Nanotechnology in Latin America

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1. Introduction

The aim of this work is to investigate the development of nanotechnology in Latin America, particularly in Argentina, Brazil, Chile, and Uruguay. These countries form a contiguous block in the south of Latin America and share various cultural and economic characteristics. All are middle-income countries (by the World Bank definition) with active research systems that receive from low-to-moderate levels of R&D investment (See Table 1.) There are also some differences: Argentina and particularly Brazil are bigger and more industrialized countries, whereas Chile and Uruguay are smaller and depend more on their natural resources. Understanding how nanotechnology evolves in countries with those characteristics can provide more insights to study the more diverse set of countries in the rest of Latin America.

The high-level interest in nanotechnology at the international level (Roco, 2005) contrasts with the weakness of research on this topic for Latin America. On the other hand, the increasing use and prospects of nanotechnology in the developed world suggest also an opportunity for developing countries in the studied region. In that context, the main interest of this work is in the potential strategies available to develop and use nanotechnologies for countries like Argentina, Brazil, Chile, and Uruguay.

2. What is going on in Nanotechnology in Latin America?

Argentina, Brazil, Chile, and Uruguay contributed about 70 percent of all nanotechnology publications in Latin America during the period 1990-2006.[1] The data about

[1] Another important player in nanotechnology in Latin America is Mexico, which is the second most important in terms of publications. However, for the purpose of this work, we chose countries that are neighbors and more likely to develop a regional collaboration strategy.

nanotechnology publications from this region show that the research activity in the field started in the 1990s, but increased considerably toward the end of that decade with Brazil and Argentina as leaders (Table 2.) Indeed, the implementation of nanotechnology-related policies in these countries is even a more recent phenomenon.

For instance, nanotechnology policy in Brazil effectively started in 2001 with the creation of four institutional, multidisciplinary networks aimed at doing research in the field. This initiative represented an important effort of the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)[2] to develop nanotechnology in terms of human resources and funding. The Ministerio de Ciencia y Tecnología (MCT), the scientific community, and the private sector were the leaders in establishing the objectives of that initiative, including an even regional development, the integration of public and private research activities, and the improvement of the technological level of Brazilian firms (Durán & De Azevedo, 2002). According to Martins et al. (2007), during the period 2002-2005 those networks involved 300 researchers, 77 research and educative institutions, and 13 companies, publishing more than a thousand research articles and obtaining more than 90 patents. Among the research areas that these networks intended to cover during this period were physics, chemistry, mathematics, medicine, biology, engineering, materials sciences, and computer sciences. Recently, with the Rede BrasilNano program, were created ten new research networks to continue with that previous research,[3] adding in this case a linking component between the program to develop nanotechnologies and the broader Industry, Technology, and Trade policy (Invernizzi, 2007). Furthermore, the new National Program of Nanotechnology is aimed

[2] CNPq is a government agency whose mission is to promote and stimulate the scientific and technological development of the country and contribute to the formulation of national S&T policy.
[3] These new networks are still in an initial stage of implementation.

at conquering one percent of the global markets for materials, products, and processes based on nanotechnology (Goncalves da Silva, 2003).

Argentina has also implemented nanotechnology policy measures, for example through the creation of Fundación Argentina de Nanotecnología (FAN).[4] FAN is a non-profit, private institution created by the Argentinean Government in 2005 to lead the development of nanotechnologies in the country. Among its objectives is the development of human resources and infrastructure, the promotion of collaboration between national public and private institutions, the promotion of international collaborations, and the establishment of priority research areas (FAN, 2007). Furthermore, its advisory council comprises the most important nanotechnology institutions, comprising a national university, a state-owned company, and four key government S&T and R&D institutions.[5] On the other hand, the inclusion of nanotechnology as a strategic priority in the national S&T agency's medium term plan and the proposal of a ten-year nanotechnology plan (Sametband, 2005) show that this technology is among the concerns of the National Government. Some private companies have also demonstrated interest in developing and acquiring nanotechnologies in the areas of chemistry, materials, biology, and textiles, but this was not accompanied by an increase in research funding. In sum, according to Fernández & Schatzmann (2007), the nanotechnology community in Argentina comprises about 200 researchers in several government and university labs and institutions and about 20 private companies.

[4] Argentinean Nanotechnology Foundation.
[5] The institutions in the advisory council are: Universidad de Buenos Aires (UBA), Instituto Nacional de Tecnología Agropecuaria (INTA), Comisión Nacional de Actividades Espaciales (CONAE), INVAP SE, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), and Instituto Nacional de Tecnología Industrial (INTI).

Chile and Uruguay are smaller countries, but they are also concerned with nanotechnology. For example, between 1999 and 2006, two broader programs to improve the Chilean S&T system[6] funded few nanotechnology initiatives in six different universities[7] in the areas of physics, biology, and materials science. In spite of that institutional involvement, according to Foladori & Fuentes (2007) there are less than 20 researchers working in the field,[8] primarily in the areas of physics, chemistry, biology, and materials science. It is worth noting that recently Universidad de Santiago (one of the top Chilean universities working in nano) has announced joint research projects with universities in USA and Canada (UNIVERSIA, 2007).

Meanwhile, nanotechnology research in Uruguay is done primarily by the G-Nanotec-Uy (Uruguay Nanotechnology Group,) a research group led by 15 researchers working at different labs at Universidad de la República (the main university in this country)[9] and Instituto Clemente Estable. Their research is concentrated in areas of biology, physics, and materials science. According to an evaluation made by that group, nanotechnology activities in Uruguay require the definition of objectives and the prioritization in the national strategy of S&T (Chiancone et al., 2007).

Finally, there is at least one joint initiative between these South American countries. The Centro Argentino Brasileño de Nanociencia y Nanotecnología (CABNN) is a virtual nanotechnology center bringing together research from groups working in

[6] Chile recently implemented two main programs for improving R&D: the Millennium Scientific Initiatives (a top-down policy recommended by the World Bank) and, more recently, the Bicentennial Program of Science and Technology.
[7] They are: Universidad de Chile, Universidad de Santiago de Chile, Universidad Técnica Federico Santa María, Universidad Andrés Bello, Pontificia Universidad Católica de Chile, and Universidad de Concepción.
[8] This total does not take into account researchers in nano-biology.
[9] This university concentrates roughly 70 percent of the country's human resources in research and about one third of its total research expenditure.

Brazil and Argentina. Using the science infrastructure of each country, researchers intend to develop joint projects, raise human resources capacity, create interchange grants for researchers, and organize activities like forums and conferences (Almeida, 2005; Diario LaU, 2005).

3. Data analysis

This work draws on datasets of nanotechnology publications and patents developed at Georgia Tech using the definition of nanotechnology and methods described in Porter et al. (2007). A two-stage modularized Boolean approach to defining nanotechnology combined with expert panel review was used to operationalize a definition of nanotechnology and develop publication and patent datasets for the 1990 to 2006 (mid-year) time period. This approach resulted in more than 400,000 records drawn from the Web of Science's Science Citation Index (WOS-SCI) and nearly 54,000 abstracts of patents awarded in this same timeframe which were obtained from the MicroPatents database.[10]

From this database, a new dataset was developed for the country group comprising Argentina, Brazil, Chile, and Uruguay.[11] This yielded a total of 7,309 publications and only 52 patents for the period 1990-2006. Since the total count of patents is very low, the analysis focuses mainly on publications with some additional comments about patenting activity.[12]

[10] The patents database covers the USPTO, EPO, JPO, World Intellectual Property Office (WIPO), and patent offices of Germany, Great Britain, and France.
[11] This dataset comprises all records where at least one author affiliation is located in one of the four target countries.
[12] It is recognized that SCI varies in strength by subject area (SCI is excellent for most life and physical sciences, but not quite as strong in chemical, medical, and engineering research.) Also, SCI does not cover all scientific journals, and in its coverage is weaker for scientific journals that publish in languages other

At the aggregate level, these four countries (which in 2004 constituted 3.8 percent of the world's population) contributed 1.6 percent of the world's total nanotechnology publications in that period. However, looking at their contribution per year, these countries have decreased from 2 percent of the total nanotechnology publications in 2002 to less than 1.5 percent in 2006 (Figure 1.) Generally speaking, this is the result of increasing research activity and publication in other leading countries, although in the case of Argentina, Chile, and Uruguay, is also observable a relative stagnation in the number of publications in recent years.

In Table 3 are shown the main publication statistics for these countries. Brazil is clearly the leader in nanotechnology research in this region with more than 5,400 publications (75 percent of the group's total.)[13] In spite of the low patenting level, this country is also the regional leader with 45 nanotechnology patents. On the other hand, Uruguay only has 54 publications (less than 1 percent of the group's total) and one patent in nanotechnology.

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than English. However, although SCI does index publication records in other languages, our data for the period 1990-2006 show that Argentina, Brazil, Chile, and Uruguay usually publish in English for nanotechnology research (more than 98 percent of the publications.) In terms of local languages, Brazil published more than one percent of its SCI nanotechnology articles in Portuguese, Argentina more than one percent in Spanish, and Chile more than 3 percent in Spanish. All SCI nanotechnology research articles from Uruguay are written in English. On the other hand, there is evidence that developing countries are not well represented in international databases when it comes to analyzing total scientific output, because they often publish in national journals (Gaillard, 1992). However, it is not clear how significant this is for the emerging field of nanotechnology. A search of SciELO (Scientific Electronic Library Online,) which specializes in providing online access to scientific journals in Latin America and the Caribbean, indicates that most of the domestic journals in Argentina, Brazil, and Chile that publish nanotechnology-relevant articles, including national and university journals in physics, chemistry, and materials science, are indexed in SCI (whether they publish in English or not) and many articles in these journals are published in English (Uruguay is not a member of SciELO.) In short, while SCI is certainly not complete, it appears that it does capture much of the region's output of scientific articles in nanotechnology.

[13] Over the period 1990-2006, Brazil ranked 19th among all 101 countries globally with nanotechnology publications by cumulative total of nanotechnology publications. Comparative rankings for the other countries were: Argentina 34, Chile 46, and Uruguay 72. Source: Georgia Tech nanotechnology publication dataset (see Porter et al., 2007).

Co-authorship and collaboration with international leading centers[14] and within the region are key variables on this database. According to them, in Brazil prevails local research (64 percent is done by national institutions only) rather than international and regional co-authorships (36 percent,) whereas in Uruguay clearly prevail international and, to less extent, regional collaborations (80 percent of the research is done with regional and international partners) (Table 4.) In this regard, Argentina and Chile present more average values: half of the nanotechnology publications of Argentina and 58 percent of Chile's are co-authored with researchers from other countries. Moreover, it is interesting that Brazil collaborates less with leading centers and does more research led by individual national institutions.

In terms of first authorship, nanotechnology research is led by universities in Brazil, Chile, and Uruguay, with a relatively low participation of government authors (Table 5.) In the case of Argentina government authors have relatively more participation, which is related to the important role of some government labs in the national S&T system. In addition, industry first authorship is very low in all four countries. Moreover, although nanotechnology research in Brazil involves more private and state-owned firms, they only account for roughly one percent of first authorships. Thus, generally speaking, industry leading role in nanotechnology research seems to be infrequent.

In general, nanotechnology research in these countries is concentrated in three areas: physics, chemistry, and materials science (Table 6.) This finding is not surprising when comparing it with results of previous research. For example, Glanzel et al. (2003)

[14] International collaborations with leading centers include collaborations with USA, France, Spain, Germany, Italy, England, Japan, Canada, Russia, and China.

found that each of those areas of research account for 50 percent or more of the total world publications in the period 1998-2001 (some publications are related to more than one area.) However, it is interesting that, in spite of the multidisciplinary character of Brazilian nanotechnology programs, most of Brazil's publications are also concentrated in physics, chemistry, and materials science areas. Meanwhile, the other countries are also concentrated in these areas, with only Uruguay showing relatively more publications in Engineering and Geology, Environmental, Energy areas (both areas with more than 11 percent of the country's publications.)

The areas of research are related to the type of institutions doing research. Among the top 20 research institutions in the region are 14 Brazilian institutions, being the majority of them federal universities (Table 7.) It is interesting that only two universities (Universidade de São Paulo and Universidade Estadual de Campinas) concentrate 34 percent of the publications from this group of South American countries. Furthermore, those 14 institutions contribute with more than 80 percent of the region's publications. Only 5 of these top 20 institutions are from Argentina and one from Chile.

Within each country is observed that in Argentina more than 80 percent of nanotechnology research is done with participation of national universities and an important role of government institutions in about 50 percent of publications (Tables 8 through 11.)[15] On the other hand, generally speaking, in Chile and Uruguay nanotechnology research is done by universities. As expected, it is worth noting that in Uruguay almost all research activity is concentrated in one university (Universidad La República.)

[15] Totals do not add up to 100 percent due to collaborations.

Network analysis is another methodological approach explored in this work. It allowed representing graphically the relationships between research institutions and obtaining a measure of centrality for the top 50 institutions. Figure 2 shows the network of collaborations between the top 50 institutions within the region, including some top international institutions that collaborate more closely with Argentina, Brazil, Chile, and Uruguay. Each node represents one institution and its color and size represent the country and the number of publications for the entire period, respectively. The lines represent co-authorships. As expected, most of the institutions are from Brazil and a handful of them are from Argentina and Chile. Although there are some institutions from other countries (France, Germany, Spain, Cuba, Italy, and USA,) generally speaking the network reflects that the majority of nanotechnology research (i.e. research in Brazil and Argentina) is done collaborating within each country. Moreover, after calculating a measure of centrality (Degree centrality) is possible to observe that the main institutions in terms of publications are not necessarily the most central in this network. For example, Universidade Estadual de Campinas has less publications than Universidade de São Paulo (both from Brazil) but is more central (more connected) to this network (Table 12.) Furthermore, few institutions from Spain, France, USA, and Germany appear as more connected than other South American universities in this network, but clearly there are still more collaboration within the region than internationally.

Patents data can also help in understanding nanotechnology development in these countries, but the lack of patenting activity impedes conclusive findings. For instance, Brazil, the most active country in this group, has only 45 patents in the period 1990-

2006.[16] There are two possible explanations for this. The first is that these countries are in an earlier stage of nanotechnology development and only after some years they will be able to transform research knowledge in commercialization of nanotechnologies and nanotechnology-based products. The second explanation has more policy implications: these countries may be doing nanotechnology research that is not aligned with local industry priorities.

4. Policy implications

Nanotechnologies promise major social and economic benefits for developing countries like Argentina, Brazil, Chile, and Uruguay. However, in order to be able to convert promises in real social and economic development, an additional effort needs to be done. Thus, the main concern of this work is to determine which strategies are available for them in pursuing that development.

At first sight, there are two main strategies that these countries may pursue: a) an indigenous internally-focused development strategy, based on the country's capabilities and the identification of opportunities or industry targets—this "national target strategy" seeks to develop nanotechnologies for key industry sectors and reach global markets through them; or, b) an outward-looking development, based on open research and international collaborations— this "international organizational alliance" seeks to develop nanotechnologies by collaborating and drawing upon resources and knowledge from leading international centers. The adequacy of these options for each country

[16] This total number of patents does not take into account patents granted by the Brazilian patent office. According to Martins et al. (2007), the Ministerio de Ciencia y Tecnología of Brazil reported more than 90 patents as a result of the activities of the nanotechnology research networks between 2002 and 2005. According to our data, more than 60 of these patents are granted by the Brazilian patent office (Instituto Nacional da Propriedade Industrial – INPI.)

depends not only on its economic profile and institutional organization, but also on its broader national development strategy. Furthermore, the existence of a regional alliance where Argentina, Brazil, and Uruguay participate[17] suggests at least a third potential strategy: c) the development of nanotechnologies based on stronger, intra-regional collaborations—this "Southern collaboration strategy" combines the benefits of collaboration with neighboring countries while developing according to national and regional markets' demand.

In Table 13 is shown each strategy in terms of few variables available for this work. It is suggested that the national target strategy is characterized by research led by individual national institutions or national collaborations, with prevailing government researchers as first authors. This strategy may involve also increasing research activity in industry (private or state-owned firms) and research areas more aligned with key national industry sectors. On the other hand, the international organizational alliance strategy is primarily characterized by increasing co-authorship with international leading centers, institutional concentration, and prevailing academic first-authorships. In this case, the research areas would be more aligned with leading centers' research and less related to local industry's demands. Finally, is suggested a southern collaboration strategy characterized primarily by increasing co-authorships at the regional level, led by either academic or government researchers. Although this strategy does not imply the lack of international collaboration, the focus is in developing institutional linkages within the region.

[17] Argentina, Brazil, and Uruguay are part of the regional trade agreement MERCOSUR. Chile has an associate member status with this block.

According to the data about publications, nanotechnology research in Brazil is more aligned with a national target strategy where national collaboration prevails and a handful of institutions lead research (although in this case universities lead research.) However, considering Brazil's stronger industrial development, the concentration of research in few disciplines suggests that nanotechnology research may be not completely aligned with all key industry sectors, like the case of, for example, engineering and electronics.[18] Furthermore, it is interesting that there is relatively little nanotechnology research in biology and agriculture areas, which may provide technologies for the agriculture sector development. In spite of these caveats, a strategy based on national industry targets is still a potential option for Brazil. For this is necessary to keep aligned nanotechnology research with industry priorities and promote national collaborations as well as the commercialization of new technologies. Indeed, the Rede BrasilNano program is oriented toward these goals.

Argentina is following a national targets strategy with some international collaboration, whereas Chile is following a strategy based more in international alliances. Their strategies cannot be termed as regional collaboration. In the case of Chile the majority of collaborations are with Spain, Brazil, and France (with some announcements of future collaborations with USA and Canada,) whereas in the case of Argentina the majority of collaborations are with Spain and USA while maintaining the national institutions' leadership (Table 14.) In any case, the relative regional collaboration is still low. Although for Argentina and Chile is important to acquire knowledge from leading

[18] Further research in this aspect should be made to draw more definitive conclusions. It is worth noting that the proportion of publications in areas like Electrical & Electronic Engineering seems to be relatively low even at the worldwide level. For example, Hullmann and Meyer (2003) found that, by 1999, only 3 percent of worldwide nanotechnology publications were in the Electrical & Electronic Engineering area.

countries they still need to satisfy the demand of the national economy to obtain positive impacts. In this regard the data show that, for example, Argentina, like Brazil, does relatively little research in biology and agricultural areas. On the other hand, Chile presents research in more diverse areas including biology, which is more related with important industry sectors like forestry and fishing.

Uruguay is more likely to follow a southern collaboration strategy, particularly based on collaborations with Chile and Brazil (Table 14.) Considering the small number of institutions doing research and the relatively low development of Uruguay industry, this strategy is adequate to take advantage of the benefits brought by nanotechnologies without having a strong national S&T system. Partnering with regional neighbors within the framework of MERCOSUR may be more advantageous (and easier) for Uruguay than forming alliances with leading centers. Among the pending tasks for this country are promoting the involvement of more institutions in nanotechnology research and an increasing research related to key economic sectors like agriculture.

Finally, the lack of nanotechnology patenting activity not only relates to the relatively low local demand for these technologies, but also provides an additional insight regarding the potential policy options for these countries. If they want to foster the development in this new field and transfer nanotechnologies to their key industry sectors they need to promote patenting to allow commercialization of new technologies in national and international markets. For this is necessary to increase collaborations between academic institutions and the private sector and increase intellectual property protection. Furthermore, nanotechnology policies may give the role of broker to

government agencies to enable knowledge transfer, sharing, and exchange between industry and academia.

5. Conclusion

Nanotechnologies promise major social and economic benefits and this is understood in Argentina, Brazil, Chile, and Uruguay. These countries, each one with its own scale, are implementing policy measures and programs to take advantage of those benefits. However, almost all activity is seen in research and still not in commercialization. Brazil is clearly the leader in nanotechnology research, followed by Argentina. On the other hand, Chile is increasingly involving more institutions in nanotechnology research and looking for regional and international collaborations, while Uruguay concentrates almost all nanotechnology research in one institution.

The assessment of data about nanotechnology publications suggests that Brazil is pursuing a strategy based on national targets more aligned with local industry needs, whereas Uruguay strategy is based more on regional collaborations. On the other hand, Argentina and Chile rely more on national and international collaborations respectively. Furthermore, generally speaking, nanotechnology research in these countries is concentrated in few areas: physics, chemistry, and materials science. This may attempt against the development and use of nanotechnologies in other key economic sectors for these countries (e.g. agriculture.) In this regard, the best policy option would be to promote research not only in leading areas at the international level but also in areas associated with local needs.

In terms of commercialization of nanotechnologies, patenting activity is infrequent. This suggests another important aspect to target with nanotechnology policies after achieving more strength in research activity. Among the measures to be considered are the promotion of industry-academy collaborations and the improvement of the business environment to favor patenting and IP protection.

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TABLE 1
Population, R&D, and publication profiles for Argentina, Brazil, Chile, and Uruguay (other countries are shown as a reference)

Country	Population 2004 (million)	GDP per capita 2004 (US$)	GDP per capita (PPP) 2004 (US$)	Researchers in R&D per million people	Scientific and journal articles	Scientific and journal articles per million people	R&D expenditures % of GDP
Argentina	38.4	3,580	12,530	720	2,930	76	0.41
Brazil	183.9	3,000	7,940	344	7,205	39	0.98
Chile	16.1	5,220	10,610	444	1,203	75	0.61
Uruguay	3.4	3,900	9,030	366	155	46	0.26
United States	293.7	41,440	39,820	4,484	200,870	684	2.6
Spain	42.7	21,530	24,750	2,195	15,570	365	1.11
Portugal	10.5	14,220	19,240	1,949	2,142	204	0.93

Source: World Bank Economic Indicators 2006 (data for latest year available if year not indicated).

TABLE 2
Nanotechnology publications in the period 1990-2006[19]

Year	World	Argentina	Brazil	Chile	Uruguay	Total four countries
1990	1,021		12	1		13
1991	4,520	8	35	2		45
1992	6,263	10	36	4	1	51
1993	7,537	12	42	6		60
1994	9,383	17	51	6		74
1995	11,068	19	89	13	1	122
1996	13,838	43	97	16		156
1997	17,178	56	158	12		226
1998	26,737	75	270	22	1	368
1999	30,092	103	377	31	4	515
2000	32,970	95	387	37	3	522
2001	37,528	140	538	42	7	727
2002	43,401	144	704	54	7	909
2003	50,053	149	674	56	4	883
2004	59,829	195	802	70	13	1,080
2005	68,019	179	864	73	9	1,125
2006 (mid)	31,028	73	320	36	4	433
Total	**450,465**	**1,318**	**5,456**	**481**	**54**	**7,309**

Source: Analysis of Georgia Tech global nanotechnology publication dataset, 1990-2006 (mid-year.) See: Porter et al, 2007.

[19] The number of publications for 2006 comprises only the first half of the year.

FIGURE 1
Share of world nanotechnology publications for the group comprising Argentina, Brazil, Chile, and Uruguay

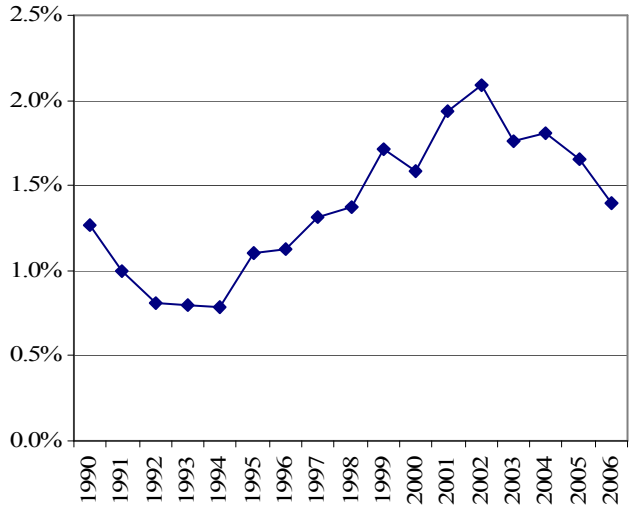

TABLE 3
Main statistics for the period 1990-2006

	Nanotechnology				
Country	**Publications**	**Pubs 90-95**	**Pubs 96-00**	**Pubs 01-06**	**Patents**
Brazil	5,456	265	1,289	3,902	45
Argentina	1,318	66	372	880	5
Chile	481	32	118	331	1
Uruguay	54	2	8	44	1

TABLE 4
International, regional, and national collaborations in nanotechnology publications

Country	Total	Co-authorship international (all)	Co-authorship international leading centers[20]	Co-authorship regional neighbors	Single, national institution	National collaboration (2 or more local institutions only)
Brazil	5,456	1,970	1,431	148	1,562	1,924
Argentina	1,318	652	514	104	344	322
Chile	481	281	181	82	88	112
Uruguay	54	43	20	26	8	3
Brazil	100%	36%	26%	3%	29%	35%
Argentina	100%	49%	39%	8%	26%	24%
Chile	100%	58%	38%	17%	18%	23%
Uruguay	100%	80%	37%	48%	15%	6%

TABLE 5
First authorship of nanotechnology publications (percentages)[21]

	Argentina	Brazil	Chile	Uruguay
Academic	54.1	74.8	69.2	48.1
Government	21.5	5.0	0.0	1.9
Industry (private)	0.1	0.2	0.0	0.0
Industry (public)	0.0	0.8	0.2	0.0
Hospital	0.4	0.1	0.0	0.0
Other (fundat, assoc)	0.5	0.1	0.0	0.0

[20] International collaborations with leading centers include collaborations with USA, France, Spain, Germany, Italy, England, Japan, Canada, Russia, and China.
[21] Totals do not add up to 100 percent because some publications have first authors from other countries (international or regional collaborations.)

TABLE 6
Main subject areas for nanotechnology publications (percentages)[22]

	Argentina	Brazil	Chile	Uruguay
Physics All	39.6	44.5	32.6	35.2
Chemistry All	31.1	22.3	31.6	24.1
Materials Science All	25.9	32.0	24.9	29.6
Biology	6.2	4.9	10.0	7.4
Engineering All	6.0	7.1	3.7	11.1
Medicine All	4.1	5.7	9.8	5.6
Electronics	3.0	4.5	4.0	7.4
Geology, Environmental, Energy All	2.8	1.4	3.5	11.1
Agricultural All	1.7	0.8	1.0	0.0
Mathematics All	0.3	0.4	0.2	0.0
Computer Science All	0.2	0.2	0.0	0.0
Social Sciences	0.1	0.0	0.0	0.0

TABLE 7
Most active institutions undertaking nanotechnology research in the region, by publications

Rank	Organization	Publications 1990-2006	Regional share (%)
1	Universidade de São Paulo (Brazil)	1,424	20.0
2	Universidade Estadual de Campinas (Brazil)	997	14.0
3	Universidade Federal de São Carlos (Brazil)	592	8.3
4	Universidade Estadual Paulista 'Júlio de Mesquita Filho' (Brazil)	431	6.0
5	Universidade Federal do Rio de Janeiro (Brazil)	401	5.6
6	Universidade Federal do Rio Grande do Sul (Brazil)	322	4.5
7	Universidade Federal de Minas Gerais (Brazil)	294	4.1
8	Universidad Nacional de La Plata (Argentina)	291	4.1
9	Universidade de Brasília (Brazil)	262	3.7
10	Universidad de Buenos Aires (Argentina)	259	3.6
11	Comisión Nacional de Energía Atómica (Argentina)	217	3.0
12	Universidade Federal do Ceará (Brazil)	201	2.8
13	Universidade Federal de Pernambuco (Brazil)	175	2.5
14	Universidade Federal do Paraná (Brazil)	164	2.3
15	Pontifícia Universidade Católica do Rio de Janeiro (Brazil)	163	2.3
16	Consejo Nacional de Investigaciones Científicas y Técnicas (Argentina)	158	2.2
17	Universidad Nacional de Córdoba (Argentina)	156	2.2
18	Associação Brasileira de Tecnologia Luz Síncroton (Brazil)	155	2.2
19	Universidade Federal de Santa Catarina (Brazil)	127	1.8
20	Universidad de Chile (Chile)	123	1.7

[22] Totals add up to more than 100 percent because some publications are categorized in more than one subject area.

TABLE 8
Most active institutions undertaking nanotechnology research in Brazil, by publications

Organization	Publication Count	National share (%)
Universidade de São Paulo	1,424	26.1
Universidade Estadual de Campinas	997	18.3
Universidade Federal de São Carlos	592	10.9
Universidade Estadual Paulista 'Júlio de Mesquita Filho'	431	7.9
Universidade Federal do Rio de Janeiro	401	7.3
Universidade Federal do Rio Grande do Sul	322	5.9
Universidade Federal de Minas Gerais	294	5.4
Universidade de Brasília	262	4.8
Universidade Federal do Ceará	201	3.7
Universidade Federal de Pernambuco	175	3.2

TABLE 9
Most active institutions undertaking nanotechnology research in Argentina, by publications

Organization	Publication Count	National share (%)
Universidad Nacional de La Plata	291	22.1
Universidad de Buenos Aires	258	19.6
Comisión Nacional de Energía Atómica	216	16.4
Consejo Nacional de Investigaciones Científicas y Técnicas	158	12.0
Universidad Nacional de Córdoba	153	11.6
Centro Atómico Bariloche	114	8.6
Universidad Nacional de Mar del Plata	88	6.7
Instituto Balseiro	68	5.2
Universidad Nacional del Sur	49	3.7
Universidad Nacional del Litoral	48	3.6

TABLE 10
Most active institutions undertaking nanotechnology research in Chile, by publications

Organization	Publication Count	National share (%)
Universidad de Chile	123	25.6
Universidad de Concepción	93	19.3
Pontificia Universidad Católica de Chile	88	18.3
Universidad de Santiago de Chile	86	17.9
Pontificia Universidad Católica de Valparaíso	62	12.9
Universidad Técnica Federico Santa María	54	11.2
Universidad Católica del Norte	26	5.4
Universidad Austral Chile	20	4.2
Universidad Tecnológica Metropolitana - UTEM	16	3.3
Comisión Chilena de Energía Nuclear - CCHEN	13	2.7

TABLE 11
Most active institutions undertaking nanotechnology research in Uruguay, by publications

Organization	Publication Count	National share (%)
Universidad La República	53	96.4
Instituto de Investigaciones Biológicas Clemente Estable - IIBCE	2	3.6

TABLE 12
Degree centrality for main research institutions in the nanotechnology network of top 50 institutions

Insitution	**Degree**	**NrmDegree**
Universidade Estadual de Campinas	43	87.755
Universidade de São Paulo	41	83.673
Universidade Federal do Rio de Janeiro	36	73.469
Universidade Federal de São Carlos	33	67.347
Universidade Estadual Paulista 'Júlio de Mesquita Filho'	32	65.306
Consejo Superior de Investigaciones Científicas, Ciencia e Investigación - Spain	30	61.224
Universidade Federal do Rio Grande do Sul	30	61.224
Univ Paris - France	29	59.184
Comisión Nacional de Energía Atómica	27	55.102
Associação Brasileira de Tecnologia Luz Síncroton	27	55.102
CNRS - France	27	55.102
Centro Brasileiro de Pesquisas Físicas	26	53.061
University of California - USA	26	53.061
Pontificia Universidade Católica do Rio de Janeiro	25	51.02
Max Planck Institute - Germany	22	44.898
Universidade Federal do Paraná	22	44.898
Universidade de Brasília	22	44.898
Instituto Balseiro	21	42.857
Universidad de Buenos Aires	21	42.857
Universidad Nacional de Córdoba	21	42.857

TABLE 13
Main strategies for nanotechnology development

Strategy	Co-authorship intl. (all)	Co-authorship intl. leading centers	Co-author ship regional neigh bors	Single, natl. institu tion	Natl. collabora tions	Institu tional concentra tion	Acad. first author ship	Gov. first author ship
a) National target strategy	+	+	++	+++	+++	+	++	+++
b) International organizational alliance	++	+++	+	++	++	+++	+++	+
c) Southern collaboration strategy	+	+	+++	+	+	+	++	++

Notes: in each cell is represented the extent to which the variable is related with each strategy, ranging from less related (+) to more related (+++).

TABLE 14
Share of publications co-authored with other countries (percentages)

Country	Argentina	Brazil	Chile	Uruguay
Brazil	6.5		11.6	14.8
Argentina		1.6	3.1	9.3
USA	12.0	9.4	7.3	11.1
Chile	1.1	1.0		24.1
France	4.9	5.3	8.7	5.6
Spain	13.5	2.2	13.5	11.1
Germany	5.0	4.3	4.4	0.0
Italy	5.0	2.3	1.5	5.6
England	2.0	1.9	2.3	1.9
Japan	1.1	2.2	0.4	1.9
Canada	1.0	1.6	2.1	0.0
Cuba	0.1	1.5	0.8	0.0
Russia	0.3	1.4	0.0	0.0
Portugal	0.6	1.2	0.8	0.0
Belgium	0.2	1.0	1.2	1.9
Mexico	1.8	0.4	2.3	0.0
China	0.5	0.8	1.0	1.9
Uruguay	0.4	0.1	2.7	

FIGURE 2 – Network of top nanotechnology institutions