in the ISI.[2] Moreover, according to recent data of CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico),[3] the number of PhD degrees granted to Brazilians grows steadily, reaching almost 6,000 per year.

These achievements result from both state and federal investments in post-graduate education and research over the last four decades.[3] An estimate (www.ifi.unicamp.br/~brito/artigos/investnac) indicates that governmental investment in science and technology has slowly, but continuosly, increased, from about 0.7% in 1976 to 0.9% of the GNP (US$ 620 billion) in 1995.

The following section shows that Brazil's innovation rate and its scientific production follow dissimilar trends.

The innovation rate of Brazilian companies

Although no accurate measure of technological development exists, patent data offer ample, valuable evidence of technological activity.[4] An indirect form of evaluating a country's innovation is to examine the record of patents granted under competitive conditions, e.g., in the USA, where only a small fraction of the patents filed are granted. Points marked by circles in Figure 1 represent the evolution of Brazil's share and ranking in the total number of patents granted in the USA from 1975 to 2000.

Brazilians were granted only 98 (or 0.06%) of the 157,497 patents issued by USPTO in 2000. This percentage has doubled over the last three decades, but is still much inferior to that of countries that publish a similar number of scientific papers, such as South Korea, Israel, Belgium, Taiwan, Denmark, Finland and Austria. These countries have long ago internationalized their economies and improved their intellectual property systems.

Figure 2 provides additional clues to understanding this issue, showing the ranking of the 39 most prolific countries according to: i) their respective contribution to the number of ISI papers published in 2000 (authored by at least one scientist of that country); ii) the total number of patents granted by the USPTO to that country from 1963 to 2000 (by residence of first-named inventor). The data pertaining to all the industrialized countries lie close to or above the straight line; i.e., the country's patent ranking is equal to or higher than its relative ISI ranking. Hence, developed countries

capitalize on their scientific culture, transforming knowledge and ideas into patents and innovation. Mexico and Argentina are the only two emerging countries that belong to this category. In contrast, inventors from Brazil and all other emergent countries publish many scientific articles but do not file a proportional number of patents.

The ratio between the number of ISI articles and USPTO patents granted to authors of the same country supplies additional evidence of the gap. In the most industrialized countries, this ratio varied from 3 to 30 in 2000, while for emerging countries, this ratio was greater than 100, sometimes reaching 1500.

A comparison of patents granted by the National Institute of Industrial Property to Brazilian companies, public research centers and universities reveals another interesting picture.

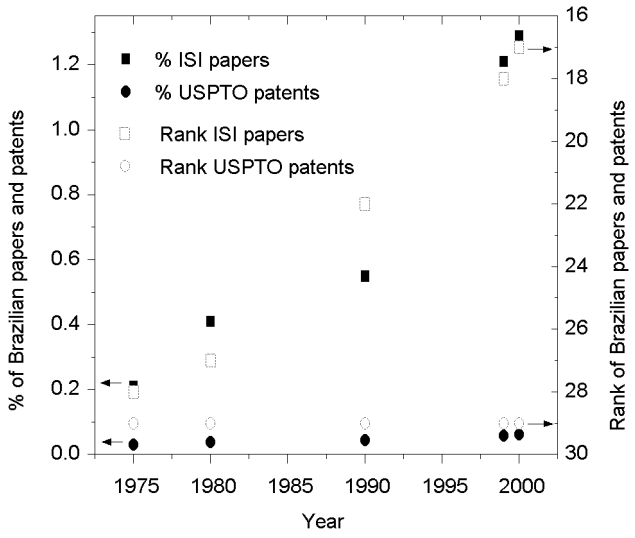

Figure 1. Percentage of articles in ISI journals signed by at least one author employed by Brazilian institutions in the last 25 years (Source: ISI database at webofscience.fapesp.br). Percentage of patents granted by the USPTO to Brazilians; by residence of the first-named inventor. (Source: www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm). Brazil's rank in the ISI in 2000 and in the USPTO from 1963 to 2000

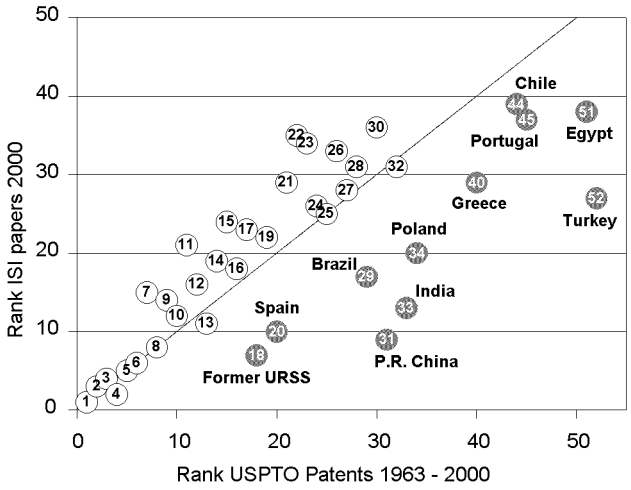

Figure 2. Ranking of the 39 most prolific countries, measured by the number of ISI papers published in 2000 by at least one author of that country compared to the cumulative number of patents granted by the USPTO from 1963 to 2000 to the first-named inventor of that country.
Empty circles: 1-USA, 2-Japan, 3-Germany, 4-United Kingdon, 5-France, 6-Canada, 7-Switzerland, 8-Italy, 9-Sweden, 10-Netherlands, 11-Taiwan, 12-South Korea, 13-Australia, 14-Belgium, 15-Austria, 16-Israel, 17-Finland, 19-Denmark, 21-Norway, 22-South Africa, 23-Hungary, 24-Czechoslovakia, 25-Mexico, 26-New Zealand, 27-Hong-Kong, 28-Ireland, 30-Singapore, 32-Argentina, respectively, in that order, i.e., decreasing patent ranking.
Solid circles: 18-formerURSS, 20-Spain, 29-Brazil, 31-China, 33-India, 34-Poland, 40-Greece, 44-Chile, 45-Portugal, 51-Egypt, 52-Turkey

Table 1. Patents granted in Brazil to the most prolific Brazilian companies, government research institutes and universities (1992 – Sept. 2000)

Companies		Research institutes		Universities-official	
Petrobrás	318	IPT	49	USP	97
Usiminas	184	Embrapa	32	UNICAMP	37
CVRD	83	INPE	16	UNESP	6
Embraco	73	CETEC	13	UFSCar	6
Telebrás	72	Fiocruz	12	UFRJ	4
CSN	62	INT	06	UFPE	4

Official = Patent owner is the university

The real number of patents originated at universities is estimated at about *double* the number suggested by official figures. This estimate resulted from a survey carried out by the present author in the Federal University of São Carlos. Such discrepancy derives from the fact that, due to loose regulations, several faculty file patents independently, without including their universities.

American corporations hold many more patents than American universities. Brazil, however, presents a different picture. Table I shows that Brazilian universities and government research institutes hold fewer patents than top companies, but both hold only a small number of patents. The most prolific Brazilian industries are, or were until recently, state-owned, operating in scale-intensive (medium tech) fields.

Discussion

The notion that technology springs from a scientific base was originally embedded in the "linear" model of innovation: from basic research to applied research continuing into technology and economic benefit. This model is now supplanted, but the origins of research knowledge in fundamental research still lye at the core of the process.

A pivotal study on the linkage between science and technology was recently published by *Narin* et. al.[5] The authors analyzed more than 100,000 patent-to-science references providing massive evidence for the contribution of public science to industrial technology. They demonstrated that 73% of the papers cited by U.S. patents are public science, authored at academic, governmental, or other public institutions. References form U.S. patents to U.S.-authored research papers have tripled over a six years interval spanning from 1987 to 1994, a period in which the U.S. patent system grew by only 30%.

A similar type of study focusing on the Brazilian system of innovation is yet unavailable, and the number of Brazilian patents in the USPTO is yet too small to produce reliable statistics. Despite this difficulty, the study of *Narin* et. al.[5] clearly indicates that technology frequently derives from scientific developments, which are steadily growing in Brazilian universities and governmental research centers (Figure 1). Therefore, this fact provides a feasible path for industrial research in Brazil (interaction between companies and universities). This issue will be discussed later on this article.

Comprehensive indicators exist to evaluate innovation capability, such as innovation surveys, including a firm's different innovation activities: R&D, design, new product/process licensing, try-out of new processes, etc. However, these indicators are relatively new and do not yet provide for time series comparisons, which are still non-

existent in many countries. Patents, on the other hand, are available in large numbers and periods, providing a good indication of trends.[4]

The gap between scientific and technological innovation in Brazil originates from several factors, but is mainly due to the structure of Brazil's economy, low investments in industrial research and Brazil's weak patent protection system. These weaknesses are discussed below.

First, the structure of Brazil's economy began to be internationalized only in 1990. Despite the threat of global competition, few Brazilian companies undertook in-house research to improve product and process technologies. Severe inflation distorted business planning in the 1980s and early '90s, partially constituting the reason for the paucity of industrial research.[6]

Second, the largest fraction of patents in developed economies is granted to companies. In the USA, for instance, only 3% of the patents are registered to universities, which is logical since companies and universities have widely different missions. A clear correlation exists between the number of patents granted to a given country and its industry's investments in research.[7] European, American and Japanese companies invest from 65 to 75% of their countries' research money, while this percentage in Brazil barely reaches 20%. Moreover, while the percentage of research engineers and scientists employed by the private sector in industrialized countries is about 75%, only about 10% of Brazil's researchers are company employees.[7] Fewer than 1,000 holders of PhD degrees work in companies in Brazil, while over 50,000 holders of PhD degrees work at universities and public research centers.[7] The paucity of Brazilian industrial investments in R&D is reflected in the scarcity of inventions and patents.

Finally, high patenting costs, lack of an intellectual property protection culture and Brazil's weak patent protection system all contribute to perpetuate the gap between science and technology. Brazil excluded several technological areas from patent protection until 1997. Moreover, similar to other emerging countries, Brazil's patent office is slow and the judicial system is yet unfamiliar with intellectual property.

One could reasonably argue that the production of new technology in Brazil is much more significant than patent data suggest, because companies conceal their new technologies instead of seeking patents. As in many other emerging countries, Brazil's legal protection of proprietary industrial technology (trade secrets) is weak.[6] Industrialists commonly view recourse to trade secrets as the second-best approach. Still, they often choose that option in the absence of effective patent protection. This practice contributes to an unknown number of would be patents.

A recent innovation survey[8] of the most industrialized state of Brazil, São Paulo, portrays its innovation pattern, revealing that 25% of the industrial companies, including TNCs, introduced technologically modified products or processes in 1994-1996. In comparison, the percentage of innovative firms in Germany, France and Italy is 53, 41 and 35%, respectively.[8] Yet this innovative performance of Brazilian firms relies little on internal R&D, depending strongly, instead, on external sources such as clients, affiliates and competitors. The best innovative performance was by TNCs, but mostly they simply adapted products and processes originated abroad. Most of the effort that Brazilian firms put into technology concentrates on intermediary and scale-intensive (medium tech) industries.[8]

Despite all these drawbacks, Brazilian technology competes internationally in some areas, e.g., aeronautics, deep-water oil prospecting, civil construction, hydroelectric energy, ceramics, automated banking services, and in some niches of medicine and agribusiness. However, with few exceptions, this is mostly due to efficient management, organization and productivity (which lead to competitive prices), rather than new inventions. Hence, Brazilian companies wishing to improve or simply maintain their position in a competitive economy must urgently implement research practices. In this unique scenario, company interaction with universities and research centers is particularly necessary, so that industry can take advantage of well-trained researchers and state-of-the-art equipment available at research universities.

Brazil has limited trained personnel, equipment and funds; therefore, where can technological growth be most effectively encouraged? The answer may lie in both high and intermediary technology. As predicted by *Schumpeter,*[9] we are in the middle of the fifth technological wave. There are signs that Brazil is capable of joining this global wave; some research groups and companies, for instance, are doing well in *biotechnology* (see Ref. 1 on genomic research potential), *aeronautics* and *software.* There is also scope for innovation in medium tech areas such as materials, mechanical, energy generation, construction, food and cosmetics industries; education technology; banking and tourism due to the nation's large internal market, well-established research groups and existing national industry – all in obvious need of greater stimulation and scientific push.

In summary, the growth rate of Brazilian scientific production has exceeded the international average, showing a six-fold increase in the last twenty-five years. However, Brazil's innovation capability is still unsatisfactory and, in contrast to its scientific production, is failing to grow significantly. Innovation originates mostly from business investments in research, which are still insufficient in Brazil. Therefore, interaction with universities and research centers is particularly necessary – far more so than in industrialized countries.

Innovation is also typical of other emergent countries. Understanding the reasons for this gap may, perhaps, help to close it.

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I am indebted to professors R. *Meneghini*, Ana L. *Tokormian*, Alceu *Filho*, Guilherme A. *Plonski* and Robert *Sherwood* for valuable suggestions.

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Appendix
Number of ISI papers* and USPTO patents** of the 39 most prolific countries (>2000 ISI papers in the year 2000)

Rank papers	Papers 2000	Patents 63-00	Rank patents
1-United States	305,596	1,870,069	1
2-United King.	87,228	101,680	4
3-Japan	78,941	452,737	2
4-Germany	75,319	231,330	3
5-France	53,467	89,218	5
6-Canada	37,866	57,290	6
7-Italy	36,497	34,146	8
8-former URSS[1]	36,690	7,159	18
9-P.R. China	30,754	930	31

(continued next page)

(Appendix cont.)

Rank papers	Papers 2000	Patents 63-00	Rank patents
10-Spain	24,543	3,871	20
11-Australia	22,856	12,090	13
12-Netherlands	21,666	27,930	10
13-India	17,498	902	33
14-Sweden	16,234	29,863	9
15-Switzerland	15,848	44,635	7
16-South Korea	14,625	18,169	12
17-Brazil	12,333	1,263	**29**
18-Israel	12,220	8,161	16
19-Belgium	11,295	11,666	14
20-Poland	10,431	699	34
21-Taiwan	10,089	24,646	11
22-Denmark	9,200	6,915	19
23-Finland	8,130	7,602	17
24-Austria	8,039	10,765	15
25-Mexico	6,872	1,907	25
26-Czechoslovakia[2]	6,235	2,226	24
27-Turkey	6,074	83	52
28-Hong Kong	5,610	1,508	27
29-Greece	5,517	368	40
30-Norway	5,204	3,841	21
31-Argentina	5,048	904	32
32-Ireland	4,917	1,303	28
33-New Zealand	4,693	1,578	26
34-Hungary	4,691	2,435	23
35-South Africa	3,968	3,162	22
36-Singapore	3,755	965	30
37-Portugal	3,478	176	45
38-Egypt	2,438	67	51
39-Chile	2,258	179	44

* ISI papers having at least one author of the designated country.
** USPTO patents by residence of first-named inventor.
[1]former URSS = URSS until 1993 + Armenia, Azerbaijan, Byelarus, Estonia, Rep of Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikstan, Turkmenistan, Russia, Ukraine and Uzbekistan.
[2]Czechoslovakia= Czechoslovakia until 1994 + Czech Republic and Slovakia.

Received April 30, 2002.

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