The role of Brazilian firms in nanotechnology development

Luciano Kay, Noela Invernizzi, Philip Shapira

***Abstract*—Brazil is the leading country in nanotechnology research in Latin America and has been the first to implement a national policy to stimulate the productive sector to innovate in that emerging field. Based on Georgia Tech global databases of nanotechnology scientific publications and patents, we analyze the role of Brazilian firms in the development of nanotechnology, their research and commercialization activities, their collaborations, and their engagement with nanotechnology programs. We look in particular at nine case studies of leading firms. Our data show that the nanotechnology policy has stimulated research in companies in close collaboration with universities and research centers. However, most of those companies were already within a very select group of innovative firms or are very dynamic starts-ups. Overall, companies still exhibit a low innovation profile in nanotechnology, in line with the overall poor industry innovation landscape of the country.**

Keywords—Nanotechnology research; nanotechnology patents; innovation; Brazilian firms; Brazil Nanotechnology Policy

I. Introduction

Nanotechnology involves "the understanding and control of matter at the scale of approximately 1 to 100 nanometers where unique phenomena enable the design and production of materials, devices and systems which have novel applications." [1] The pervasive benefits that nanotechnology may bring to multiple industry sectors have led many developed economies to greatly increase public research investment in nanotechnology since 2000. Meanwhile, with the notable exception of China, which is now the world's second largest producer of research publications in nanotechnology [2], there are only a few other developing countries which have significant research and innovation activities in this emerging field.

In Latin America, nanotechnology development is concentrated mainly in Brazil. Over the last decade, there have been major changes in Brazilian S&T policy to foster innovation. This new approach incorporated nanotechnology as a strategic area. As of today, Brazil is the foremost country in Latin America in terms of research infrastructure, number of researchers, number of publications, and budget allocated to nanotechnology research [3, 4]. However, compared to developed countries (and those exceptions like China) the performance of Brazilian companies in nanotechnology research and innovation is weak. Less than 80 companies in Brazil are pursuing any development in nanotechnology and only a small number of nanotechnology patents are assigned to these companies.

In view of the significant infrastructure that Brazil has built for nanotechnology research, the connection between the scientific knowledge creation sector and the productive system is perhaps rather weaker than might have been expected. Several questions emerge from this inconsistency, including: what is the role of those Brazilian firms in the development of nanotechnology, what type of research and commercialization activities are they undertaking, and to what extent do they collaborate with other research institutions?

To answer these questions, we analyze here the performance of Brazilian firms involved in nanotechnology research and patenting, based on the analysis of scientific publications, patents, and mini case studies. Firstly, in the following section, we describe recent changes in Brazilian S&T policy to stimulate innovation in order to contextualize nanotechnology policy and innovation trends. Then, we describe in more detail the Brazilian nanotechnology policy and discuss the potential role that companies may have in developing this new technology. Thirdly, we present our analysis, based primarily on Georgia Tech global databases of nanotechnology scientific publications and patents, and nine mini case studies of companies involved in nanotechnology. Finally, we discuss the nanotechnology research strategies followed by different firms, the relevance of nanotechnology in their innovation and commercial strategies, their ways to engage in nanotechnology policy programs promoted by the government, and their potential emerging roles.

II. The Broader Innovation Context In Brazil

At the beginning of the decade, the Brazilian S&T Ministry's Livro Verde (Green Book) [5] offered a diagnosis of the country's S&T status. It acknowledged that S&T policies have developed a good research infrastructure and qualified human resources, yet they had been unsuccessful in integrating the S&T system with the productive sector, helping the latter to increase its innovativeness and competitiveness. Several indicators showed the contradiction between an increasing scientific performance and underdeveloped innovation capabilities. In particular, the rise of Brazilian participation in the worldwide production of science, measured in number of publications and citations, was contrasted to an insignificant number of granted patents, low private investment in R&D, and scarce employment of scientific personnel by companies.

Indeed, data from PINTEC 2000 (a survey of technological innovation in the country) showed that, between 1998 and 2000, only one-third of Brazilian firms with more than 10 employees introduced a technologically new product or

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process. Furthermore, among the firms that did introduce new technologies, the most common mean was the purchase of new equipment, while only 16% of them undertook R&D activities. [6, 7]. Another indicator of the weak commitment of Brazilian firms with innovation activities is the low employment of scientific personnel. According to the Livro Verde, scientists and engineers were only 0.5% of the total formal employment in Brazil in 1999 [5, 8].[1]

Since the end of the 1990s, Brazil's S&T policy has undergone changes in its focus, institutional base, instruments, and funding mechanisms to embrace stimulus for innovation. The current national policy for Science and Technology, and Innovation, introduced in 2003, is characterized by the efforts of the government in raising the companies' innovation capacity through the promotion of R&D activities [see also 9]. The Innovation Law (10.973/2004) and the Law 11.196/2005 represented fundamental changes in this regard. These laws proposed mechanisms to bring together the private sector and the S&T system, stimulating cooperation between firms, universities, and research institutions; offering non-reimbursable subsidies for innovation in strategic areas, including expenses for personnel, materials, services, and patents; granting fiscal incentives for innovative firms; and establishing a legal framework to support firms incubation and use of public and private human resources and infrastructure for technological development. Increasing resources were allocated to S&T and innovation, including new funding mechanisms to target priority sectors. In relation to funding, a new approach is observed in the direct allocation of public resources to companies' innovative activities and to company-university joint R&D projects [7, 10].

The new policy engendered increasing public expenditure in ST&I—more than doubled between 2000 and 2006 to reach about US$7 billion—and a major part was directed to innovation activities of firms. For instance, the National Council of Technological and Scientific Development (CNPq) increased significantly the number of scholarships related to collaborative industry-university projects for technological development. On the other hand, the Research and Projects Financer's (FINEP) programs to support firms' innovative activities, included several mechanisms as non-reimbursable subsidies, fiscal incentives, reimbursable funds, and matched funds (about one-third of the investment of this agency has been matched with firms' funding. [10]

Still, some authors have pointed out that, in spite of these government efforts, there has been little impact on innovation performance. [10] Similarly to what previous reports showed, only 33% of 84,000 Brazilian firms with 10 or more employees had introduced at least one new product or process between 2005 and 2007. For those that introduced novelties, the total innovation expenditures were primarily allocated to acquisition of new equipment (48%), internal R&D (21%), and external R&D sourcing (3%). Additionally, it was known that only 170 firms developed new-to-global-markets products and only 100 firms developed new-to-global-markets processes between 2005 and 2007. Still, the explanation would not be the lack of public funding or poor industry-university interactions, but a logical firm response to the structural market conditions of Brazil, which favor competitive strategies such as short-term productive efficiency rather than longer-term innovation [see also 10].[2]

III. Nanotechnology Policy In Brazil And The Role Of Firms

In 2000, the S&T Ministry (MCT) started to articulate efforts for the implementation of a national policy for nanotechnology, starting by identifying national expertise in the field [11]. In 2001, the CNPq funded with US$1 million four cooperative research networks in nanoscience and nanotechnology involving 300 researchers, 600 graduate students, 77 universities and research centers, and 13 companies from different regions of the country [12].[3] Other scientists gathered at four Millennium Institutes oriented to research in different areas of nanotechnology, which were funded with about US$7 million for the period 2001-2003.[4]

In 2003, a team at the MCT began working on a Program for the Development of Nanoscience and Nanotechnology that was later incorporated into the MCT's Multi-year Plan for 2004-2007 [13].[5] Accompanying the general ST&I policy, this program had the purpose of fostering competitiveness and increasing the internationalization of the Brazilian industry by advancing innovation in this emerging field. It recommended actions to create and support laboratories and research networks, with a US$28 million budget [14]. That first program was strengthened in 2005, giving way to a more comprehensive National Nanotechnology Program with additional US$31 million for 2005 to 2006. This new program has been better aligned to the strategic Industrial, Technological and Foreign Trade Policy started in 2004 [15]. Nanotechnology, described in the latter as "a gateway to the future," has been considered a strategic area to enhance the country's competitiveness.

In the context of this convergence between research and industrial policies, ten new cooperative research networks, connecting about 1,000 researchers, were funded in 2005.

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1 For 2005, there were 461 full-time equivalent researchers per million inhabitants in Brazil, compared with 852 for China and 4,651 for the USA. Fewer than 24 % of Brazil's R&D personnel were employed in business enterprise; in China, 65% of R&D personnel were employed in business enterprise [8].

2 There have been different interpretations of these data. For example, Arbix and Negri argue that PINTEC results should be understood in relation to the importance of innovative firms in the economy. Although this type of firms represented only 1.7% of all industrial firms in 2000, they contributed 25.9% of the total industrial revenue for Brazilian firms [11]. According to these authors, these firms are part of a group of dynamic firms that emerged after the Brazilian market reforms of the 1990s, and they would be developing a high-road competitiveness strategy based on technological innovation.

3 The four networks were: Nanostructured Materials, Molecular Nanotechnology and Interphases, Nanobiotechnology and the Network of Semiconductor, Nanoinstruments and Nanostructured Materials.

4 The Millennium Institutes program was supported by the World Bank in several Latin-American countries. The goal of the program was to integrate research group in networks, boost the use of the national research infrastructure and connect national scientists with international research centers in order to promote excellence level research in strategic areas, including nanotechnology. This program has recently been substituted by the more extensive National Institutes of Science and Technology program.

5 Also during President Cardoso's government the first proposal for a National Program of Nanotechnology was designed. However, with the change of government, this project was soon interrupted.

These networks were supported with additional US$12 million for the next four years.[6] These networks' research profile was more oriented towards industrial application, involving cooperation with the productive sector. At the same time, the FINEP funded several projects to incubate new nanotechnology companies and to undertake collaborative research in this field.

Moreover, the S&T Ministry's Plan of Action for 2007-2010 states that the food, biotechnology, electrical/electronics, aerospace, textiles, metal-mechanic, and energy sectors should be given priority for the development of the National Nanotechnology Program [16]. A recent study estimates that Brazil could have a market share of US$10 billion or 1% of the expected trillion dollar market for nanoproducts in 15 years [17].

Overall, between 2004, when the first program was introduced, and 2008 inclusive, the budget for nanotechnology in the MCT was about US$95 million [18]. The nanotechnology programs have been relevant to strengthen the infrastructure for nanotechnology research, particularly in relation to government and university laboratories.[7] On the other hand, the programs to support research in networks have quickly connected researchers from practically all over the country, creating synergies that increased the potential of invested resources. The MCT estimates that Brazil today has around three thousand nanotechnology researchers, including professors and students [19].

As a result of both the stimulus given by MCT to nanotechnology over the current decade and the prior efforts over several decades to improve its science and technology system, Brazil is now positioned as the country with the strongest potential in nanotechnology in Latin America. However, given the overall poor innovation activity shown by companies, it is less clear whether Brazil will be able to realize the potential nanotechnology research capabilities into concrete technology applications.

Our data suggest that there is some incipient industry activity in developing nanotechnologies. We have identified at least 75 firms that have published or co-authored nanotechnology scientific articles or applied for nanotechnology patents since 1990. However, while bibliometric and patent analyses reveal who is doing what type of research or commercialization of new technologies, the strategies of these firms and their potential contribution to nanotechnology development require a closer look for a clear understanding.

We suggest two hypothetical paths of development of nanotechnology for Brazilian firms. Considering the central role of some state-owned firms in particular industry sectors and the existing nanotechnology policy, it is expected for these firms to engage more in basic research in areas in which Brazil's research has relative strength, collaborating more with local research institutions than other types of firms. On the other hand, for Brazilian private firms and foreign subsidiaries we expect them to target specific research areas aligned with their commercial strategies, patenting their technologies after undertaking research in-house or in collaboration with local or foreign research institutions. In particular, we expect for Brazilian firms to be more likely to engage in collaborations with universities to access to nanotechnology programs funding.

IV. Nanotechnology Performance of Brazil

Our bibliometric and patent analyses are based on the Georgia Tech global databases of scientific publications and patents, using the WoS Science Citation Index (WoS-SCI Expanded,) the Patstat patents database (which covers more than 160 patent offices,) and the definition of nanotechnology and methods described in previous works [20]. We look at the 1990-2008 time period. The qualitative analysis of selected case studies is based on secondary data sources like official policy reports, publications, and company websites. The criteria to select the case studies are described in the following sections.

Brazil is very active in nanotechnology scientific research, increasing steadily its number of publications and number of research organizations since 1990 (Fig. 1).

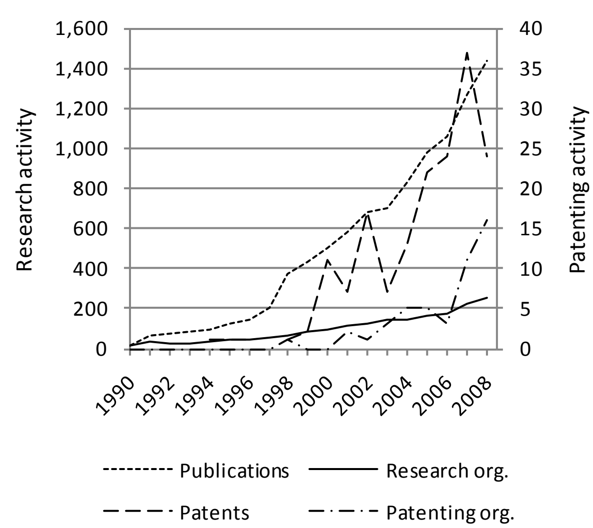

Figure 1. Overall research and patenting activity in nanotechnology in Brazil. Patent activity for 2008 only includes until month of July.

Since that year, 294 universities or education institutes, 137 government organizations, 64 companies, and 40 hospitals have published 10,304 scientific articles on nanotechnology. However, only 157 nanotechnology patents have had either Brazilian inventor or assignee since that year, which includes only 28 unique organizations reported as assignees. About 95% or more of nanotechnology publications in Brazil are

6 The ten networks research in the areas of nanophotonics, nanobiotechnology and biostructured materials, molecular nanotechnology and interphases, nanobiomagnetism, nanostructured coatings, microscopy, carbon nanotubes, simulation of nanostructures, glyco-nano-biotechnology, and nanocosmetics.

7 New or upgraded research centers include the Inmetro Nanometrology Center (National Institute of Metrology, Normalization and Industrial Quality,) the Multi-user Nanotechnology Laboratory of the CETENE (Center for Strategic Technology of the Northeast,) the National Nanotechnology Laboratory for Agribusiness at Embrapa, and the Center of Nanoscience and Nanotechnology at the Brazilian Synchrotron Light Laboratory.

contributed by universities. Corporate publications reached a maximum 5% contribution in 2008. Meanwhile, the low activity in patents impedes to draw definitive conclusions about shares and trends. Still, since 1998, most of the patents have had corporate or, in few cases, large university assignees.

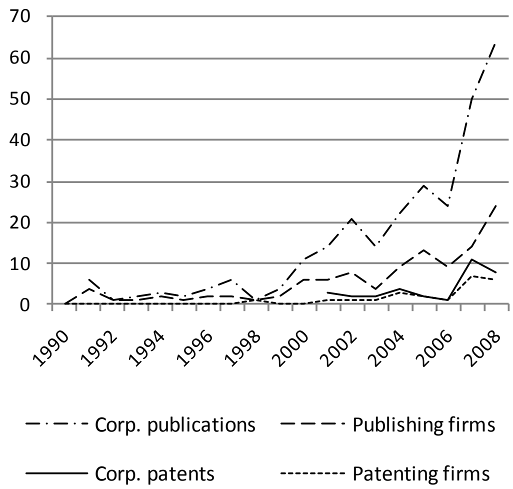

Figure 2. Publications and patents by companies and total firms in Brazil (1990-2008). Patent records include both applications and grants for companies established in Brazil.

The levels of scientific publication and patenting by firms established in Brazil (Brazilian firms or foreign subsidiaries) are still very low (yet, growing) (Fig. 2). Between 1990 and 2008, 64 companies had published only 313 nanotechnology scientific articles, and only 15 companies appeared as assignees in 31 nanotechnology patents. Still, most of these firms are very dynamic with more publications or patents in other technologies or research fields. While the first Brazilian nanotechnology patent was published in 1998, there is no significant corporate activity in nano until 2003, when the federal nanotechnology programs were implemented [21].

To better understand the role that companies have in nanotechnology development in Brazil, we looked in particular at nine companies (Table I). The selection followed these criteria: a) company's publication or patent activity and links to government-sponsored nanotechnology projects; b) coverage of different types and size of companies; and, c) data availability. We selected two state-owned companies (Embrapa and Petrobras), three Brazilian large national or multinational enterprises (Braskem S.A., Biolab Sanus Farmacêutica Ltda., and Oxiteno S/A Indústria e Comércio), two Brazilian affiliates of foreign multinationals (Rhodia Brasil Ltda. and Acesita S.A.), and two start-up or spin-out companies (Nano Endoluminal S.A. and Nanox Tecnologia S.A.). In Table I we show data on their size, publications, and patents. In the following sections, Table II shows company collaborations with other research organizations, participation in government nanotechnology programs, and sources of funding. Table III shows company industry sector, areas of nanotechnology research, patented technologies, and nano-related developments.

TABLE I. SELECTED BRAZILIAN COMPANIES FOR CASE STUDIES AND MAIN STATISTICS

Company	Emp[a]	Sales (US$ million)	All Pub.[b]	Nano Pub.	Share Nano Pub.[c]	Rank Nano Pub.[d]	All Pat.[b]	Nano Pat.	Share Nano Pat.[c]	Rank Nano Pat.[d]
Brazilian state-owned companies										
Petrobras	50,000	92,916	415	32	10.2%	2	1,714	-	-	-
Embrapa	8,440	583	5,161	170	54.3%	1	209	-	-	-
Brazilian large national or multinational enterprises										
Braskem S.A.	4,700	7,775	41	9	2.9%	4	43	1	3.2%	4
Biolab Sanus Farmacêutica Ltda	1,100	182	-	-	-	8	43	1	3.2%	8
Oxiteno S.A Indústria E Comercio	960	91	7	2	0.6%	14	30	-	-	-
Brazilian affiliates of foreign multinationals										
Rhodia Brasil Ltda.	3,100	1,348	19	3	1.0%	7	255	10	32.3%	1
Acesita S.A.	3,000	2,349	7	3	1.0%	12	38	-	-	-
Start-up or spin-out companies										
Nano Endoluminal S.A.	30	2.6	-	-	-	2	5	5	16.1%	2
Nanox Tecnologia S.A.	15	0.2[e]	-	-	-	3	4	4	12.9%	3

a. total employment and sales data as of 2007, otherwise indicated; sales values were converted approximately from R$ to US dollars based on the end of the year exchange rate; b. total scientific publications and company patents for time period 1990-2008; c. shares of nanotechnology publications and patents are based on totals for Brazilian companies; d. ranks based on 76 unique companies publishing or patenting in nanotechnology in Brazil; e. as of 2006—according to company data, revenue in 2008 increased 1,000% compared to 2007.

V. Discussion Of Case Studies And Implications

In principle, the nanotechnology policy in Brazil has stimulated research in this emerging field, not only in universities and other research centers but also in companies that actively collaborate with those universities and centers. Indeed, there is an increase in both research and patenting activities after 2003, which coincides with the implementation of federal nanotechnology programs. However, in spite of its leadership in nanotechnology policy implementation, research infrastructure, number of researchers and publications, and budget allocated to nanotechnology research in Brazil, firms still demonstrate, in general, a low innovative profile in nanotechnology. In this regard, nanotechnology is not an exception in the overall poor industry innovation landscape of the country.

Still, nanotechnology research is actively undertaken by at least some very dynamic and innovative companies and start-ups. Our case studies are examples of firms of different types and size that are engaged in nanotechnology research and commercialization as well as in other R&D activities. They are companies that carry out R&D activities on a regular basis, have well equipped research facilities and employ qualified personnel, all traits that are uncommon even among other dynamic firms in Brazil according to the PINTEC surveys. These innovative firms are also main users of funding from federal programs for nanotechnology and others (Table II), which raises the question about the effectiveness of the nanotechnology policy to engage a larger group of firms in this priority research area.

TABLE II. COMPANY COLLABORATIONS, PARTICIPATION IN NANO PROGRAMS, AND RECEIVED FUNDING IN SELECTED CASE STUDIES

Company	**Collab. in nano publications[a]**			**Collab. in nano patents[a]**			**Participate in nano programs[b]**	**Other sources of funding[c]**
	With univ.	***With firms***	***Intl.***	***With univ.***	***With firms***	***Intl.***		
Petrobras	Yes	Yes	Yes	-	-	-	No	-
Embrapa	Yes	No	Yes	-	-	-	Yes	CNPq, FINEP
Braskem S.A.	Yes	No	Yes	Yes	No	No	Yes	FINEP
Biolab Sanus Farmacêutica Ltda.	-	-	-	No	No	No	No	CNPq, FINEP
Oxiteno S/A Indústria e Comércio	Yes	No	No	-	-	-	Yes	MCT, FINEP
Rhodia Brasil Ltda.	Yes	Yes	Yes	Yes	No	No	No	-
Acesita S.A.	Yes	No	No	-	-	-	No	-
Nano Endoluminal S.A.	-	-	-	No	No	No	No	CNPq, FINEP, seed capital, VC
Nanox Tecnologia S.A.	-	-	-	No	No	No	Yes	Foundation of the State of São Paulo, seed capital, CNPq, FINEP

a. collaborations in publications refer to existing co-authorships between the company and other organizations; collaborations in patents refer to existing patents with the company and other organization as co-assignees; b. participation in nanotechnology network programs implemented since 2001; c. other funding sources related to other non-nanotechnology S&T and I policies yet applied to nanotechnology development.

Our hypothetical paths of development of nanotechnology and the role of firms cannot be definitely discredited. Embrapa and Petrobras, the state-owned firms, do have strong basic research programs, which are related to core their business areas and to strategic industry sectors of the country. Still, they have somewhat different research profiles (Table III). Embrapa focuses more in Plant Sciences, Biotechnology, Genetics, and Agriculture, while Petrobras focuses more on Materials Science, Engineering, Environmental Sciences, and Metallurgy (to some extent, these research areas relate also to the natural endowments of the country.) Moreover, these state-owned companies not only collaborate with local research organizations as expected, but have also established their own nanotechnology research networks in research areas of their interest and engaged universities as members. Their research programs are very well aligned with the priority areas of the National Nanotechnology program and the nanotechnology guidelines included in the industrial policy. However, our data do not show patents for these companies and it is not clear what commercialization strategies these companies will pursue (whether they use nanotechnology for own processes or market new products.) Petrobras is already using its research results in its own processes; commercialization of nanotechnology developments is possible, but using nanotechnology as a competitive advantage in processes is more likely to happen. In the case of Embrapa, a better understanding of potential strategies would require to follow up the transference of new technologies to the agribusiness sector.

On the other hand, we expected for private firms (Brazilian or foreign subsidiaries) to align their nanotechnology developments with their commercial strategies rather than policy priorities. We found, in fact, different market strategies and different importance given to nanotechnology research. The start-up companies, Nanox Tecnologia and Nano Endoluminal, are strongly R&D driven and focused in nanotechnology as a core strategy, successfully positioning themselves in market niches in Brazil and abroad. More than priority areas of research and development (they do not publish,) their products are very specific applications of nanotechnology targeting final consumer or broader industry markets. Meanwhile, Rhodia Brasil, Brasken, Oxiteno, and Biolab Sanus (two multinational subsidiaries and two national firms) are using nanotechnology to enhance their competitiveness in areas in which they are already market leaders. These are priority industry sectors in the industrial policy as well, yet the nanotechnology developments are specifically targeted to their product lines and processes (e.g. textiles, resins and plastics, and additives.) These developments are likely to spill over other applications within the same or other industry sectors only if these companies commercialize their nanotechnology developments. Otherwise, the impact of nanotechnology would be less direct.

The significance of collaborations between companies and universities demands further investigation. Overall, we expected for the state-owned firms to be more fully integrated into academic networks for R&D collaboration, yet we discover in our case studies that this type of collaboration is not only typical of state-owned firms. For most of the companies studied here, including foreign subsidiaries, collaborations are very important for their research activities, with some differences in patterns of networking. State-owned firms have engaged universities and research centers in both nanotechnology research networks organized by them and networks created by universities as well. Moreover, the extensive use of collaborations may be related to the research centre-like structure of Embrapa or, in the case of Petrobras, the result of an aggressive strategy that leverages as many resources as possible to become more competitive and a global leader. Overall, both companies seem to play a central role in R&D networks, which include more than 120 other R&D organizations in the case of Embrapa and 25 other R&D organizations in the case of Petrobras, according to our data for the period 1990-2008.

Regarding the private firms, we find for example that both Braskem and Oxiteno only publish collaborating with local universities for nanotechnology research, while Braskem did that for patents as well. Still, for some of the private firms, relationships with universities seem to be strategic but also critical for their nanotechnology research programs, since the most of relevant of the projects have been carried out in cooperation between their R&D centers and universities. This is the case of Oxiteno and Braskem for example. Meanwhile, collaborations were much closer for other companies, like Biolab Sanus, which has not co-authored publications or co-assigned patents with universities, yet it has R&D labs located at a university incubator. Moreover, the start-ups Nanox Tecnologia and Nano Endoluminal are in fact university spin-offs and have maintained fluid relationships with their universities and others. For Rhodia, collaborations have been more focused in specific projects, yet still strategic for the company's developments in nanotechnology. Finally, although nanotechnology research in Acesita is marginal, its two projects were pursued in collaboration with universities.

The use of nanotechnologies and potential contributions of this set of companies are diverse. In some cases, companies try to incorporate them in their processes to be more competitive, like in Petrobras (e.g. anticorrosive coatings) and Rhodia (e.g. silicone for textiles.) Although nanotechnology may contribute to increasing competitiveness in these companies, the effect is less likely to spill over other industry sectors or companies. In other cases, companies develop nanotechnology-enabled products and raw materials for the same or other industry sectors, like Oxiteno (e.g. additives) and Braskem (e.g. resins.) These types of technologies may enhance local industry's competitiveness with probably the broadest possible impact for nanotechnology in the short- or medium-term. In other cases, companies specialize in nanotechnology to develop nano-enabled consumer products, like Biolab Sanus (e.g. cosmetics), Nano Endoluminal (e.g. prosthesis), or Nanox Tecnologia (e.g. coatings.) Such products may capture significant global niches and contribute to Brazil's nanotechnology exports, although they are the most likely to face increasing health and risk concerns and, therefore, may have uncertain growth outlooks. In other cases, it is less clear how developed nanotechnologies will be used and their potential effect. Embrapa's sensors, for example, may be commercialized or transferred as technology to Brazil's agricultural sector to improve activities of small scale agricultural establishments. Or they may be exported to other leading agricultural countries. Acesita may, for example, eventually commercialize steel alloys with nano-coatings for special uses, something that may impact significantly some industry activities like cars or aircrafts manufacturing.

There are some interesting findings in relation to the impact of nanotechnology policy in Brazil. While nanotechnology programs have had an orientation towards the formation of research networks and more organizational involvement, they have had an overall weak effect in industry participation, at least in terms of number of companies engaged. Only four companies out of our nine case studies have been involved in network programs created by the nanotechnology policy (Embrapa, Braskem, Oxiteno, and Nanox Tecnologia.) Still, for the companies that were engaged, nanotechnology programs may have been critical for them. Indeed, we find that Brasken, Oxiteno and Biolab Sanus used extensively federal funds for their research programs in spite of their company size and well established research resources. Moreover, in terms of research, we find that those companies that collaborated with universities did that in most of their nanotechnology publications.

TABLE III. AREAS OF NANOTECHNOLOGY RESEARCH AND PATENTED TECHNOLOGIES IN SELECTED CASE STUDIES (1990-2008)

Company	Industry sector	Top research areas in nano (shares for publications)[a]	Top patented nanotechnologies (shares for IPC classes)[b]	Nano-related products and processes
Embrapa	Agricultural Research	Chemistry (27%); Polymer Science (14%); Biochemistry & Molecular Biology (12%); Materials Science (12%); Plant Sciences (12%); Physics (11%); Biotechnology & Applied Microbiology (9%); Genetics & Heredity (7%); Agriculture (6%)	No patents	Sensors and biosensors for product and process monitoring; nanofilms and membranes, and biodegradable, bioactive, intelligent packages; and new uses for agricultural products, like edible nanofilms coverings for fruits or methods for animal protein detection in food.
Petrobras	Petrochemical - Oil refining	Chemistry (34%); Materials Science (31%); Polymer Science (16%); Engineering (13%); Environmental Sciences (13%); Physics (13%); Metallurgy & Metallurgical Engineering (9%)	No patents	Nanostructured materials, nanocomposites, and molecular nanotechnology interfaces and devices; use of anticorrosive nanostructured coatings produced by Nanox Tecnologia S.A. to protect pipes and equipment.
Braskem S.A.	Petrochemical – plastics	Polymer Science (56%); Chemistry (22%); Materials Science (22%)	C08K-Use Of Inorganic Or Non-Macromolecular Organic Substances As Compounding Ingredients (100%)	New properties in resins and plastics for “intelligent” high performance packages, for applications in cars, machines and equipments, and domestic appliances.
Nano Endoluminal S.A.	Medical devices	No publications	A61F-Filters Implantable Into Blood Vessels; Prostheses [..] (75%); A61M-Devices For Introducing Media Into, Or Onto, The Body [..] (25%)	Endovascular prosthesis for aneurisms repairs for non invasive treatments plus other medical nano-enabled products for commercialization.
Biolab Sanus Farmacêutica Ltda.	Pharmaceutical	No publications	A61K-Preparations For Medical, Dental, Or Toilet Purposes (100%)	Nanocosmetics, drug formulations in nanoscale, and controlled drug delivery devices for commercialization.
Oxiteno S/A Indústria e Comércio	Chemical	Agriculture (50%); Chemistry (50%); Veterinary Sciences (50%)	No patents	Additives for nanodispersions and nanocomposites for diverse industrial processes (car, construction, and packaging industries) can make materials lighter, fire-resistant, or more homogenous.
Nanox Tecnologia S.A.	Nanomaterials	No publications	A61L-Methods Or Apparatus For Sterilising Materials Or Objects In General [..] (25%); B05D-Processes For Applying Liquids Or Other Fluent Materials To Surfaces [..] (25%); C23C-Coating Metallic Material; Coating Material With Metallic Material [..] (25%); C30B-Single-Crystal Growth [..] (25%)	Nano-structured coatings with biocides properties (clean up and sterilization) for industry and final consumer plus related services of application for manufacturers. Diverse applications like metal, glass, ceramics, and plastic, in products such as packages, instruments, personal objects, houses, and hospitals. Current developments target oil and gas plants (pipes and tanks.)
Acesita S.A.	Steel	Engineering (33%); Materials Science (33%); Metallurgy & Metallurgical Engineering (33%)	No patents	Coatings to change properties in steel, like the use of magnesium oxide in ceramic coating to affect magnetic properties of steel.
Rhodia Brasil Ltda.	Chemical (textile fiber, cosmetics, agrochemical, plastics, and solvents and paints sectors)	Chemistry (33%); Materials Science (33%); Nanoscience & Nanotechnology (33%); Polymer Science (33%)	B01D-Separation (60%); B01F-Mixing, Dissolving, Emulsifying, Dispersing (60%); C02F-Treatment Of Water, Waste Water, Sewage, Or Sludge (60%); C08B-Polysaccharides; Derivatives Thereof (60%)	Enhancement of textiles and plastics to develop products (e.g. silicone nanotechnology emulsion for textiles) in own manufacturing processes; intelligent fibers and special nanocomposite polymers for packaging and food preservation.

a. shares may exceed 100% since publications may be related to more than one subject area; b. shares may exceed 100% since patents may be related to more than one IPC class.

In spite of the dynamism of the studied companies in nanotechnology development, the innovation pattern that has been characteristic over the last decades remains unchanged when we compare the engagement of university, research centers, and state-owned firms with nanotechnology research, given by rapid increase in number of publications yet poor innovative performance if measured by number of patents. Strongly stimulated by the new federal funding mechanisms, even corporate research in nanotechnology is linked to universities, yet also in this case patenting levels are very low and decreasing in relative terms (while universities' share increases.) The data available for this study does not provide additional elements to assess in more detail other innovation that is not patented. Therefore, future investigations should examine more deeply how innovative are nanotechnology products and processes developed by Brazilian firms in order to evaluate Brazil's potential to develop nanotechnology, foster competitiveness, and increase the country's international market share of nanotechnology-based products, a goal stated in nanotechnology policy.

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