Chapter 4

Analysis of scientific production based on publications in specialized journals

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1. Introduction

Indicators of scientific production have been produced and used for a long time, but are currently the focus of growing attention as tools for measuring the results of activity in the sector. Scientific production is increasingly important as a driver of science, technology and innovation (ST&I) activities and a key competitiveness factor. Scientific production indicators contribute, for example, to the analysis of the outputs of available infrastructure and investment policies in ST&I research. They are also useful in analyzing the dynamics of different scientific area, including the identification and comprehension of emerging or consolidated areas. Many national and international ST&I development agencies produce and use scientific production indicators to formulate, execute and monitor ST&I policy. Another reason for the growing attention paid to such indicators is the increasing availability of methodologies and electronic resources for their production, often including pre-established indicators that can be accessed relatively easily.

Despite the methodological complexity of constructing and using scientific production indicators, as described in item 1 of the Methodological Annex, their application is spreading, not only in public policy planning and execution but also for a better understanding of science in the business community as well as the scientific community itself and other sectors of society. The development of methodologies for measuring scientific output is the object of scientometrics and encompasses interdisciplinary techniques that involve bibliometrics, economics and administration, among others. Scientometrics is a discipline that analyzes science, understood as the entire universe of physical, biological and social sciences, in order to understand its structure, evolution and connections, its linkages to factors of influence, outputs, and technological, economic and social development. Quantitative bibliometric indicators based on published documents, especially articles in scientific journals, are statistical measures of publications, co-authorship, citations and word co-occurrence, among others, as presented in the methodology used for this chapter (Ashton & Klavans, 1997; Spinak, 1996, 1998; Trzesniak, 1998; Okubo, 1997; FAPESP, 2005).

Europe, the United States and other leading countries and regions in world scientific production have produced important studies of systematic indicators that are accessible to researchers (NSB, 2006, 2008; European Commission, 2003). However, these studies use indicators and analyzes focused on their own needs. They are limited and inadequate for direct use in the analysis of scientific activity in countries whose participation in world scientific output is far smaller (Spinak, 1998; De Meis & Leta, 1996; Mugnaini, Jannuzzi & Quoniam, 2004). Because the production and use of indicators depend strongly on purpose and context, it is vitally important for Brazil to undertake research on national scientific production and its share of international production based on the specificities and interests of the country and of its regions, states, municipalities and institutions.

Scientific production in Brazil and São Paulo State is growing significantly, but its use to develop technology, intensify innovation and contribute to economic competitiveness and improved social conditions is still weak (Cruz & Pacheco, 2004; FAPESP, 2002, 2005). The importance of science to national development is not widely recognized, largely owing to insufficient dissemination of knowledge about national science in the media, government agencies, business, society in general and even the scientific community. This ignorance may also lead to inadequate use of information and procedures for analyzing scientific production, and to a loss of credibility for science itself.

Scientific production can be analyzed on a macro level, using indicators for world production and the shares of countries and regions in major scientific fields, for example; on a micro level, focusing on the role of a single institution, research group or scientific field; or on an intermediate or meso level (Macias-Chapula, 1998; Spinak, 1998; Okubo, 1997; Bornmann & Daniel, 2008). Important examples of international studies on a macro level are those conducted by the U.S. National Science Foundation (NSB 2002, 2004, 2006, 2008) and the European Commission's Directorate-General for Research (European Commission, 2003). In Brazil, several researchers have produced macro-level studies since the 1980s (Carvalho & Barreto, 1980; Lancaster & Carvalho, 1982; De Meis & Leta, 1996; Leta & Cruz, 2003; Glänzel, Leta & Thijs, 2006), as have the Ministry of Science & Technology (CNPq, 2008b) and the São Paulo State Research Funding Agency (FAPESP), especially in specific chapters devoted to the analysis of scientific production (FAPESP, 2002; FAPESP, 2005). Examples of Brazilian micro-level studies include Campos & Carvalho (1981), Figueira, Leta & De Meis (1999), Rodrigues & Friederich (1998), and Faria, Gregolin & Hoffmann (2007).

Scientific production indicators can be constructed using a broad array of types of publications, such as articles in journals, books, theses etc. The volume of scientific information produced worldwide is enormous. There are estimates that some 2.5 million scientific articles are published annually in 34,000 journals and that this is probably less than half the scientific knowledge produced by all of the world's universities and research centers (Rehen, 2007).

Despite the abundance of publications, it is difficult to obtain sufficiently organized bibliographic data for the bibliometric processing required to construct indicators (Okubo, 1997). Scientific production circulates as part of a large social system and with certain specific functions such as presenting research findings, disseminating knowledge of discoveries, attributing credit and recognizing work. Furthermore, given the peculiarities of each knowledge area, the scientific communities in each area have different preferences for the media used to diffuse their work, which may include books as well as local and international journals. For example, publication of scientific papers in journals tends to be preferred over books by researchers in the exact and biological sciences, while the reverse tends to be true in human and social sciences (Prat, 1998; Spinak, 1998; Macias-Chapula, 1998; Targino & Garcia, 2000; Van Leeuwen, 2006). The spread of new information and communications technologies (ICT), including the internet, also points to other possibilities, such as the use of blogs to disseminate scientific production (Rehen, 2007).

The growing availability of online research databases, digital journals and other electronic and computerized resources has made this type of source the most widely used to construct indicators on a global basis, because it facilitates data extraction, storage and treatment. However, it should be mentioned that indicators based on publication in journals are ill-suited for direct comparison of different knowledge areas owing to the diversity of publications available and the different preferences for types of publication in different knowledge areas. It should also be stressed that these databases were not originally developed for quantitative research purposes and that each database has its own specific criteria for selection of content, often entailing limitations in terms of coverage, structure, levels of aggregation and the standardization or content of the bibliographic records concerned. To make proper use of these databases, it is necessary to understand their characteristics and carefully select the sources of data, which must be adequately treated in accordance with the goals of the study in question. None of the databases concerned covers everything produced worldwide. Hence the need to select the most suitable databases for each analysis, taking into account such aspects as geographic coverage, knowledge area and time period. In addition, it is advisable to use more than one database in order to assure comparability and complementarity, given the lack of total coverage of publications in the knowledge areas researched (Okubo, 1997; Trzesniak, 1998; Macias-Chapula, 1998; Rocha & Ferreira, 2004).

The databases most used worldwide to construct scientific production indicators are *Science Citation Index Expanded* (SCIE), *Social Science Citation Index* (SSCI), and *Arts & Humanities Citation Index* (A&HCI), originally created by the now defunct ISI but now all owned by Thomson Reuters and available on line from its *Web of Science* portal. These databases constitute the largest structured multidisciplinary collection of journals and articles, comprising a significant proportion of global production in the form of published material in many sciences. They are among the few databases that permit research based on citations of indexed articles, a form of analysis increasingly used worldwide. More information on SCIE, SSCI and A&HCI (Thomson Reuters, 2008a) can be found in item 2 of the Methodological Annex. The vast majority of the journals indexed by these databases are international, but Thomson Reuters has recently added 700 titles (some of them Brazilian) in different scientific areas and considered regional rather than international in coverage (Thomson Reuters, 2008b). Coincidentally or not, another important multidisciplinary database has been created recently (in 2004), with global coverage and the possibility of citation analysis: this is Scopus, owned by Elsevier. Increasing attention is being paid to Scopus because it indexes more bibliographic records than all the databases compiled by *Web of Science* in any given year and because it represents a consistent alternative to the latter's hegemony for indicators prior to its creation.

There are other specialized databases that can also be useful for the production of indicators, such as Compendex (engineering), PubMed (medicine and health-related areas), Inspec (physics, electrical and electronic engineering, computing and information technology), *Biological Abstracts* (biology) and *Sociological Abstracts* (sociology and related areas), as well as others (more information on these can be found in item 3 of the Methodological Annex). However, they do not include citation data and only the first author's institution (or country) can be identified, considerably restricting the production and analysis of indicators in cases of co-authorship.

There is also the Brazilian database SciELO (Scientific Electronic Library On Line), developed and maintained in partnership by FAPESP, the Latin American & Caribbean Center for Health Science Information (BIREME) and the National Council for Scientific & Technological Development (CNPq) to promote national and international visibility for scientific publications in Latin America and the Caribbean (more information on SciELO can be found in item 3 of the Methodological Annex). This has indeed been the case thanks to an increase in the impact factor[1] for local journals indexed both by SciELO and *Web of Science*, with international recognition (Alonso & Fernández-Juricic, 2002; Meneghini, Mugnaini & Packer, 2006). SciELO is also increasingly used as an instrument for analyzing the characteristics of national and regional science (Packer, 1998; Spinak, 1998; Fusaro, 2003; Goldenberg, Castro & Azevedo, 2007). Other Brazilian databases developed in recent years have played an important role in the construction and analysis of national scientific production indicators, in particular the Lattes Platform (CNPQ, 2008a), the CAPES Thesis Bank (CAPES, 2008a) and the Brazilian Digital Library of Theses & Dissertations (IBICT, 2008).

The main data sources for this chapter were SCIE and SSCI, chosen because of their multidisciplinary nature and global coverage, as well as the possibility of citation analysis and their widespread use around the world, permitting comparisons with international results.

Scopus was used for an exploratory study, given its importance, multidisciplinary nature and global coverage, as well as the possibility of citation analysis. SciELO, the Brazilian database, was also used in specific cases. A case study in the area of nanotechnology, presented in Box 4.2, involved a comparative analysis using *Derwent Innovations Index*, one of the main international databases of bibliographic patent data. It should be noted that while the use of multiple databases as a source of data for indicators enriches the analysis it also increases its complexity, since concordance among indicators based on different sources contributes to their validation while discordance alerts to the need for more in-depth analysis (Okubo, 1997; FAPESP, 2005; Packer & Meneghini, 2006).

For specific aspects on a global scale, data were taken from studies by the National Science Foundation (NSB, 2002, 2004, 2006) rather than directly from scientific databases, owing to access restrictions. The studies in question were also based on SCIE and SSCI. This solution was adopted in particular to construct an indicator of world scientific production by knowledge area and to produce citation indicators for the years 1990, 1992, 1994, 1996, 1997, 1999, 2001 and 2003.

The data collected and treated were used to produce indicators of publications, collaboration and citations, in the form of graphs for the period 2002-2006, tables for the period 1998-2006, and case studies for specific periods and situations. The analysis encompassed absolute numbers, contributions, percentage shares and growth rates for Brazil and São Paulo State in global, national and state scientific production, as well as network linkages for specific cases and situations. The data were disaggregated by country, state, city, institution and knowledge area when required by the analysis. More details on the methodology and tools utilized can be found in the Methodological Annex (see also Box 4.1 at the end of this section).

The chapter has four main parts. The first discusses scientific production in Brazil and São Paulo State against the backdrop of global production and highlighting growth in the period 2002-2006, the contributions of regions, states, cities and institutions, and the distribution of publications by knowledge area.

The second part deals with scientific collaboration in Brazil and São Paulo State, analyzing changes in collaboration across national and state borders, as well as within the state, in terms of growth and contributions to the total number of publications in Brazil and São Paulo State in the period. The main international partner countries and the knowledge areas in which collaboration has expanded are identified. Collaboration between institutions in São Paulo State and its contribution to the state total are also highlighted. Institutional collaboration is analyzed in depth in section 5, which contains boxes on the research networks formed in Brazil around five themes of special interest in today's S&T universe: nanotechnology, climate change, sugarcane genomics, "Omics"[2] and biophotonics. The third part focuses on the relevance of Brazilian scientific production in terms of international citations to Brazilian publications, highlighting the evolution of citations to Brazilian publications in the world context and by knowledge area.

The fourth part focuses on the use of other multidisciplinary and specialized databases for the creation of scientific production, collaboration and relevance indicators in addition to those based on SCIE and SSCI.

The conclusions sum up the relevant findings and present recommendations for the strengthening of scientific production support policy in São Paulo State and Brazil. In light of the breadth and complexity of scientific production when analyzed for the purposes of public policy formulation, the chapter sets out to contribute to an understanding of scientific production in Brazil and São Paulo State, comparing it with production in the world and in selected countries where

1. Impact factor (IF) is a measure of the frequency with which the average article in an indexed journal is cited in a particular year or period. IF is calculated by dividing the number of citations of articles in a journal in the period concerned by the total number of articles published in the period. In the case of Thomson Reuters, IF is derived by dividing the number of citations in year 3 to any items published in the journal in years 1 and 2 by the number of substantive articles published in that journal in years 1 and 2.

2. The simplified denomination "Omics" is used here to refer to the "scientific collaboration network in *genomics, proteomics and lipidomics.*"

Box 4.1 Analysis of scientific production by knowledge area: possibilities and reservations

Classification of scientific production by knowledge area is a basic precondition for scientometric analysis. Despite its importance, there are no indicators that permit direct comparisons between knowledge areas and it is still difficult to classify publications by area and subarea without frequent dissension, overlaps and confusion (Glänzel & Schubert, 2003; Vinkler, 2002; Zitt, Ramanana-Rahary & Bassecoulard, 2005).

There is no single or correct method for classifying sciences into areas and subareas. As a result, several different classifications exist. Journals are classified according to various approaches, such as a “cognitive” approach based on the experience of specializts, a “pragmatic” approach based on existing systems, and a “scientometric” approach based on citations and co-citations, as well as a combination of approaches (Glänzel & Schubert, 2003; Jarneving, 2005; Leydesdorff, 2008). Many information sources and studies of science develop their own classification, with differences in both the names, number and coverage of knowledge areas and subareas, and the links between these and the journals classified. Thomson Reuters uses two classifications in its databases and information products: one is generic, comprising 22 areas and assigning journals exclusively to one area, while the other is more detailed, comprising some 200 subareas and assigning journals to more than one subarea in many cases. Some products, such as Essential Science Indicators, use the generic classification; others, such as SCIE, SSCI and JCR, use the more detailed system. There is no public explicit list of correspondences between areas and subareas in the two classifications. These classifications are widely used in scientometric studies, more for lack of an alternative than for their robustness (Leydesdorff, 2008). Scopus has its own classification which differs from that used by SCIE and SSCI. Any Brazilian study that sets out to compare investment and human resources as ST&I inputs, as well as scientific production by knowledge area, faces the problem that the classification methods used by CNPq and CAPES are mutually compatible but differ from those used by FAPESP in Brazil and by foreign organizations such as NSF. These are all different in turn from the classifications used by the journal databases, so that only partial comparisons are feasible.

Another aspect that must be highlighted is the advisability of avoiding direct comparisons between knowledge areas. The different areas and subareas display differences in publishing speed (the time taken to publish articles and the number of annual publications), the useful life of published information, the average number of references in articles etc., as well as differences in the frequency of publishing in books or journal articles, different scale effects etc. (Vinkler, 2002; Leydesdorff, 2008; Costas et al., 2008). These differences affect the analysis of scientific production, publications and citations by knowledge area, and may result in misleading conclusions. For example, impact factors may vary considerably when mathematics and genetics journals are compared (Leydesdorff, 2008). However, it is possible to compare indicators for the same area at different times or in different geographic regions.

It is worth stressing that the increasingly multidisciplinary nature of scientific research, driven by its importance to the application of scientific knowledge for innovation, makes the classification of publications by knowledge area more complex (Leydesdorff, 2008). In what areas should publications in such topical subjects as nanotechnology or climate change be classified, for example?

The main question, therefore, is how to find a trade-off between the requirements of “scientometric best practice” and the production of indicators that are acceptable to and useful for institutions, researchers and science policy formulators (Vinkler, 2002).

possible, with emphasis on the period 2002-06. Without being exhaustive or conclusive, the aim is to provide input for the debate and for decision making with regard to ST&I policy.

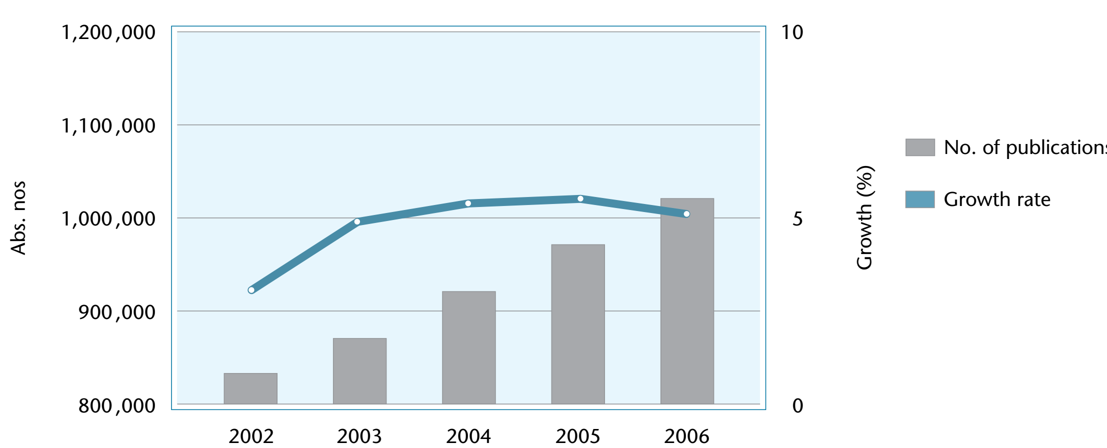
2. World scientific production

Worldwide scientific production indexed by the SCIE and SSCI databases grew 22.7% from 832,048 publications in 2002[3] to 1,020,533 in 2006. This is 3.4 times more than growth in the period 1998-2002, which was 6.6% (Figure 4.1; Detailed Table 4.1), reflecting a significant increase in the number of indexed publications for most of the countries that contribute substantially to world scientific production (Detailed Table 4.3), probably due to strong global economic growth in the period, rising investment rates, S&T policy implementation, growth of investment and human resources in S&T, and increasing numbers of indexed titles, among other factors.

According to data from *Essential Science Indicators* for the period 2002-06, the United States ranks first worldwide in terms of the number of scientific publications, well ahead of Japan in second place (Figure 4.2; Detailed Table 4.2).[4] Behind the U.S. come a group of countries (Japan, Germany, England representing the U.K., China and France) with significant scientific production. Another group of eight countries at a lower level (Canada, Italy, Spain, Australia, Russia, South Korea, India and the Netherlands) have more than 100,000 publications. Brazil ranks 17th, with 77,876 publications quantified in this source. Sweden ranks 15th but with only 6% more publications than Brazil, whereas the Netherlands ranks 14th with 44% more publications than Brazil, indicating that Brazil must increase its publications significantly in order to rise above 15th place in the rank order.

In order to analyze the evolution of world scientific production in the period 2002-06, 15 selected countries were divided into three groups with different levels of contribution to total world production (Figure 4.3; Detailed Table 4.3), according to the procedure adopted in the previous edition (FAPESP, 2005). The U.S. ranks first with 31.3%, far more than any other country, as has been the case for a long time. Next come the U.K. (8.7%), Japan (8.1%), Germany (7.8%), China (6.3%) and France (5.6%). These are the only countries that

Figure 4.1
World publications indexed by SCIE and SSCI – 2002-2006



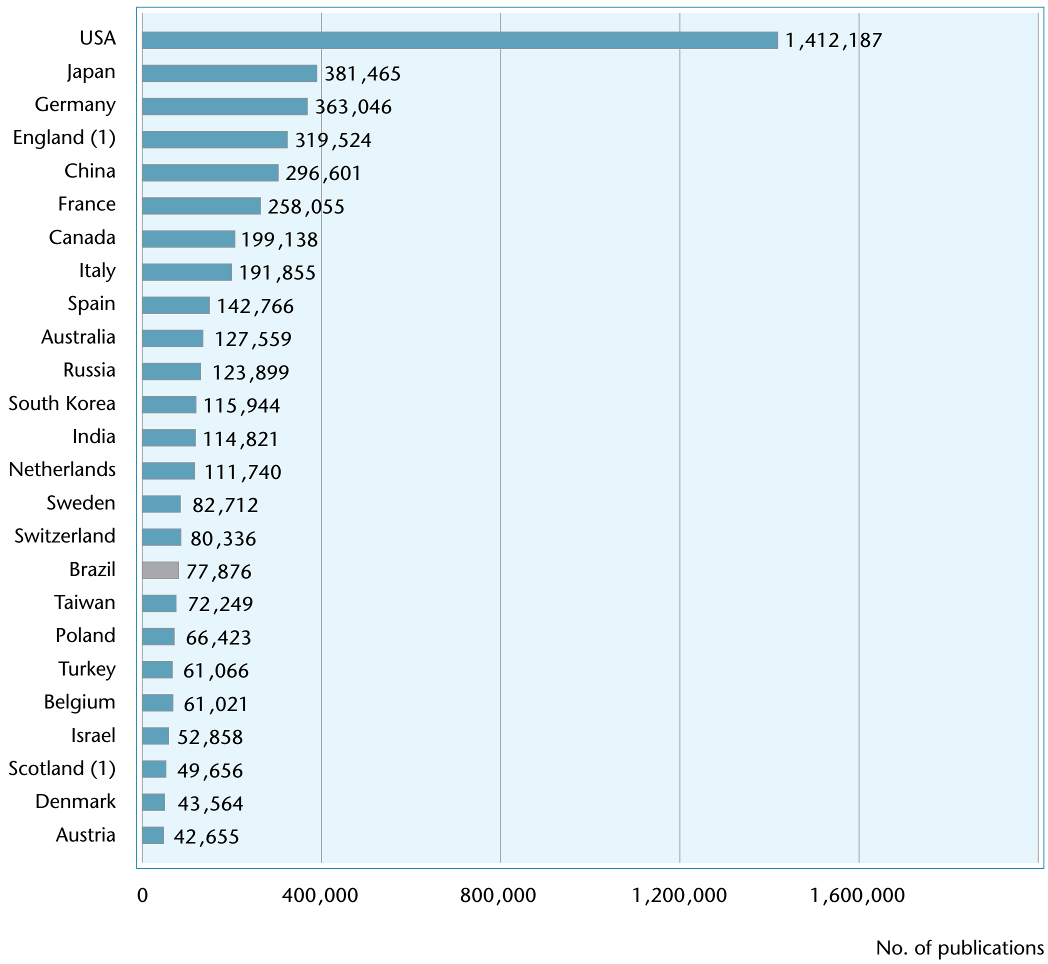
Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.1.

3. The total number of publications for 2002 cited in the previous edition of this report (FAPESP, 2005, chapter 5) was 1,028,391. The difference is due to a change in the dataset used to produce these indicators. The previous edition considered all types of publications indexed by SCIE. This edition considers only articles, letters, notes and reviews indexed by SCIE and SSCI. The change was made in order to comply with the procedures used in international studies (NSB, 2002, 2004, 2006; European Commission, 2003).

4. Essential Science Indicators treats England, Scotland, Wales and Northern Ireland as separate entities and it is impossible to aggregate publications for the United Kingdom accurately. This may explain why Japan ranks second.

Figure 4.2
Ranking of selected countries by number of publications quantified in *Essential Science Indicators* – 2002--2006 (cumulative)



Source: Thomson Reuters (2008), *Essential Science Indicators*.

Note: See Detailed Table 4.2.
(1)England, Scotland, Wales and Northern Ireland are treated as separate entities and it is impossible to aggregate publications for the United Kingdom accurately.

contribute more than 5% to world scientific production. It is worth highlighting the rapid ascent of China, which joined this small group of leaders in scientific production in 2003, having contributed only 2.4% in 1998, when Brazil accounted for 1.1%, or less than half China's share (Figure 4.3a; Detailed Table 4.3).

The U.S. share fell from 32.5% in 1998-2002 to 31.5% in 2002-06 (Figure 4.3a; Detailed Table 4.3).[5] The U.S. share of world scientific production has been falling for a long time. It was overtaken by the European Union as a bloc in 1996. More recently this fall has been associated with the rapid growth of production by China, Taiwan, South Korea, Singapore (the "Asian Tigers") and other countries (Ley-

5. Detailed Table 4.3 was constructed on the basis of the number of publications resulting from searches by country name and year of publication. The searches in question covered more parameters and were performed at a later date than the collection of data on Brazilian publications in 1998-2006, used in most of the Detailed Tables. Detailed Table 4.3 permits a comparison between Brazilian publications and those of other countries, but owing to methodological differences the numbers in Detailed Table 4.3 do not coincide with those of other Detailed Tables.

desdorff & Park, 2005; Zhou & Leydesdorff, 2006; Shelton, 2008), largely thanks to rising investment in research and development (R&D) in these emerging-market countries, while U.S. investment, which remains huge, is not rising so fast (Shelton, 2008). It should also be noted that country shares are strongly influenced by journal selection criteria, language barriers and other factors inherent in the databases used for this analysis (Leydesdorff & Park, 2005; Zhou & Leydesdorff, 2006). Database bias can underestimate the production of countries not considered part of the so-called mainstream, such as Brazil, and certain knowledge areas such as human and social sciences (Collazo-Reyes et al., 2008; Testa, 1998; Spinak, 1998; Zitt, Ramanana-Rahary & Bassecoulard, 2003; Leydesdorff; Park, 2005; Zhou; Leydesdorff, 2006).[6]

Most of the countries in the group with the largest shares of world scientific production have been there for a long time, with the exception of China, a relative newcomer, and for this reason are deemed to constitute the *mainstream* in this field. This predominance has been explained as a reflection of the large numbers of scientists and engineers in activity in these countries, combined with heavy investment in R&D, among other factors (FAPESP, 2002; Contini, Reifschneider & Savidan, 2004; Shelton, 2008; Unesco, 2008).

In the group of countries selected for the purposes of this study, with contributions ranging from 2% to 5%, Canada is the leader but it is worth highlighting the growth of production in South Korea (65.3%) and India (45.6%), as shown in Figure 4.3b and Detailed Table 4.3. The other countries in this group – Canada, Spain and Australia – also display higher growth than the mainstream countries except China. South Korea, which was in the bottom group in the period covered by the previous edition (FAPESP, 2005), has since moved up into the intermediate group.

Brazil stands out among Latin American countries. Its contribution to world scientific production indexed by SCIE and SSCI was 1.9% in 2006, up from 1.6% in 2002 and 1.2% in 1998 (Detailed Table 4.1). This strong growth evidences continuation of the trend seen since the 1980s: Brazil's share was 0.2% in 1981 (behind Argentina) and averaged 0.7% in the period 1995-97 (FAPESP, 2002). Nevertheless, it lags behind other emerging-market countries, such as South Korea, with which Brazil is frequently compared. South Korea's share rose from 1.3% in 1998, similar to that of Brazil (1.2%), to 2.7% in 2006, similar to that of India, while Brazil's contribution reached only 1.9% in 2006. In 2002-06 Brazil contributed 1.7%, while South Korea's share reached 2.5%, equivalent to India's (Detailed Table 4.3). South Korea's growth may be associated with greater deployment of financial and human resources, alongside higher investment in R&D than Brazil. For example, according to statistics from the U.N. Educational, Scientific & Cultural Organization (Unesco, 2008), Brazil invested some US$15 billion in R&D on a purchasing power parity basis in 2005, or 0.97% of gross domestic product,[7] while South Korea invested more than US$30.6 billion, or 2.79% of GDP. The number of full-time-equivalent researchers in Brazil in 2004 was 84,789, of whom 56,008 were in higher education (66%), while South Korea had 156,220 FTE researchers, 25,522 (16%) of whom were in higher education and most were in business organizations, affording the latter country better conditions for innovation (Cruz & Pacheco, 2004; OECD, 2007; World Bank, 2008). Two other Latin American countries selected for comparison, Chile and Mexico, also significantly increased their scientific production in the period 2002-06 although both lagged behind Brazil, while Argentina's grew much less (Figure 4.3c; Detailed Table 4.3).

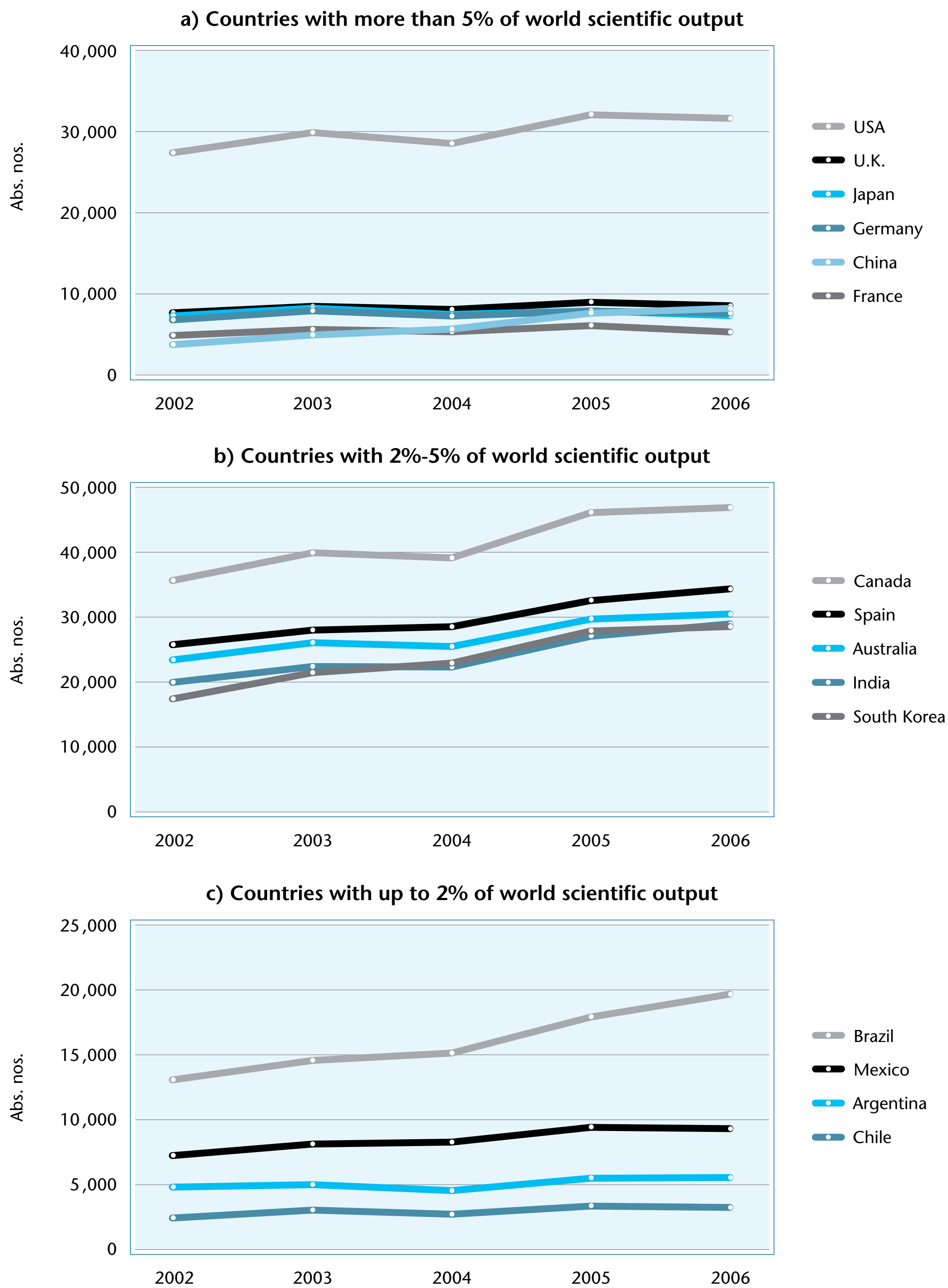
As can be seen from the breakdown by knowledge area in Table 4.1, medicine was the top area for five out of the six leading countries in terms of scientific production in 2003: the U.K., Germany, the U.S., Japan and France. This reflects the predominance of life sciences in the countries concerned (NSB, 2006). Meanwhile, China produced the most in physics, chemistry and engineering, which accounted for the largest proportion of Chinese journals indexed by Thomson Reuters. This may be associated with the country's technological innovation policy and rapid industrialization. Biomedical, earth and space sciences were also important to a greater or lesser extent for most of the countries in this mainstream group of world scientific production, as shown by Table 4.1. This predominance of certain knowledge areas in scientific production may be associated largely with the principles used to construct the databases concerned.

Brazil's scientific production broke down similarly to those of the mainstream countries and those of the databases used. Physics, biomedical research and biology accounted for a larger share than the world average. Chemistry, engineering, psychology and health were

6. The particularly strong growth in indexed publications between 2002 and 2003 may to some extent reflect changes in the structure of these databases, which may have been taking place since 2001 (FAPESP, 2005), although they apparently stabilised in later years. The number fell in 2006, the last year of the period analyzed (Figure 4.1).

7. According to the data presented in Chapter 3 of this edition, Brazilian investment in R&D was somewhat larger in 2005, corresponding to 0.98% of GDP.

Figure 4.3
Publications indexed by SCIE and SSCI – selected countries, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.3.
This table was constructed on the basis of the number of publications resulting from searches by country name and year of publication. The searches in question covered more parameters and were performed at a later date than the collection of data on Brazilian publications in 1998-2006, used in most of the Detailed Tables. Detailed Table 4.3 permits a comparison between Brazilian publications and those of other countries, but owing to methodological differences the numbers in Detailed Table 4.3 do not coincide with those of other Detailed Tables.

close to the world average, while medicine, earth and space sciences, social sciences, mathematics and other areas were significantly below the world average (Table 4.1). These findings partly reflect the biases of the databases used, which emphasize areas and topics of world interest to the detriment of regional interests and are restricted to texts published in journals, whereas in some areas authors prefer to publish in books or other media. Moreover, lower shares for certain areas in the databases used do not necessarily mean scientific outputs in smaller quantities or of lower quality (Okubo, 1997; Spinak, 1998; Prat, 1998; Hamilton, 1991; Vinkler, 2002; Leydesdorff, 2008; Costas et al., 2008).

Table 4.1
Breakdown of SCIE- and SSCI-indexed publications by knowledge area for selected countries according to their contribution to world scientific production – Brazil & selected countries, 2003

Selected countries according to their contribution to world scientific production (2002-2006)	Breakdown of SCIE- and SSCI-indexed publications by knowledge area (%)												
	Total (Abs. nos.)	Medicine	Physics	Biomedical	Chemistry	Biology (1)	Engineering	Earth & space (2)	Social sciences	Mathematics	Psychology	Other (3)	Health
World	**698,726**	27.9	13.9	13.7	11.9	7.1	9.0	5.5	3.1	2.2	2.2	2.1	1.4
Countries contributing more than 5%													
USA	**211,233**	31.2	8.8	16.3	7.5	6.6	7.0	5.9	4.6	3.7	1.8	4.1	2.4
U.K.	**48,288**	32.1	9.3	14.2	8.2	6.2	7.1	6.0	6.1	3.1	1.6	3.4	2.8
Japan	**60,067**	27.2	20.8	13.3	14.7	6.3	12.1	3.1	0.5	0.4	1.3	0.1	0.1
Germany	**44,305**	31.3	16.8	13.7	12.4	5.3	7.7	5.4	1.9	2.0	2.2	0.8	0.6
China	**29,186**	10.7	24.9	8.2	24.8	4.2	16.8	4.3	0.8	0.4	3.6	0.9	0.3
France	**31,971**	26.4	16.9	14.3	12.9	5.9	8.6	6.8	1.8	1.0	4.7	0.5	0.3
Countries contributing 2%-5%													
Canada	**24,803**	29.0	7.3	14.6	8.0	9.9	8.6	6.9	4.6	3.9	2.0	2.4	2.6
Spain	**16,826**	24.5	11.9	13.0	17.8	12.0	7.4	5.5	1.9	1.1	3.5	1.0	0.4
Australia	**15,809**	30.2	6.8	12.3	7.3	14.9	6.6	7.5	4.2	3.7	1.4	2.6	2.4
India	**12,774**	15.5	18.1	12.9	26.6	6.9	11.9	4.9	1.1	0.2	1.2	0.4	0.2
South Korea	**13,746**	17.0	22.7	12.0	16.5	4.3	20.7	2.8	0.9	0.3	1.8	0.8	0.4
Countries contributing up to 2%													
Brazil	**8,684**	**24.6**	**17.1**	**15.7**	**12.9**	**10.8**	**9.0**	**4.3**	**1.0**	**0.6**	**2.4**	**0.4**	**1.4**
Mexico	**3,747**	17.5	21.2	12.0	9.8	15.6	8.4	7.4	2.1	1.5	2.1	0.5	1.9
Argentina	**3,086**	21.3	14.5	15.2	13.4	18.7	5.7	6.7	1.4	0.5	1.9	0.3	0.4
Chile	**1,500**	24.5	10.8	10.5	15.2	11.7	7.7	10.5	2.1	0.9	4.3	1.3	0.5

Source: *Science and Engineering Indicators (* NSB, 2006).

Note: This table uses the National Science Board's classification of publications by knowledge area. The classification used in the rest of the chapter is the same as that used by Thomson Reuters' *Essential Science Indicators.*
(1) Includes agriculture and food sciences, botany, animal science, ecology, entomology, general biology, general zoology, marine biology and hydrobiology, biology (miscellaneous), zoology (miscellaneous).
(2) Includes astronomy and astrophysics, earth and planetary sciences, environmental science, geology, meteorology and atmospheric sciences, oceanography, limnology

(3)) Includes communication, education, library and information science, law, administration and business, social work, other professional fields.

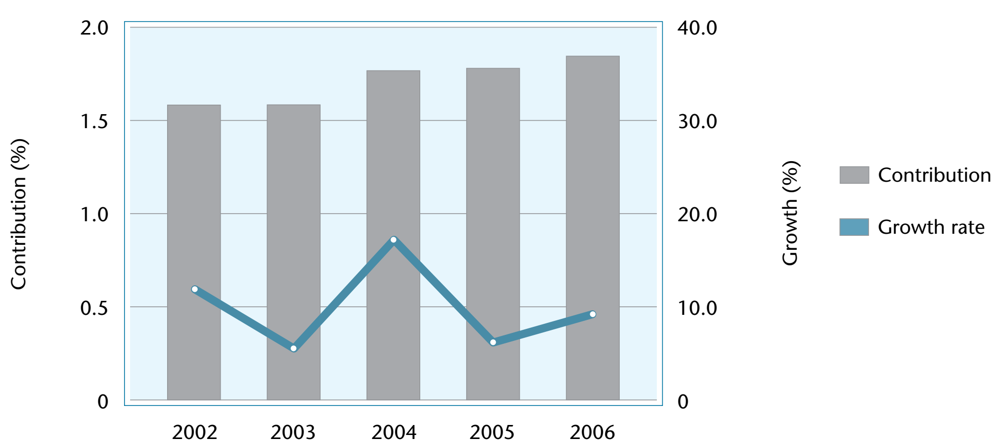
3. Brazilian scientific production

3.1 Brazil's contribution to world scientific production

As noted earlier, Brazil's contribution to world scientific production indexed by SCIE and SSCI rose from 1.6% in 2002 to 1.9% in 2006. The 43.5% growth in the number of publications in the period was well above world growth of 22.7%. The number of publications rose 43.5% from 13,180 in 2002 to 18,915 in 2006, well above world growth of 22.7% (Figure 4.4; Detailed Table 4.1).

The strong uptrend in Brazilian production has already been noted in previous studies, such as earlier editions of this publication, and is probably due to expansion in post-graduate programs and in numbers of post-graduate students and degrees awarded, as well as better qualification of academic staff at universities (Leta & Cruz, 2003; FAPESP, 2005; De Meis, Arruda & Guimarães, 2007). For example, according to data from CAPES (2008b), also analyzed in Chapter 2 of this publication, the number of PhDs awarded in Brazil rose 35.9% from 6,893 in 2002 to 9,366 in 2006, and the number of doctoral programs rose 2.84% to 1,185 in the same period. However, a lack of sufficient research funding to meet demand means that even highly productive research groups experience difficulties in obtaining funds, as shown by De Meis, L., Carmo, M.S. & De Meis, C. (2003). According to Chapter 3 of this publication, investment in R&D corresponded to 0.98% of GDP in 2006, whereas countries whose scientific production is growing faster than Brazil's, such as China and South Korea, invested far more – 1.42% of GDP in China's case and 3.01% in that of South Korea (Unesco, 2008).

Figure 4.4
Brazil's contribution to world publications indexed by SCIE and SSCI and annual growth rate – Brazil, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

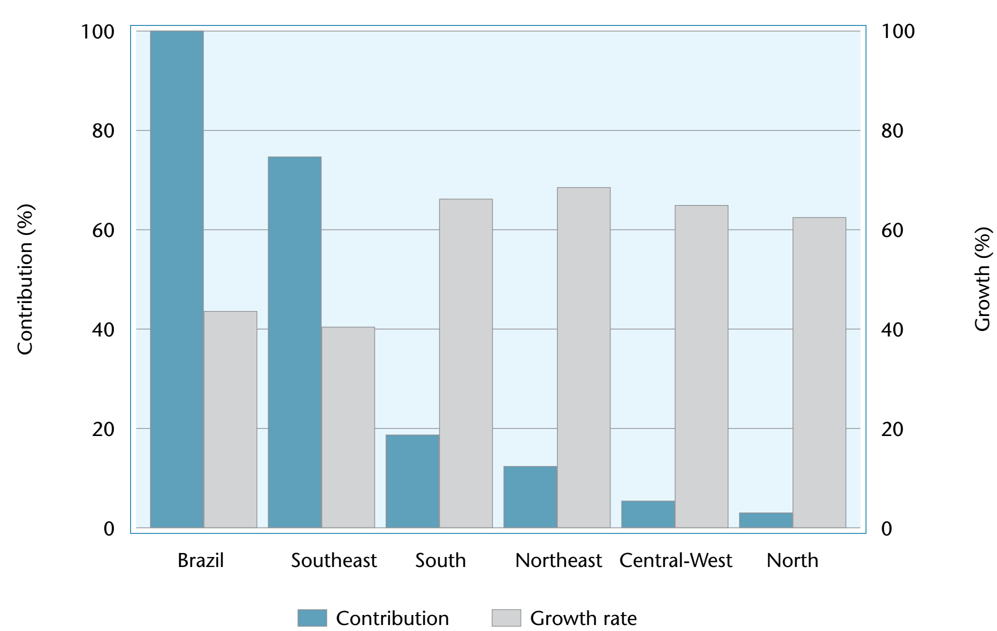
Note: See Detailed Table 4.1.

3.2 Contributions by regions and states to Brazilian scientific production

The Southeast is the leading region in SCIE- and SSCI-indexed scientific production, with 74.5% of the total in the period 2002-06, followed by the South (19%), Northeast (12.2%), Central-West (5.4%) and North (2.7%), as can be seen from Figure 4.5 and Detailed Table 4.4. The predominance of the Southeast may be associated with the installed R&D infrastructure, larger numbers of researchers and specialized human resources, and higher volumes of investment. Its scientific production grew 40.1% in 2002-06, which is impressive but less than all other regions of Brazil, where production grew 60%, led by the Northeast (68.3%). The difference in growth between the Southeast and other regions reflects at least partly the impact of S&T policies implemented by the federal and state governments, especially inasmuch as they seek to deconcentrate S&T activities and foster post-graduate studies and technological innovation in regions apart from the Southeast. For example, in 2006 the Southeast had 50.4% of all Brazilian research groups and 54.1% of Brazilian researchers with PhDs registered with these groups. The region received 57.3% of CNPq's investment, which was a similar proportion to those of previous years. However, human and financial resources originating from CNPq grew more in other regions, especially the Northeast and North (CNPq, 2001, 2002).

Concentration of scientific production in a single region is not recent and is not exclusive to Brazil. It also occurs in the United States, for example, as well as in other countries (De Meis & Leta, 1996; FAPESP, 2002). In Brazil, concentration in the Southeast is associated with the predominance of higher education institutions (HEIs) in this region, with their post-graduate programs and human resources, supported by S&T policy and programs implemented by FAPESP in the case of São Paulo State and by federal agencies such as CNPq, CAPES and FINEP. Where resources are scarce there is competition for government support

Figure 4.5
Contributions to SCIE- and SSCI-indexed Brazilian publications and annual growth rate by region – Brazil, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via Web of Science.

Note: See Detailed Table 4.4.

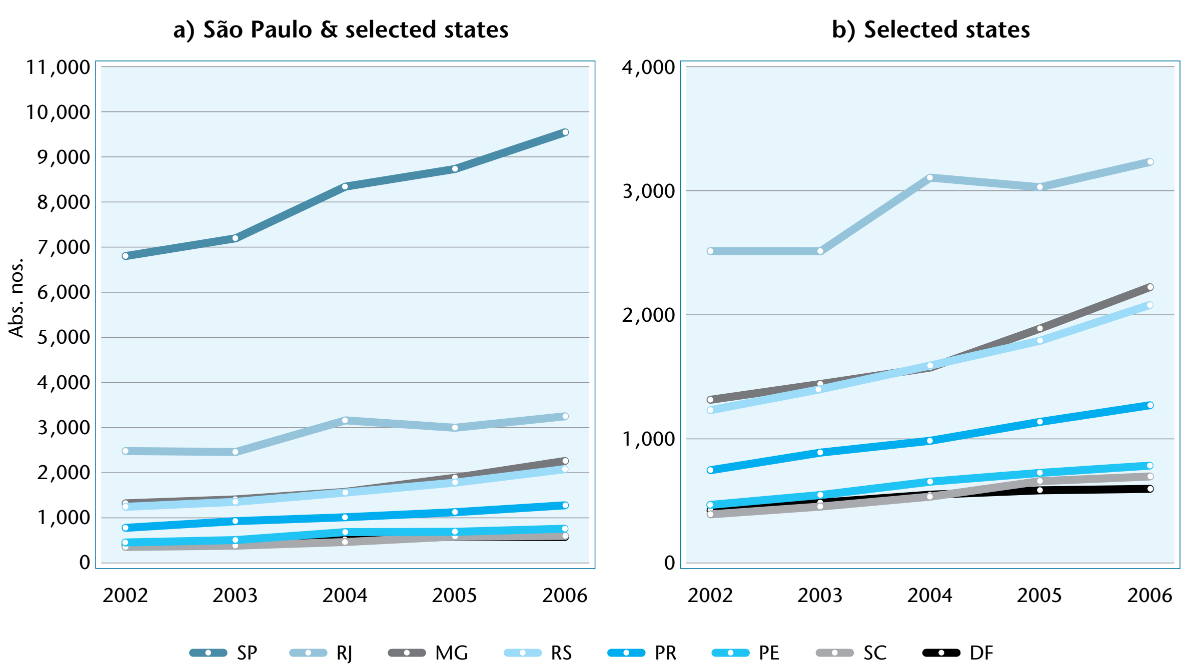
and it is very important to consider what is best for the country. The resources employed in policy measures to deconcentrate ST&I capabilities may to some extent hamper full utilization of human resources in regions where scientific activity is most dynamic (ABEQ, 2003; Leta & Cruz, 2003).

Scientific production indexed by SCIE and SSCI grew in almost all states in the period 2002-06. The exception was Roraima, where production is very small (about 0.1% of the Brazilian total). Production grew strongly in São Paulo State, albeit moderately less so than in Brazil (41.4% versus 43.5%). However, performance improved during the middle years of the period, enabling São Paulo State to increase its contribution to the national total from 49.9% between 1998 and 2002 to 51% between 2002 and 2006. The states with the largest numbers of publications in the period 2002-06 were São Paulo, with 51% of the national total, Rio de Janeiro (18%), Minas Gerais (10.6%), Rio Grande do Sul (10.2%), Paraná (6.3%), Pernambuco (4%), Santa Catarina (3.5%) and the Federal District (3.3%), as shown by Figure 4.6 and Detailed Table 4.4.

These findings confirm the concentration of scientific production in São Paulo and a few other states, especially in the Southeast, as found in previous editions since 1985, owing to the concentration of institutions, researchers, investment etc. (FAPESP, 2002, 2005). The positions of the mainstream states can be analyzed, for example, in terms of the distribution of research groups, researchers with PhDs and investment. The 2006 census of research groups in Brazil (CNPq, 2008b) identified 21,024 groups and 65,515 researchers with PhDs, with the top five states in scientific production in the period 2002-06 accounting in 2006 for 67.8% of the groups and 69.1% of the researchers with PhDs, as follows (in the same rank order as scientific production): São Paulo with 27% of the groups and 30.4% of the PhDs, Rio de Janeiro with 13.2% and 13.4%, Rio Grande do Sul with 10.4% and 9.5%, Minas Gerais with 9.1% and 8.8%, and Paraná with 8.1% and 8.8%.

With regard to investment, CNPq's outlays on scholarships and research funding in 2006 display similar concentration in these states, with São Paulo receiving 28.7% of the total invested, which was R$ 908.47 million. The top five states (SP, RJ, RS, MG and PR) received in aggregate 66.8% of CNPq's outlays in 2006 (CNPq, 2008c). The predominance of São Paulo is also

Figure 4.6
SCIE- and SSCI-indexed Brazilian publications – São Paulo State & selected other states – 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.4.

largely associated with the state's policy of support for S&T research and innovation via programs implemented by FAPESP, which invested some R$ 580.78 million in 2006 (FAPESP, 2008a).

3.3 Breakdown of Brazilian scientific production by knowledge area

Despite biases in the databases and the complexity of analyzing scientific production by knowledge area (see Box 4.1) (Prat, 1998; Spinak, 1998; Okubo, 1997; Costas et al., 2008; Glänzel & Schubert, 2003), it is clear that Brazil's share of world scientific production increased in the period 2002-06 compared with 1998-2002 in practically all knowledge areas quantified by *Essential Science Indicators* (with the exception of physics, which remained the same in percentage terms), according to the classification used[8] (Figure 4.7; Detailed Table 4.5). The areas that contributed most in the second period were botany and zoology, agrarian sciences, microbiology, physics, neuroscience and behavior, ecology, pharmacology and toxicology, and space sciences, among others.

According to a breakdown by knowledge area of SCIE- and SSCI-indexed Brazilian production in the period 2002-06, the leading areas were medicine, physics, chemistry, botany and zoology, biology and biochemistry, and engineering. This was similar to the rank order for 1998-2002 except for an inversion in the positions of medicine and physics (Figure 4.8; Detailed Table 4.6). Production grew significantly during the period in medicine, botany and zoology, all of which account for substantial shares of world and Brazilian production indexed by the databases concerned. Important knowledge areas in Brazilian and world scientific production that grew relatively little in Brazil during the period included physics and space sciences, although Brazil's share of world production also rose in these areas. Areas with relatively small shares of indexed production, such as ecology, computer science, social sciences, psychology and psychiatry, displayed strong growth (Figure 4.8; Detailed Table 4.6).[9]

CNPq, CAPES and FAPESP have statistics that can contribute to an approximate analysis of the relations between human resources and investment, both of which are highly important factors in scientific production, in terms of knowledge areas. In addition to the difficulties inherent in the databases used, a new difficulty arises from the different classifications used by Brazilian research funding agencies and the Thomson Reuters databases (SCIE and SSCI), even though the names are the same in many cases. An approximate analysis can be performed using the data in Tables 4.2, 4.3 and 4.4, which shows that the top knowledge areas in terms of scientific production indexed by SCIE and SSCI in 2006 (medicine, physics, chemistry, botany and zoology, biology and biochemistry, and engineering) also involve a significant quantity of human resources and investment, which may contribute to this production. The same applies to the fastest-growing knowledge areas, such as agrarian sciences, ecology, computer science, social sciences, psychology etc. With regard to aerospace engineering, the following can be stated for the period between 2002[10] and 2006 (see Tables 4.2 and 4.3): (a) 43.5% growth in the proportion of academic staff with PhDs (from 0.23% to 0.33%);[11] (b) 30% growth in the proportion of PhD holders (from 0.20% to 0.26%); and (c) 64.3% growth in CNPq's outlays as a proportion of the total (from 0.28% to 0.46%).

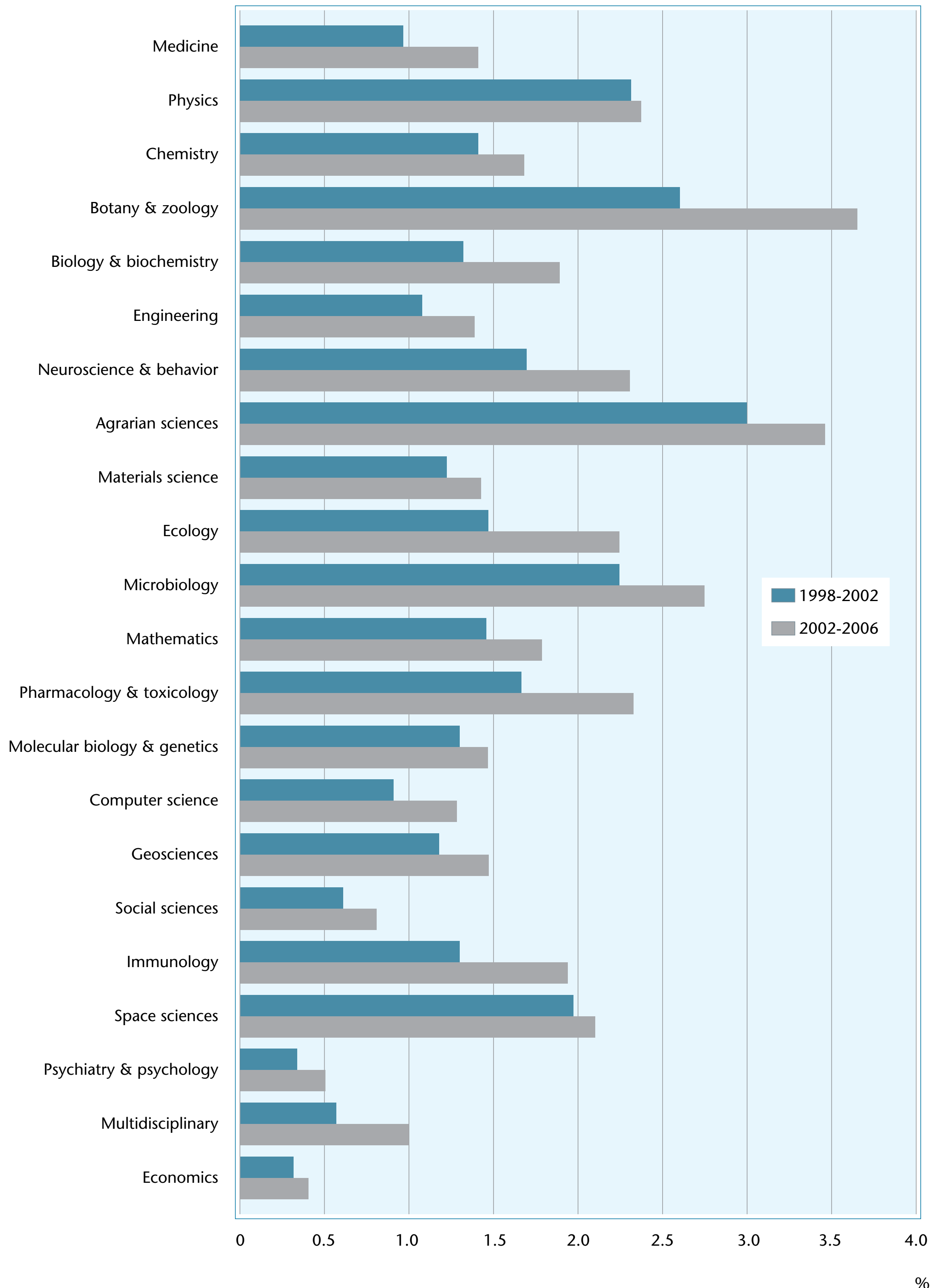
8. The analysis of Brazilian scientific production by knowledge area was based on the classification of areas established by Thomson Reuters to construct its *Essential Science Indicators* (Thomson Reuters, 2008d), which differs from that used by the National Science Foundation to classify world production by knowledge area and as a basis for Table 4.1 above (NSB, 2006).

9. Growth in scientific production by knowledge area, especially for areas in which the number of indexed publications is relatively small, should be analyzed with care, since it can be significantly affected by temporary changes in the sets of journals indexed by SCIE and SSCI. For example, *Revista Brasileira de Ciência do Solo (RBCS)* was included in the ecology area in 2003. The number of Brazilian publications in ecology was 344 in 2002 and 631 in 2006, with RBCS accounting for 105. A similar phenomenon occurred in psychology and psychiatry, with the inclusion of *Revista Brasileira de Psiquiatria (RBP)* in 2005. The number of publications in this area was 76 in 2002 and 209 in 2006, of which 74 in *RBP*. However, for areas such as social sciences, computer science, agrarian sciences, pharmacology and toxicology, immunology and others that have significantly increased their share of Brazilian publications the inclusion of journals in SSCI and SCIE did not have a significant effect and the comparison of the numbers of publications in 2002 and 2006 basically involved the same set of journals.

10. Data for 2002 were obtained in 2008 from the CAPES statistical system, then available at http://www.capes.gov.br/estatisticas. The system was discontinued and replaced by Geocapes, a new system accessible at the same address and currently with some of the data consulted available.

11. In 2002 there were 73 doctors in aerospace engineering (40 at INPE and 33 at ITA/CTA), and 32,710 academics with PhDs at HEIs throughout Brazil. Thus: 73/32,710 x 100 = 0.23%.

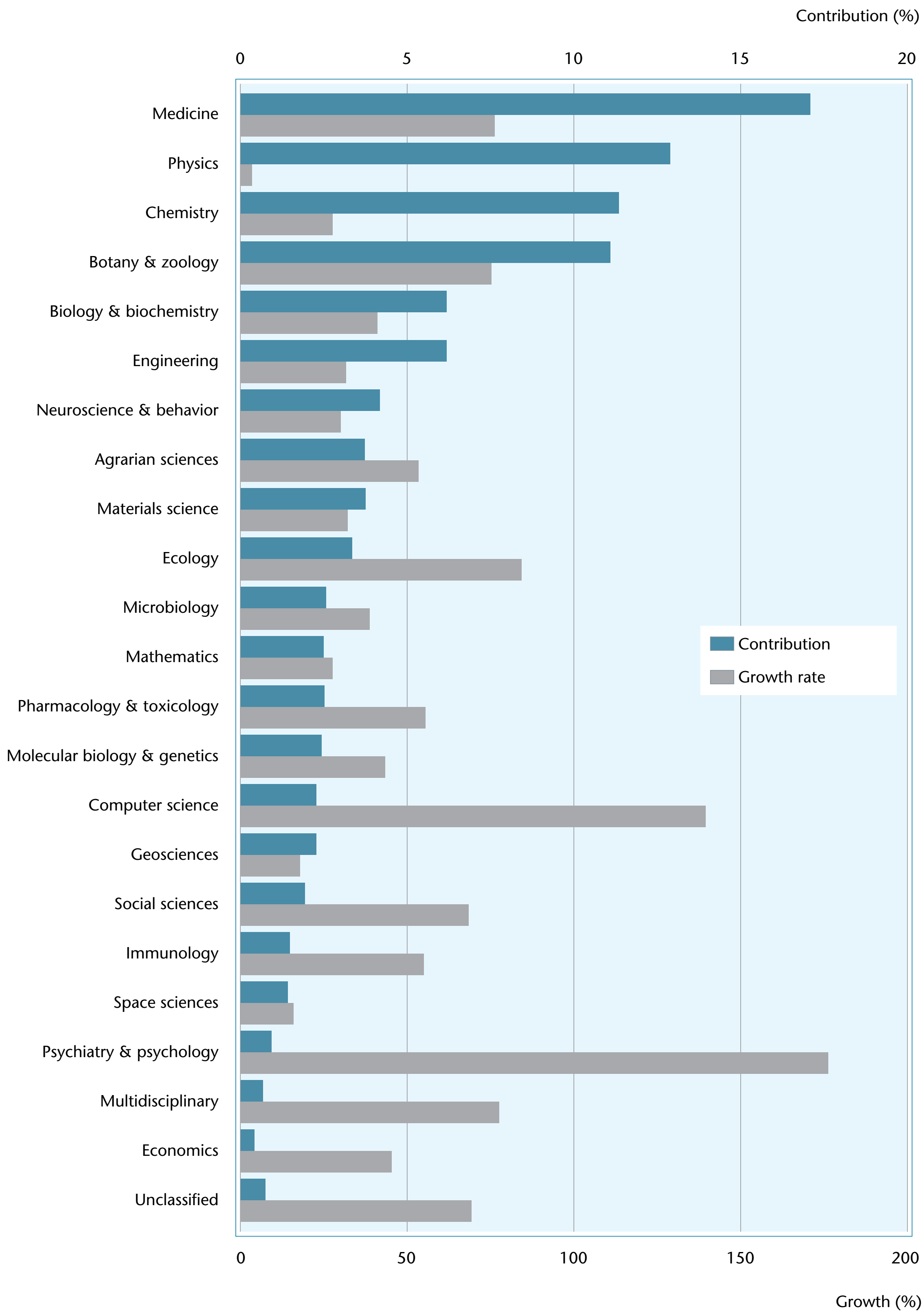
Figure 4.7
Brazilian contributions to publications quantified in *Essential Science Indicators* by knowledge area – Brazil, 1998-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.5.

Figure 4.8
Contributions of SCIE- and SSCI-indexed Brazilian publications and growth rates by knowledge area – Brazil, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.6.

Table 4.2
Researchers in selected knowledge areas – Brazil & São Paulo State, 2006

Knowledge area	Academic staff with PhDs in post-graduate programs		PhD holders	
	Brazil	São Paulo State	Brazil	São Paulo State
Total (abs. nos.)	**47,373**	**15,485**	**9,366**	**4,683**
Share (%)				
Medicine	8.43	13.83	10.60	14.90
Physics	2.72	2.88	2.50	2.11
Chemistry	2.76	2.45	3.50	3.89
Botany & zoology (1)	2.15	1.73	2.25	1.86
Biology & biochemistry (1)	2.98	2.19	3.37	2.50
Engineering (2)	11.46	12.16	11.39	10.57
Agronomy & agricultural engineering (1)	5.16	4.18	6.66	5.36
Computer science	2.00	1.57	1.16	0.73
Ecology	1.41	0.64	1.06	0.98
Psychology (3)	1.96	2.14	2.40	2.73
Aerospace engineering (4)	0.33	1.02	0.26	0.51

Source: CAPES (2008b).

(1) Areas added up from original data.

(2) Excludes materials and metallurgical engineering, with 1.34% of staff with PhDs, 1.33% of PhD holders and 2.21% of investment by CNPq. The area has affinity mainly with "materials science" in the SCIE/SSCI classification, although this engineering discipline as classified in Brazil does not exactly match the discipline thus named in SCIE and SSCI.

(3) No psychiatry in isolation.

(4) No space sciences in isolation.

Table 4.3
CNPq's investment in selected knowledge areas – Brazil, 2006

Knowledge area	CNPq's investment in scholarships & research funding
Total (R$ 000)	833,377
Share (%)	
Medicine	4.03
Physics	5.38
Chemistry	4.85
Botany & zoology (1)	2.84
Biology & biochemistry (1)	3.26
Engineering (2)	14.74
Agronomy & agricultural engineering (1)	6.23
Computer science	4.06
Ecology	2.19
Psychology (3)	2.07
Aerospace engineering (4)	0.46

Source: CNPq (2008c).

(1) Areas added up from original data.

(2) Excludes materials and metallurgical engineering, with 1.34% of staff with PhDs, 1.33% of PhD holders and 2.21% of investment by CNPq. The area has affinity mainly with "materials science" in the SCIE/SSCI classification, although this engineering discipline as classified in Brazil does not exactly match the discipline thus named in SCIE and SSCI.

(3) No psychiatry in isolation.

(4) No space sciences in isolation.

Table 4.4
FAPESP's investment in selected knowledge areas – São Paulo State, 2006

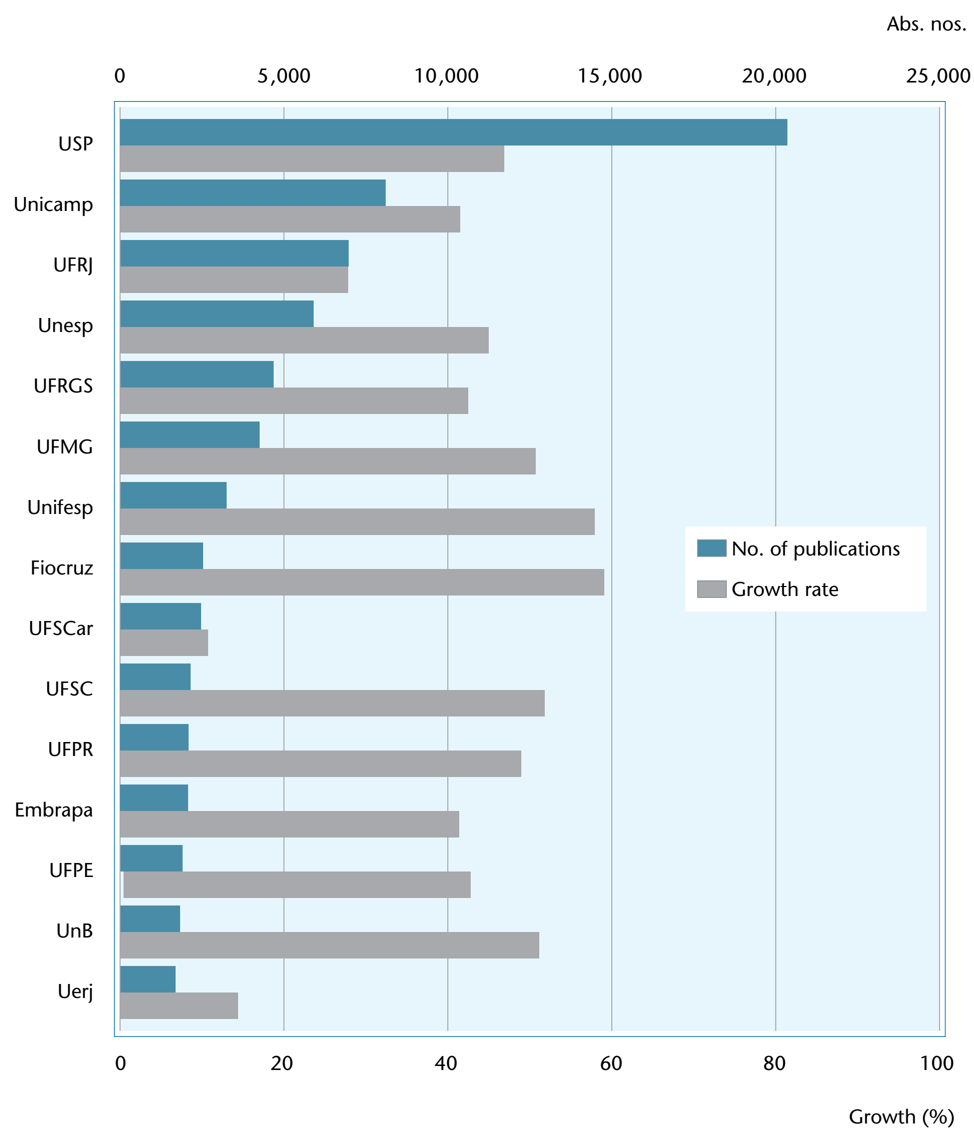
Knowledge area	FAPESP's investment
Total (R$ 000)	521,840
Share (%)	
Agronomy & veterinary medicine	7.00
Architecture & urbanism	0.67
Astronomy & space science	0.57
Biology	15.66
Human & social sciences	7.93
Computer science & engineering	6.69
Economics & administration	1.06
Engineering	14.37
Physics	5.74
Geosciences	3.16
Interdisciplinary	7.78
Mathematics	1.04
Chemistry	7.25
Health	21.09

Source: FAPESP (2006).

3.4 Contributions of institutions to Brazilian scientific production

Brazil's SCIE- and SSCI-indexed scientific production is concentrated in a set of institutions, most of which are public institutions in all regions and states, with the Southeast region in the lead. In the period 2002-06, the following institutions contributed most to total scientific production in Brazil: the Universidade de São Paulo (USP), with 25.5%; Universidade Estadual de Campinas(Unicamp), with 10.1%; the Universidade Federal de Rio de Janeiro (UFRJ), with 8.7%; Universidade Estadual de São Paulo (Unesp), with 7.3%; Universidade Federal de Rio Grande do Sul (UFRGS), with 5.8%; Universidade Federal de Minas Gerais (UFMG), with 5.2%; Universidade Federal de São Paulo (Unifesp), with 4.0%; Fundação Oswaldo Cruz (Fiocruz), with 3.1%; and Universidade Federal de São Carlos (UFSCar)), with 3.0% (Figure 4.9; Detailed Table 4.7). Five of these ten leading institutions are located in São Paulo State. Three are state public universities (USP, Unicamp and Unesp), and two are federal (Unifesp and UFSCar). Indexed publications for 12 of the top 15 insti-

Figure 4.9
SCIE- and SSCI-indexed publications and growth rates by institution – Brazil, 2001-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science.*

Note: See Detailed Table 4.7.

tutions grew more than 40%, led by Fiocruz and Unifesp with 58.9% and 57.8% respectively.

4. São Paulo State's scientific production

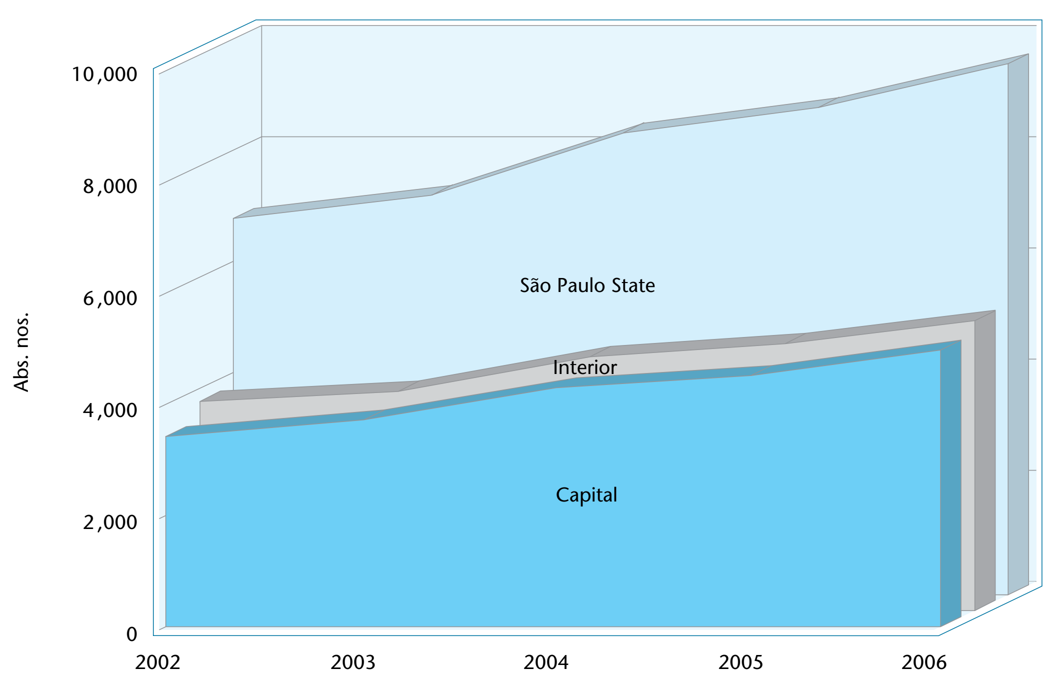
4.1 Contributions of São Paulo State, São Paulo City and other cities in the state to scientific production

São Paulo State contributed 51% of Brazilian scientific production indexed by SCIE and SSCI in 2002-06 (Figure 4.10; Detailed Tables 4.4 and 4.8), for a small increase compared with 1998-2002 (49.9%). Its contribution to world production rose from 0.81% in 2002 to 0.94% in 2006 (Detailed Table 4.1). The increase in São Paulo State's contribution to Brazilian and world scientific production is associated with 41.4% growth in the state's production in 2002-06 (Detailed Table 4.4). However, growth in this period was significantly less than in previous periods, such as 1993-97, when it reached 80% according to data from FAPESP (2002) or 78% according to Leta & Cruz (2003); and 1998-2002, when it was 63% according to FAPESP (2005) or 51% according to data in this study.

The slower pace of growth may have been partly due to the modest rise in S&T funding in the period compared with the expansion of institutions, their staffing levels and scientific activities. Nevertheless, production grew strongly, mainly owing to the concentration of institutions, post-graduate programs, human resources, infrastructure and ST&I investment in the state, which receives substantial funding from FAPESP and from the federal agencies CNPq, CAPES and FINEP, as well as partnerships with the private sector. It is also worth noting the importance of researchers' contributions to the strong growth in Brazilian scientific production (De Meis, L., Carmo & De Meis, C. 2003), which must also apply to São Paulo, given the relative scarcity of funding compared with demand.

The state capital's contribution to SCIE- and SSCI-indexed scientific production by São Paulo in 2002-06 was 51.8%, while the interior contributed 54.7%[12] (Figure 4.10; Detailed Table 4.8). This reflects the deconcen-

Figure 4.10
SCIE- and SSCI-indexed publications – São Paulo State, interior & capital, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.8.

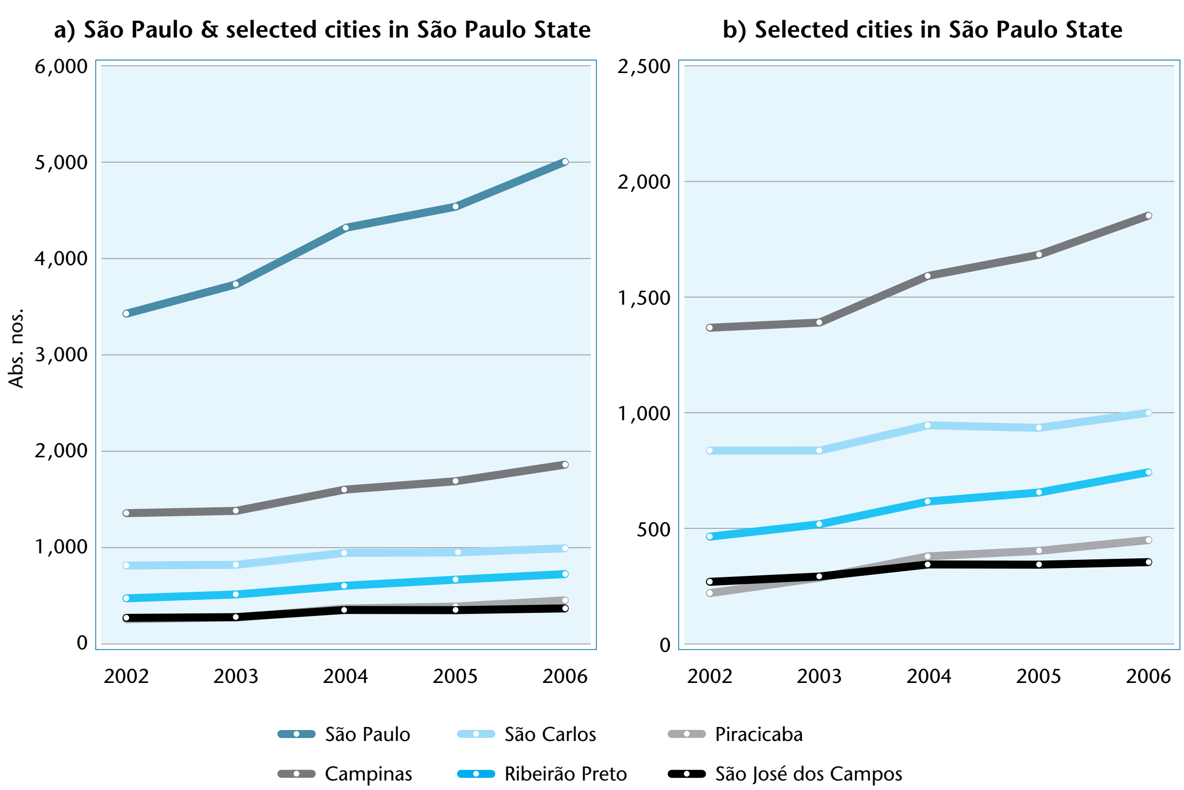
tration of scientific production and the dynamism of the state's interior due mainly to successful public policy. Other states with significant contributions to scientific production do not benefit from such dynamism to the same extent. For example, the contributions of other capitals to production in their states were 89% for Rio de Janeiro, 77% for Florianópolis, 73% for Recife, 68% for Porto Alegre and 56% for Belo Horizonte, the latter being the closest to São Paulo City's contribution to its state among the cases analyzed.

The cities in the interior that most contributed to São Paulo State's scientific production in 2002-06 were Campinas (19.4%), São Carlos (11.3%), Ribeirão Preto (7.4%), Piracicaba (4.2%) and São José dos Campos (3.9%). Piracicaba's production increased 105.6%, raising its contribution from 2.8% in 1998-2002 to 4.2% in 2002-06, while that of São José dos Campos rose from 3.3% to 3.9%. Ribeirão Preto's production grew 58.3%, more than the averages for the interior (40.3%) and the entire state (41.4%), while those of Campinas, São Carlos and São José dos Campos grew less than the average for the interior and the state (Figure 4.11; Detailed Table 4.8).

The strong dynamism of scientific production in the state capital and cities of the interior is largely due to the existence of federal and state public university campuses, many of which also have research institutions. The outstanding examples in the capital are USP, Unifesp, Unesp, Instituto Butantan, the Energy & Nuclear Research Institute (IPEN), the Adolfo Lutz Institute, the Dante Pazzanese Institute, the Botany Institute, the Technological Research Institute (IPT), the Biology Institute, the Emílio Ribas Institute and Hospital A.C. Camargo, among other public and private institutions.

Decentralization of scientific production away from the capital is due largely to the presence of the following public institutions: in Campinas, Unicamp,

Figure 4.11
SCIE- and SSCI-indexed publications – selected cities in São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science.*

Note: See Detailed Tables 4.8 and 4.9.

12. The sum of the capital's and interior's contributions is more than 100% owing to publications co-authored by researchers in the capital and interior, leading to cases of multiple counting.

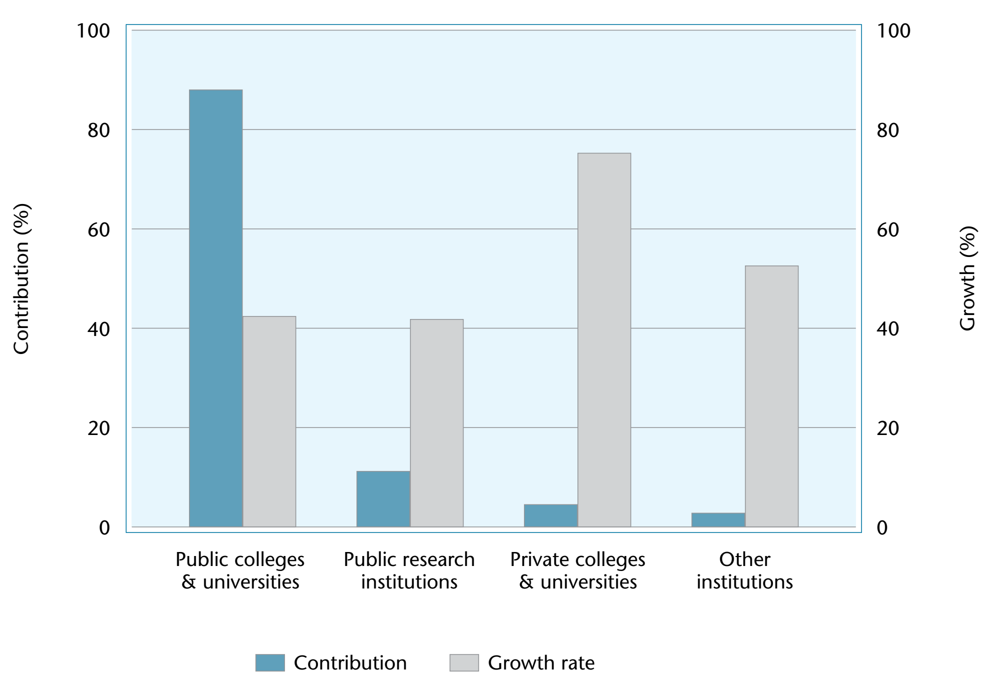
the Agronomy Institute, the Brazilian Agricultural Research Corporation (Embrapa), the National Synchrotron Light Laboratory (LNLS) and the Food Technology Institute (ITAL); in São Carlos, UFSCar, USP and Embrapa; in Ribeirão Preto, USP; in Piracicaba, USP and Unicamp; in São José dos Campos, the National Space Research Institute (INPE), the Aerospace Technical Center (CTA) and Unesp. All these cities are among the leaders in terms of their contributions to Brazilian scientific production indexed by SCIE and SSCI, as can be seen from Detailed Table 4.9.

More information on São Paulo State's scientific production by region, city and knowledge area can be found in Chapter 8 ("The regional dimension of ST&I activities in São Paulo State").

4.2 Contributions of universities and research institutions to scientific production in São Paulo State

The contributions of public universities and research institutions to São Paulo State's scientific production in the period 2002-06 were 87.7% and 10.8% (Figure 4.12; Detailed Table 4.10). The main drivers of scientific production in public universities are post-graduate programs and research groups funded by FAPESP, a state agency, and CNPq, CAPES and FINEP, all federal, as well as a good installed research infrastructure. It should be stressed that production by public research institutions in the state, amounting to 4,400 publications in the period 2002-06, lagged only total production in four entire states (RJ, MG, RS and PR), as shown by Figure 4.12 and Detailed Tables 4.10 and 4.4. This significant contribution by research institutions can be explained as resulting largely from their strong links to universities, as discussed below in section 5, which deals with collaboration. Private universities contributed relatively little to the state's scientific production (4.4%), but this contribution rose 74.8%, far more than those of other types of institutions in the state, reflecting the influence of policy measures introduced to improve quality in these institutions and of collaboration with public universities and institutions. Figure 4.13 presents the main institutions that contributed to scientific production in their respective categories and to the aggregate production of the state.

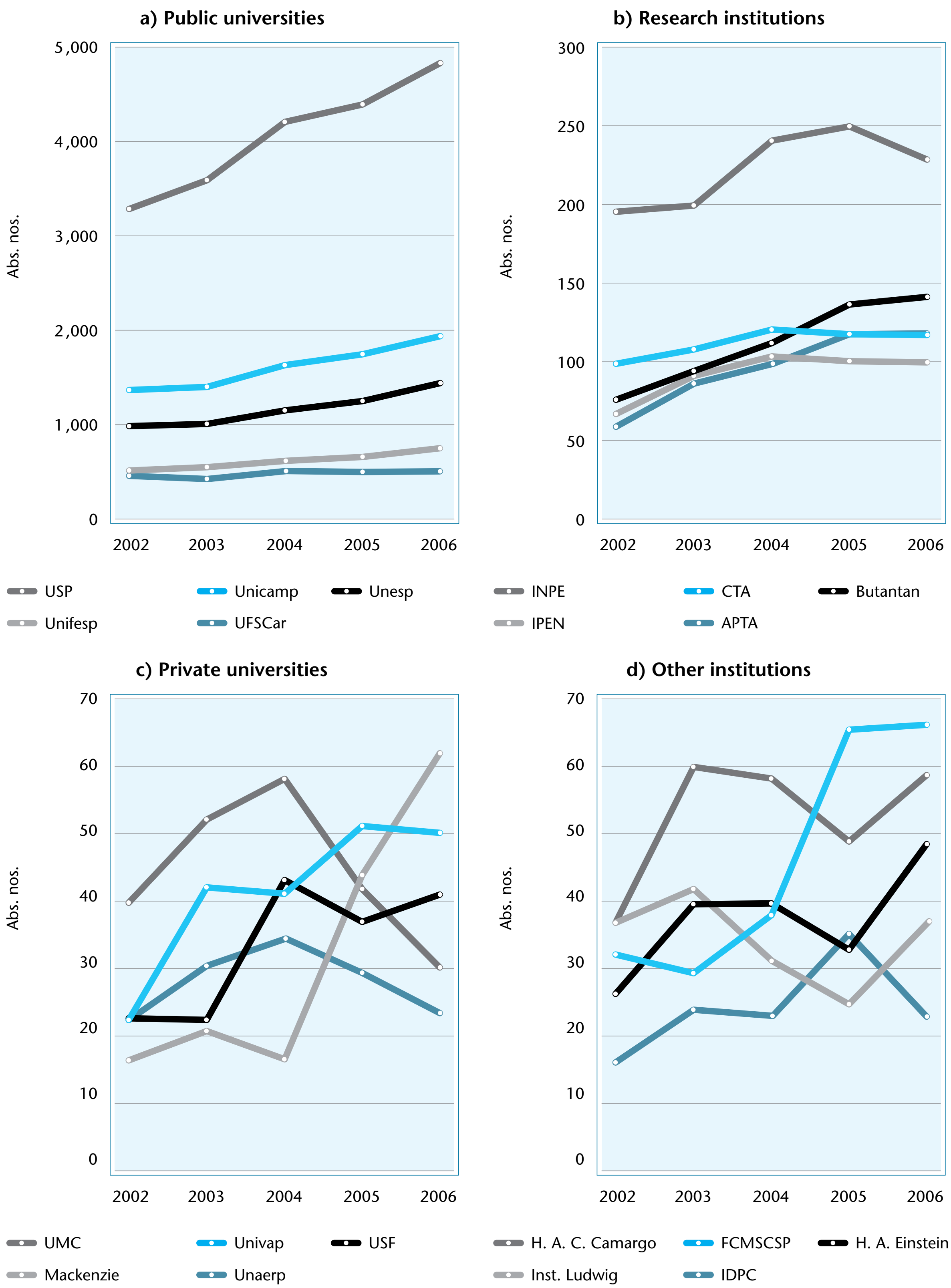
Figure 4.12
Contributions of institutions to SCIE- and SSCI-indexed publications and growth rates by type of institution and jurisdiction – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.10.

Figure 4.13
SCIE- and SSCI-indexed publications by HEI and research institution – São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

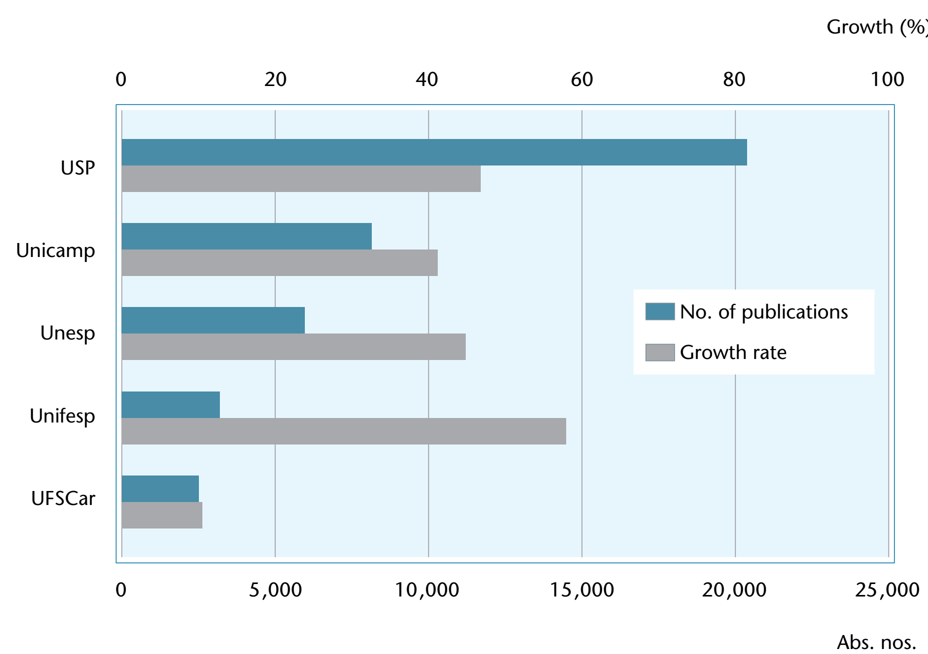
Note: See Detailed Table 4.10.

USP, the leading university in São Paulo State and Brazil in terms of scientific production indexed by SCIE and SSCI, had 3,297 publications in 2002 and 4,830 in 2006, for growth of 46.5%. It contributed 50% to production in the state and 25.5% to nationwide production in the period 2002-06. Unicamp's contribution rose 41% from 1,364 publications in 2002 to 1,923 in 2006, accounting for 19.8% of the state total, while Unesp's rose 44.7% from 982 to 1421, accounting for 14.4%. São Paulo's federal universities are also significant players: Unifesp's share of production rose 57.8% from 510 publications in 2002 to 805 in 2006, while UFSCar's rose 10.5% from 446 to 493. All the public universities mentioned are among São Paulo's and Brazil's top ten institutions in scientific publications (Figures 4.9, 4.13a and 4.14; Detailed Tables 4.7 and 4.10).

The leading research institutions in São Paulo State include INPE, with the largest scientific output in the period rising 17.1% from 193 indexed publications in 2002 to 226 in 2006, and a contribution of 2.7%, as well as CTA and Instituto Butantan which each contributed 1.4% of the state's scientific production in the period 2002-06. The strongest growth in scientific production occurred, for example, in Instituto Butantan (81.8%), the institutions linked to APTA, the São Paulo State Agency for Agribusiness Technology (103.7%), specific units of Embrapa and other institutions that contributed relatively little to the total (Figures 4.13b and 4.15; Detailed Table 4.10).

Private universities contributed relatively little (4.4%) to the state's scientific production in 2002-06, but in aggregate displayed the highest growth rate

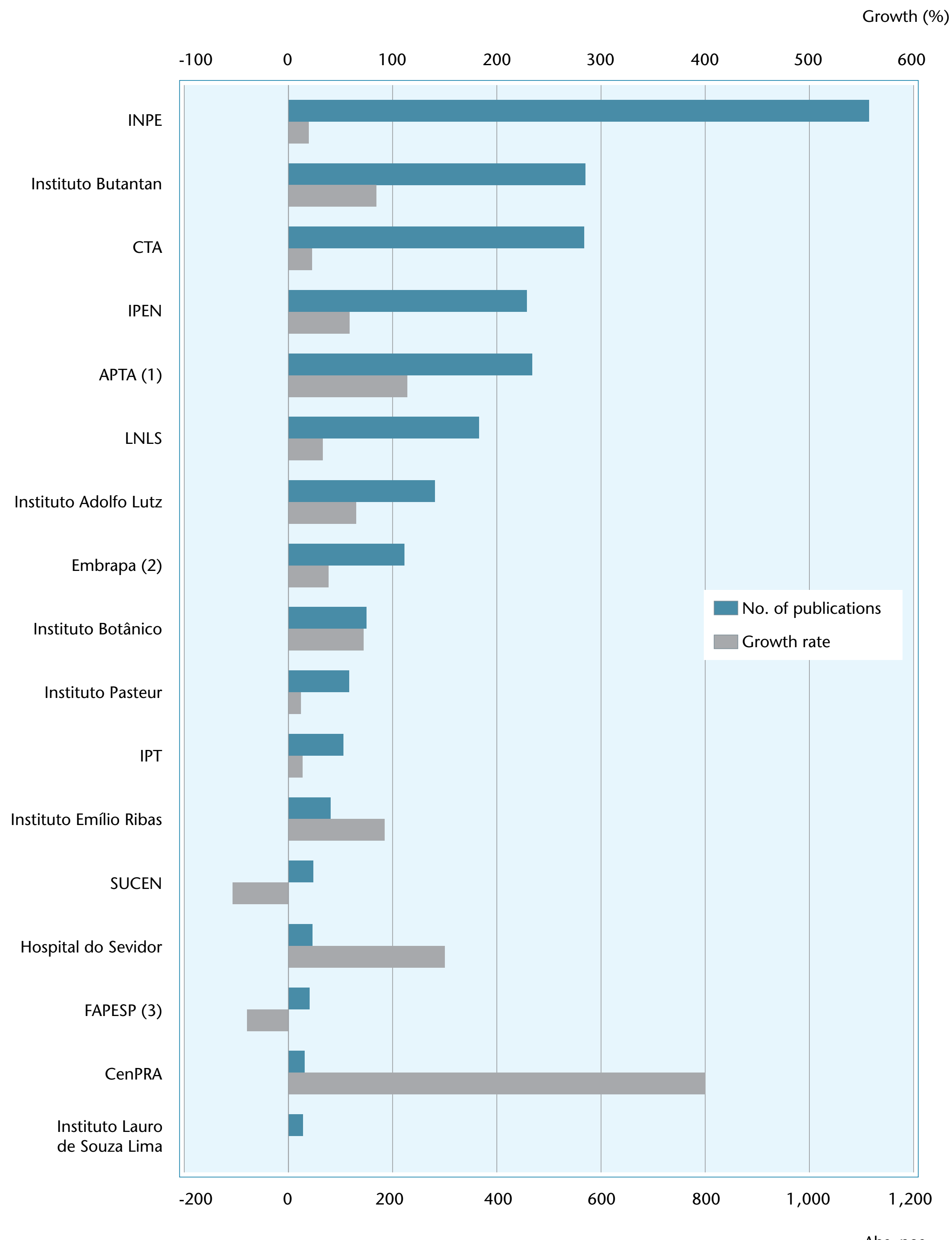
Figure 4.14
SCIE- and SSCI-indexed publications by public universities located in São Paulo State and growth rates – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.10.

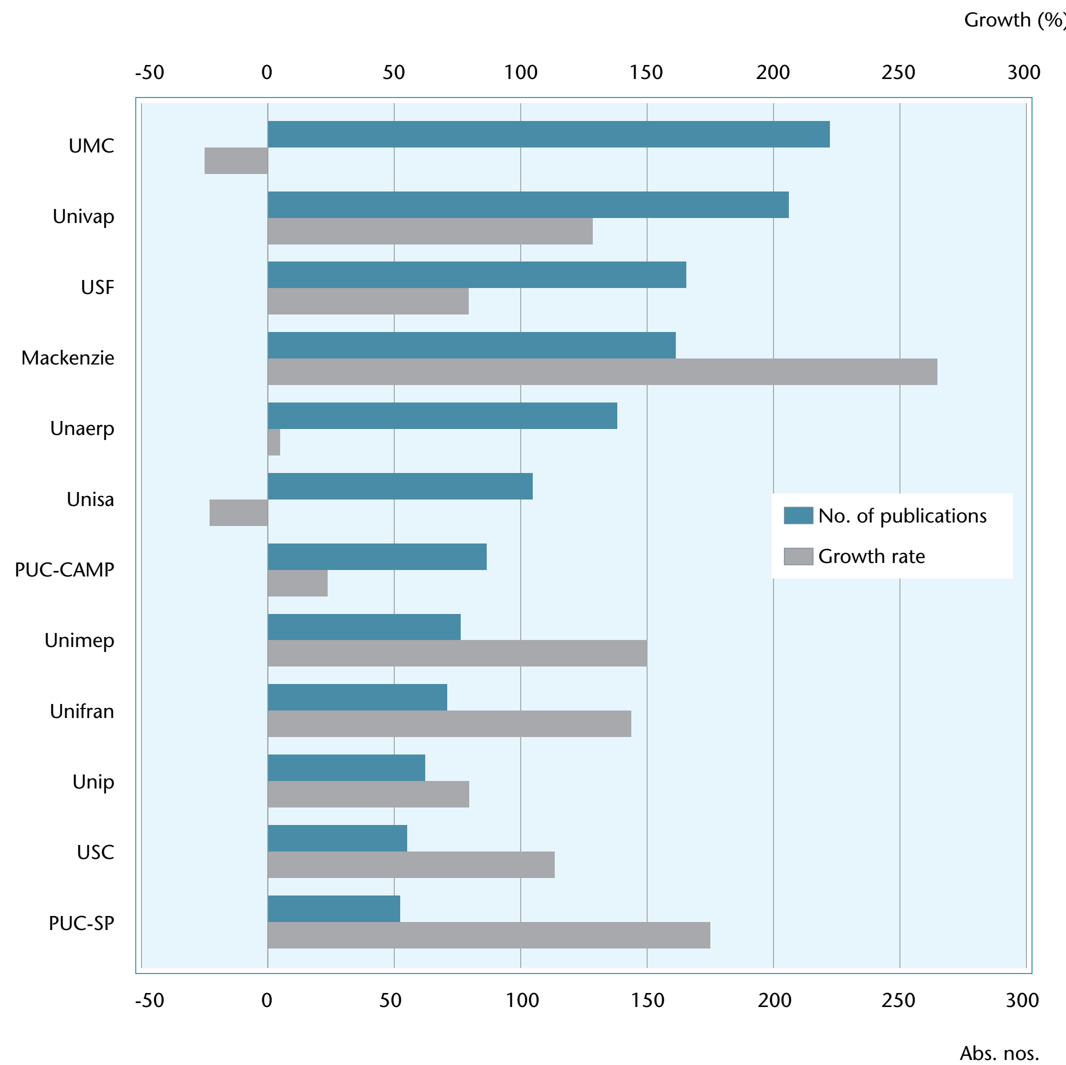
Figure 4.15
SCIE- and SSCI-indexed publications by research institutions located in São Paulo State and growth rates – São Paulo State, 2002-2006 (cumulative



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.10.
(1) APTA's production includes the production of its units: Instituto Agronômico, Instituto Biológico, Instituto de Zootecnia, Instituto de Tecnologia de Alimentos, Instituto de Pesca and Instituto de Economia Agrícola.
(2) Embrapa's production considers only five units in São Paulo: Instrumentação Agropecuária, Pecuária Sudeste, Meio Ambiente, Monitoramento por Satélite, Informática Agropecuária.
(3)) In *Web of Science* databases, the address field corresponds to the institution to which each author is affiliated according to the journal in which the article was published. Some authors supported by Fapesp mistakenly included the agency in this field and this figure therefore includes articles attributed to FAPESP.

Figure 4.16
SCIE- and SSCI-indexed publications by private universities located in São Paulo State and growth rates – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.10.

(74.8%). Universidade de Mogi das Cruzes (UMC), Universidade de Vale do Paraíba (Univap), Universidade São Francisco (USF) and Universidade Presbiteriana Mackenzie accounted for the largest individual contributions (0.4%-0.5%) but UMC's production fell 25%, while the output of the other universities mentioned rose strongly. Several institutions with small shares of the total achieved strong growth, but a comparison between the two periods shows a downturn in the performance of private institutions as a whole, with strong growth in 1998-2002 (220.5%) and much weaker growth in 2002-06 (74.8%) (Detailed Table 4.10). This may be associated with the small number of articles published by each of the institutions concerned (so that a few more or a few less makes a significant difference) and/or with changes in institutional policies and strategies for investment in research and employment of PhD holders with research profiles, in accordance with governmental requirements and regulation.

4.3 Breakdown of scientific production in São Paulo State by knowledge area

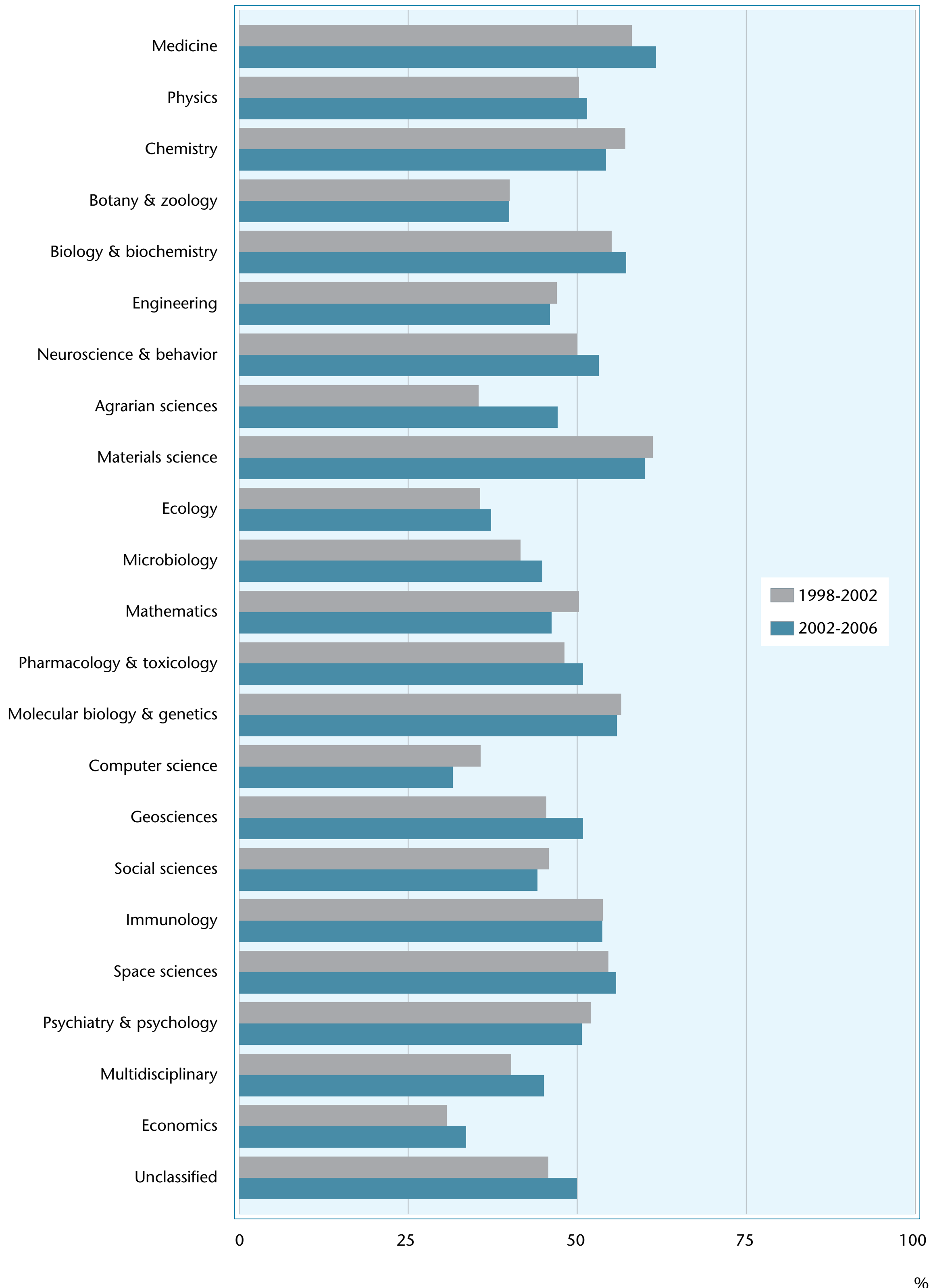
Despite biases in the databases and the complexity of analyzing scientific production by knowledge area, São Paulo State can be said to have contributed significantly to total Brazilian production in practically all areas indexed by SCIE and SSCI in the period 2002-06 and to have increased its production in comparison with 1998-2002. For example, in medicine, the area with the largest output in Brazil and São Paulo State, the latter accounted for 61.5% of total Brazilian publications in the area in 2002-06, compared with 57.7% in 1998-2002. It is also worth highlighting agrarian sciences, in which the state's contribution to the Brazilian total reached 46.7% in 2002-06, up from 35.1% in 1998-2002 (Figure 4.17; Detailed Table 4.11).

A breakdown of São Paulo State's scientific production in 2002-06 by knowledge area shows medicine, physics, chemistry, botany and zoology, biology and biochemistry, and engineering in the lead, as in the previous period. The main growth areas were medicine, agrarian sciences, computer science, psychiatry and psychology, ecology, social sciences, and pharmacology and toxicology, among others (Figure 4.18; Detailed Table 4.11).

Despite biases in the databases and forms of publication, as well as the complexity of analyzing production by knowledge area, a breakdown of USP's and Unesp's scientific production by knowledge area in 2002-06 can be said to highlight five predominant areas. For USP they are medicine (20%), physics (13%), chemistry (12%), botany and zoology (8%), and biology and biochemistry (7%). For Unesp, they are botany and zoology (21%), physics (16%), medicine (11%), chemistry (10%), and biology and biochemistry (7%). In the case of Unicamp, engineering (8%) ranks fourth, after chemistry (18%), medicine (18%), and physics (14%), and ahead of biology and biochemistry (7%), while botany and zoology do not feature among the top five areas.

Federal public universities in the state have differing profiles and also differ from state universities. Unifesp has a vocation for medicine, with a share of 50%, and other health-related areas such as neuroscience and behavior (14%), biology and biochemistry (10%), immunology (5%), and microbiology (4%). In the case of UFSCar, three areas contribute more than 65% – chemistry (26%), physics (22%), and materials science (17%) – while biology and biochemistry (7%), and botany and zoology (6%) also feature among the predominant areas indexed by SCIE and SSCI (Figure 4.19; Detailed Table 4.12).

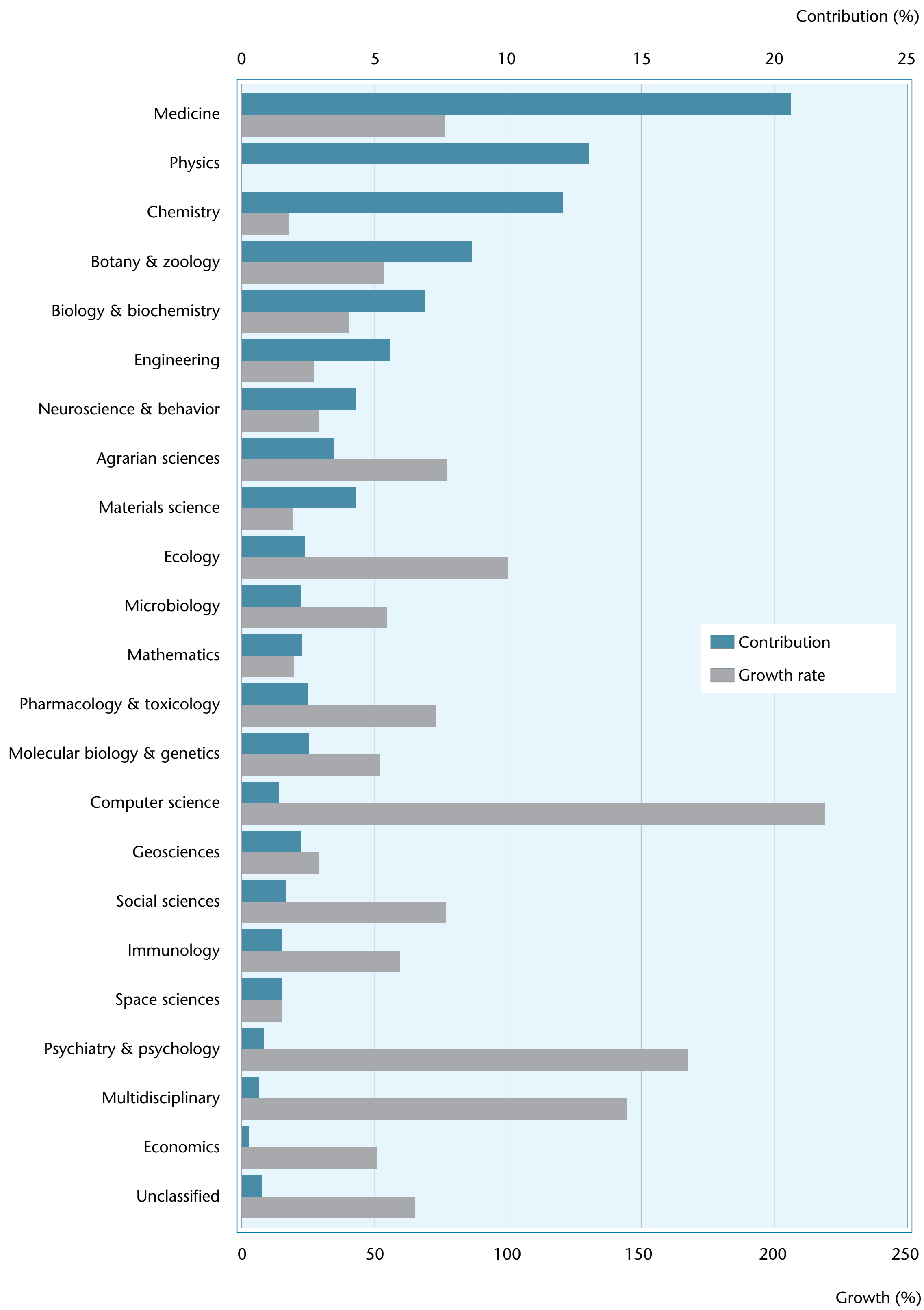
Figure 4.17
Contributions of São Paulo State's SCIE- and SSCI-indexed publications to Brazilian total by knowledge area – São Paulo State, 1998-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.11

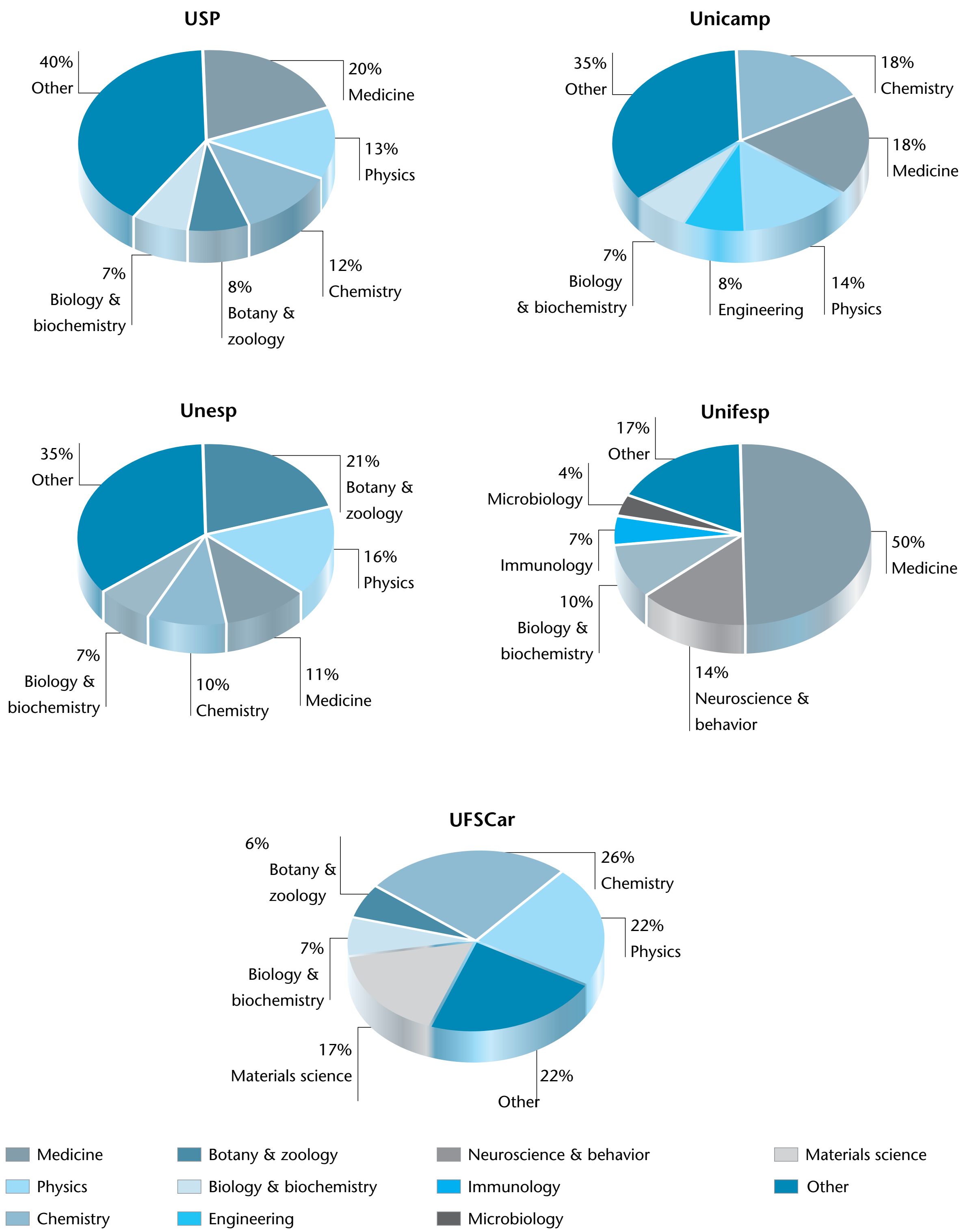
Figure 4.18
Contributions to São Paulo State's SCIE- and SSCI-indexed publications and growth rates by knowledge area – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.11.

Figure 4.19
Breakdown of SCIE- and SSCI-indexed publications by universities in São Paulo State by knowledge area – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.12.

5. International and national scientific collaboration

5.1 Scientific collaboration by Brazil and São Paulo State with other countries

International scientific collaboration involving Brazilian researchers, analyzed in terms of co-authorship of articles published in journals indexed by SCIE and SSCI in the period 2002-06, fell as a percentage of total Brazilian production from 33.1% in 2002 to 30% in 2006. In absolute numbers, however, publications co-authored by Brazilians and foreigners rose 30.4% from 4,357 in 2002 to 5,681 in 2006 (Figure 4.20a; Detailed Table 4.13). International scientific collaboration involving São Paulo-based researchers also fell as a percentage of the state's total production, from 31.3% in 2002 to 28.2% in 2006. In absolute numbers, however, co-authored publications rose 27.6% from 2,115 to 2,698 in the period (Figure 4.20b; Detailed Table 4.13).

International collaboration has fallen since the 1990s as a share of total scientific production in both Brazil overall and São Paulo State. This fall can be explained as due to the maturing of post-graduate programs (FAPESP, 2005) and growth of S&T investment in Brazil. International collaboration fell most intensely in proportional terms in 2002-06, when there was an increase in outlays for grants and scholarships to study abroad (for PhDs, post-docs etc.) by the main Brazilian agencies responsible for funding S&T. Outlays by CNPq[13] and CAPES in aggregate rose about 24% in current dollars between 2002 and 2006, from US$40.7 million to US$50.5 million (CNPq, 2008c; CAPES, 2008b). FAPESP's outlays for overseas scholarships and study grants rose 14.8% from US$1 million (R$ 3 million) in 2002 to US$ 1.2 million (R$ 2.6 million) in 2006 (FAPESP, 2008a).

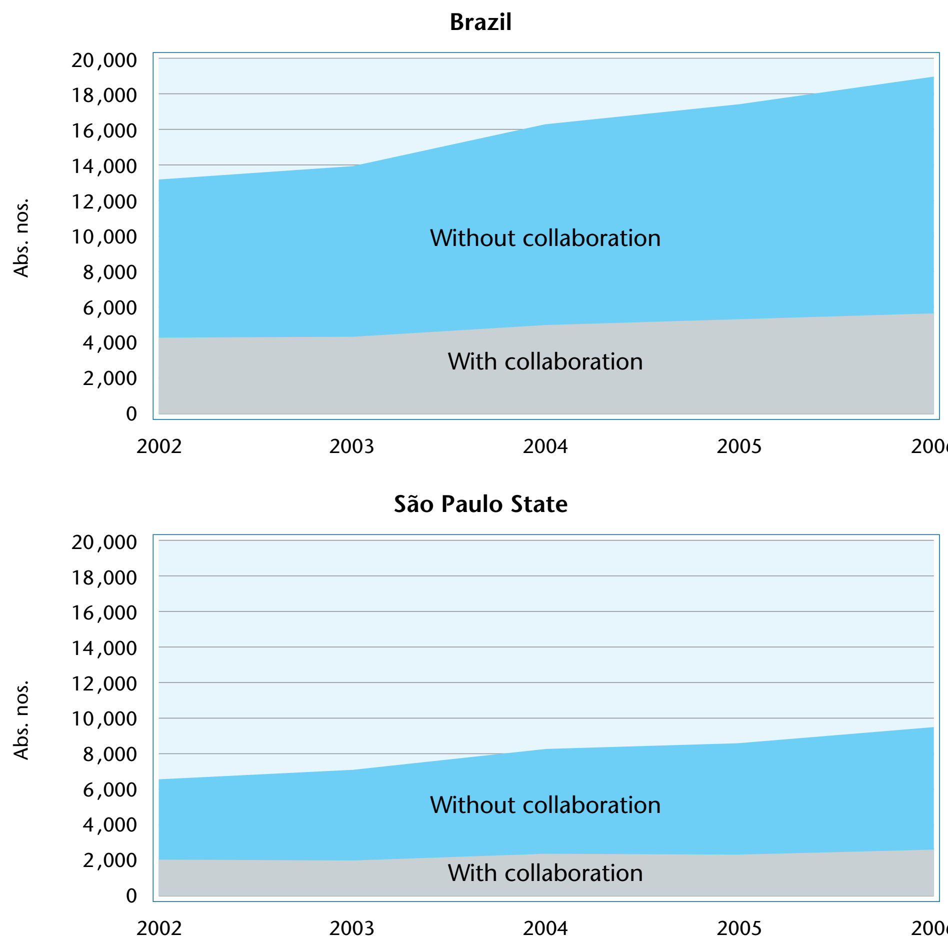
There are also factors that tend to drive growth in international collaborative research, such as the increasing complexity of S&T research and information and communications technology (ICT), with collaborative networks acting as an important form of scientific production around the world today (NSB, 2006; FAPESP, 2002, 2005; Leta & Cruz, 2003; Marques & Zorzetto, 2008). Other examples include the pursuit of specialization, funding opportunities, the capacity to negotiate international projects, and an interest in partnerships that enable publication by journals with a high international impact, which tends to strengthen the hegemony of the leading countries in terms of scientific production (Katz & Martin, 1997; Marques & Zorzetto, 2008). Europe is frequently cited as an example of significant growth in international collaboration, which has driven a rise in production and citations. This example could be emulated by countries such as Brazil, which would benefit from increased international collaboration, participation in relevant collaborative networks and investment in overseas doctoral scholarships (Marques & Zorzetto, 2008).

The existence of cooperation agreements and programs to support international collaborative research is also an important factor. Brazil has had technical cooperation agreements with the United States since 1950, with France and Portugal since 1968, with the United Kingdom since 1997, with Japan since 1970, with Mexico since 1974, with Canada since 1975, with Argentina since 1980, with India since 1985, with Chile since 1990, with Spain since 1992, with China since 1995, with Germany since 1996, with Italy since 1997, with South Africa since 2003, and with the European Union since 2004, among others, including Cuba, the Netherlands, East Timor and other Latin American countries (MRE, 2008; CAPES, 2008c; CNPq, 2008d). In addition to agreements at the federal level that may stimulate international collaboration, FAPESP also has agreements, for example, with the U.S. (Museum of Fine Arts-Houston, Fulbright), France (ENS, Inria, Inserm, Cirad, CNRS, Cofecub), the U.K. (British Council), Germany (DFG, DAAD), Switzerland (Ludwig Institute) and Cuba (Mesc, Minvec).

The countries with which Brazil collaborated most in scientific research in the period 2002-06 were led by the U.S., with publications co-authored by Brazilian and U.S. researchers accounting for 37.9% of total interna-

13. CNPq's outlays fell 39% in dollar terms in the period 2002-06, from US$19 million (R$ 55.7 million) to US$11.6 million (R$ 25.3 million) (CNPq, 2008c). CAPES's outlays rose 78.8% from US$21.7 million to US$38.8 million (CAPES, 2008b). The exchange rates used for these calculations in the case of CNPq were R$ 2.9212 per US$ in 2002 and R$ 2.1761 per US$ in 2006, in accordance with FAPESP's previous practice (FAPESP, 2008a).

Figure 4.20
SCIE- and SSCI-indexed publications with and without international collaboration – Brazil & São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.13.

tional collaboration on this criterion, up slightly compared with 1998-2002. The number of such publications rose 32.7% from 1,615 in 2002 to 2,143 in 2006. Growth in the previous period had been moderately higher at 39.3%. Although U.S. leadership of collaboration corresponds to the reality, the finding may be partly a reflection of the fact that U.S.-authored publications account for the largest proportion of these databases (31.3%). Next comes collaboration with France (13%), the U.K. (12.2%) and Germany (11.4%), which are among the leaders of world scientific production (Figure 4.21a; Detailed Table 4.14), followed by Canada (6.4%), Spain (5.9%), Argentina (5.9%) and Japan (4%), as shown by Figures 4.21a, b and c and Detailed Table 4.14. This profile changed little compared with 1998-2002, apart from a moderate increase in collaboration with Germany, Canada, Argentina and Japan, among the group of countries already mentioned, and with other countries lower down the list. Although Japan is one of the countries with the most SCIE- and SSCI-indexed publications, Brazilian collaboration with Japan in terms of co-authorship is not significant, corresponding to 4% in 2002-06, or less than with the other leading countries in world scientific production. This probably reflects sociocultural differences as well as different interests and a lack of national policies to foster scientific collaboration between the two countries.

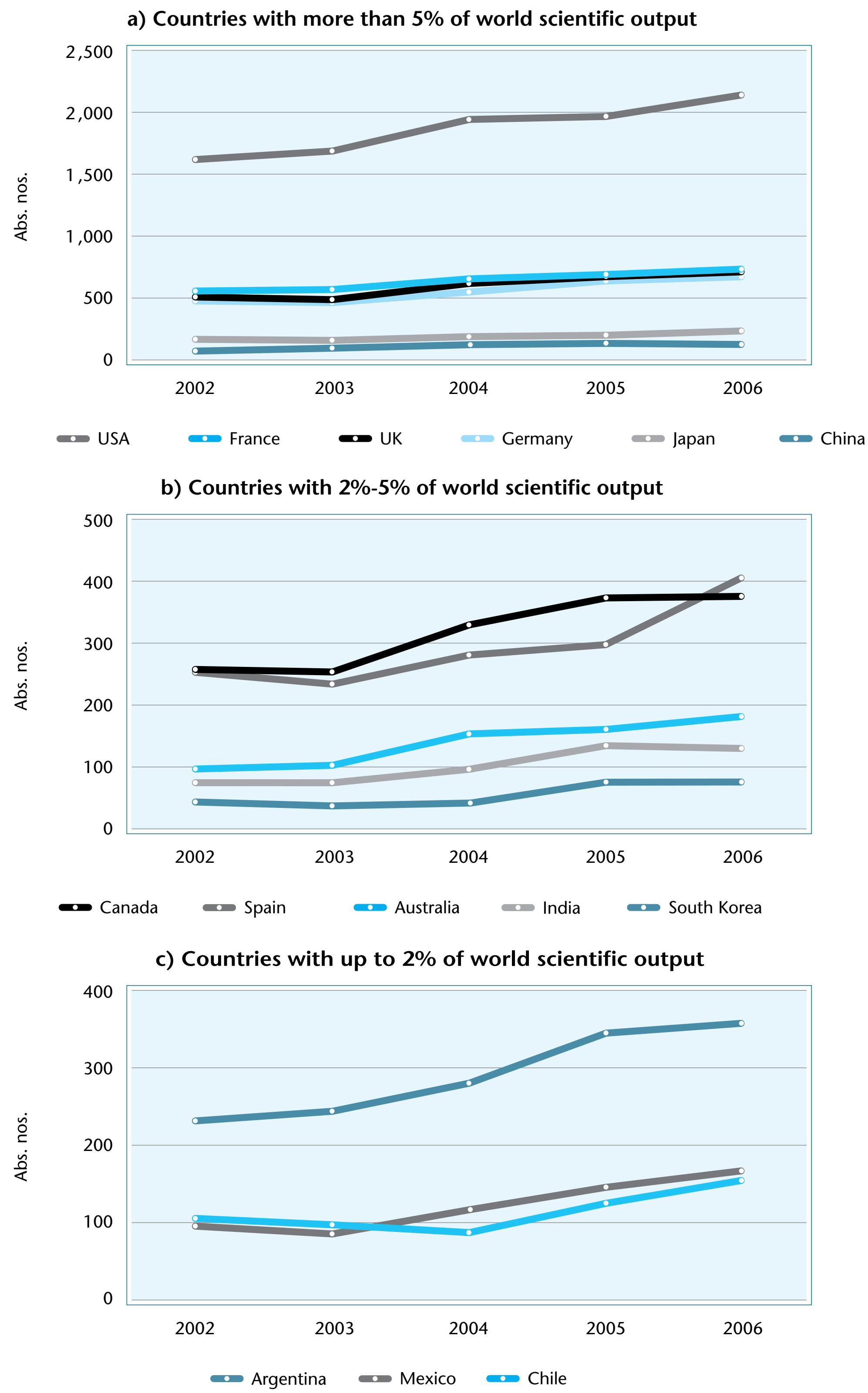
Brazilian collaboration with all the selected countries grew 30.4%, more than the overall average, and growth was particularly strong in collaboration with countries with which it is still relatively small, especially South Korea (90.2%), Australia (88.8%), Mexico (74.2%), India (73.7%), China (64.7%), Spain (59.1%), Argentina (53%) and Chile (46.2%). These growth rates point to a process of deconcentration and diversification in collaboration, with Latin America, Asia and Oceania all increasing their shares (Figures 4.21a, b and c; Detailed Table 4.14).

The profile of collaboration by authors based in São Paulo State with authors in the selected countries in 2002-06 is similar to that of Brazilian collaboration in terms of percentage contributions. Collaboration with the U.S. predominates, as would be expected given that this country is the leader in SCIE- and SSCI-indexed publications. Collaboration with China is small (3.1%), despite this country's large scientific production, but also the fastest-growing (107%) among the leading countries in SCIE- and SSCI-indexed publications. Growth rates for collaboration by São Paulo State, which are higher than for Brazil in most cases, are led by South Korea (313.3%), India (184.8%), Mexico (126.8%), Argentina (82.8%), Australia (77.6%), Spain (58.3%), the U.K. (51.9%) and the U.S. (38.4%) (Figures 4.22 a, b and c; Detailed Table 4.15).

Growth in collaboration by Brazil and São Paulo with other countries breaks down fairly evenly by knowledge area. It is important to recall that indicators based on knowledge areas must be constructed and analyzed with care owing to the bias built into databases such as SCIE and SSCI in terms of their coverage of knowledge areas and subareas. The areas in which growth rates for Brazil and São Paulo differed most included agrarian sciences, pharmacology and toxicology, and economics, with collaboration by the latter growing far more than the former. The strongest growth areas for both included medicine, computer science, and psychology and psychiatry. The weakest growth areas for both included physics, chemistry, engineering, materials science, and space sciences, all of which belong to the groups classified as exact sciences, engineering or technology (Figure 4.23; Detailed Tables 4.16 and 4.17).

The possible drivers of faster growth in international collaboration by São Paulo include FAPESP's projects and programs to foster collaborative networks of researchers in Brazil and elsewhere, such as CEPID (Centers of Research, Innovation & Dissemination), Thematic Projects, the BIOTA program, the Genome program, and the Structural Molecular Biology Network, among others (FAPESP, 2008b).

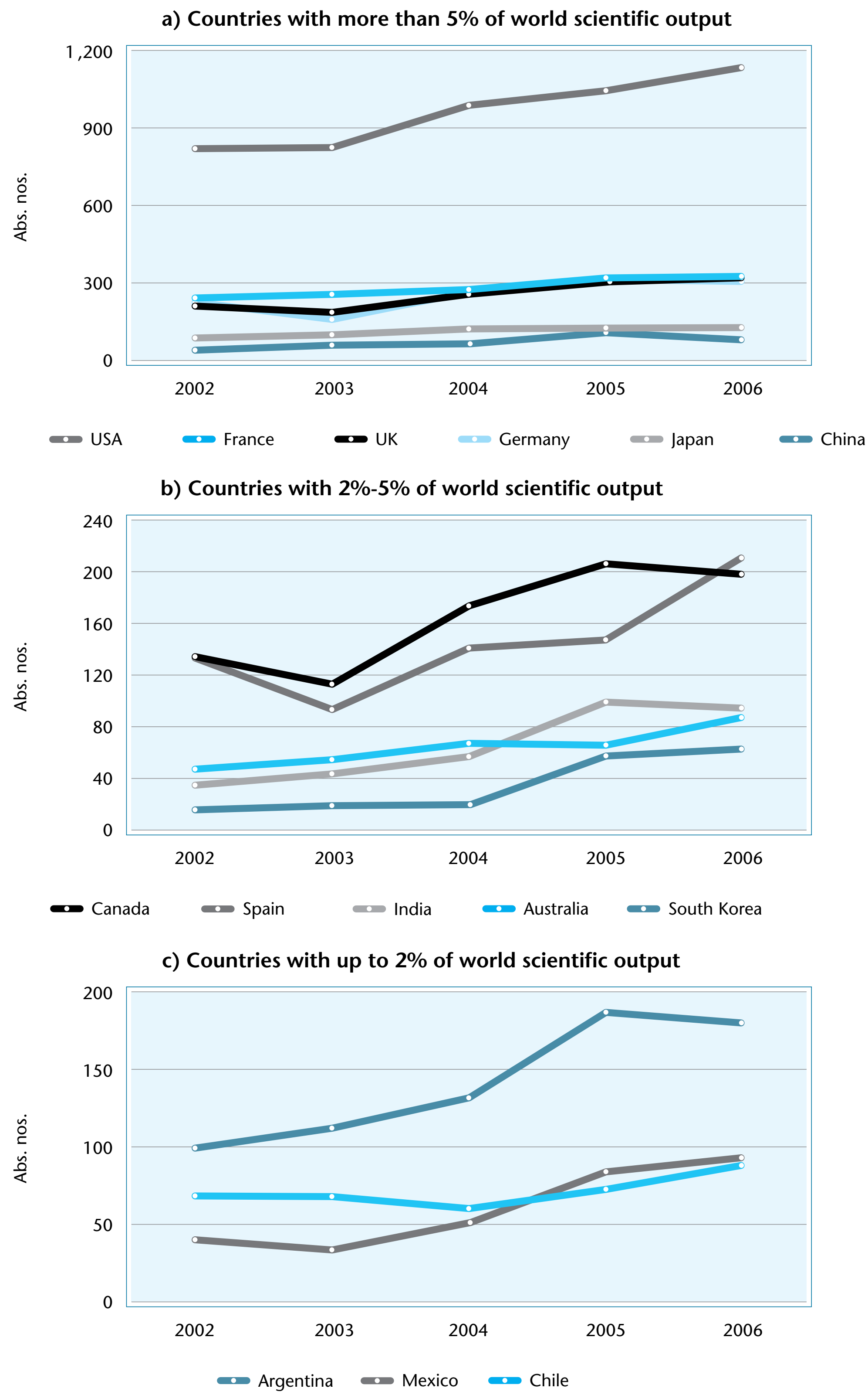
Figure 4.21
SCIE- and SSCI-indexed publications by Brazilian authors with co-authors in selected other countries – Brazil, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.14.

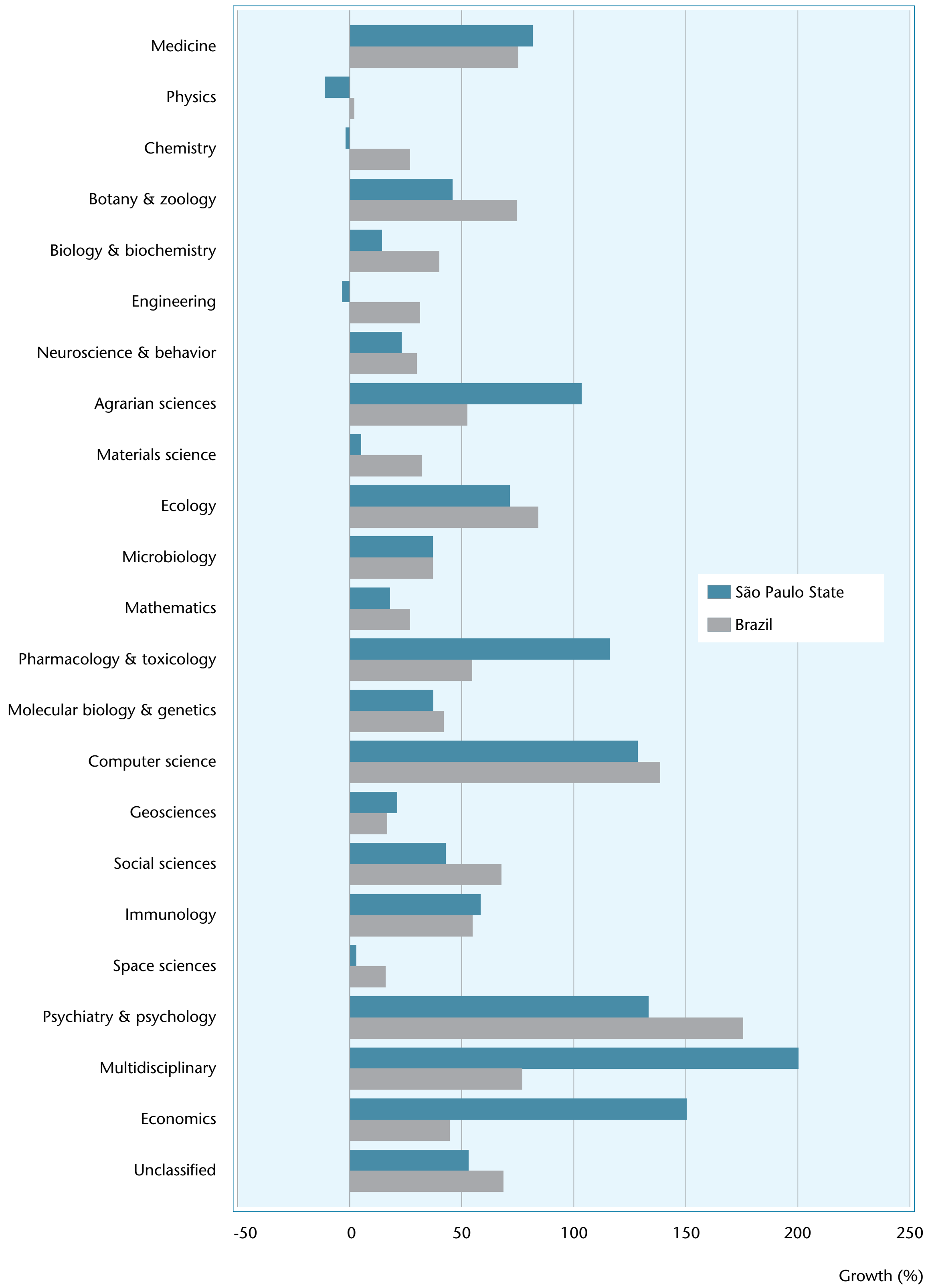
Figure 4.22
SCIE- and SSCI-indexed publications by São Paulo authors with co-authors in selected other countries – São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.15.

Figure 4.23
Growth in SCIE- and SSCI-indexed publications by Brazilian and São Paulo authors with co-authors in other countries by knowledge area – Brazil & São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

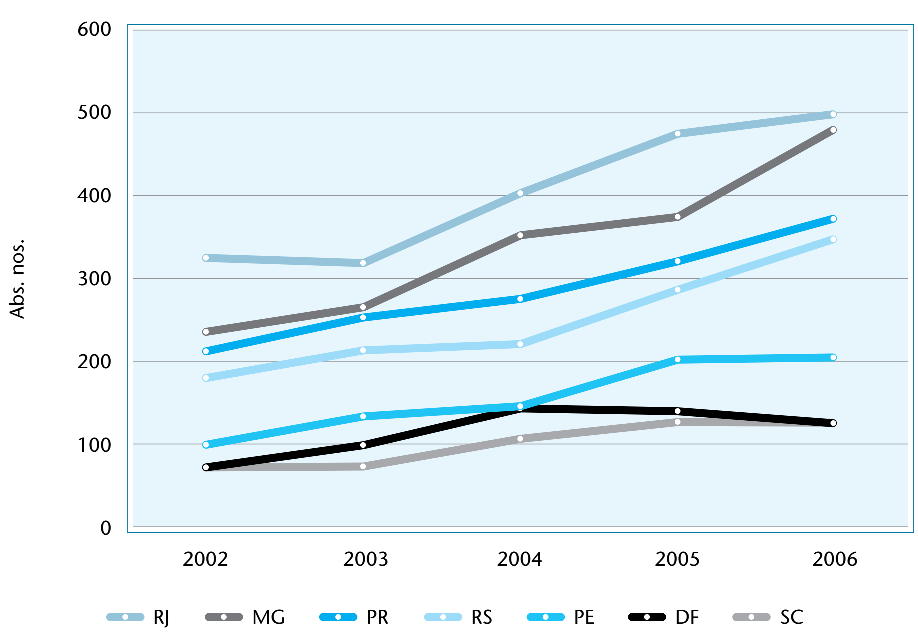
Note: See Detailed Tables 4.16 & 4.17.

5.2 Scientific collaboration by São Paulo with other Brazilian states

The main state with which authors based in São Paulo collaborated in 2002-06 was Rio de Janeiro, which contributed 20.7%, followed by Minas Gerais (17.5%), Paraná (14.9%), Rio Grande do Sul (12.8%) and Pernambuco (8%). Collaboration grew strongly (100% or more) with the following states: Minas Gerais, Espírito Santo, Pernambuco, Ceará, Piauí, Alagoas, Goiás, Mato Grosso do Sul, Mato Grosso, Pará, Amazonas and Rondônia. Some of these states display low percentages because the number of publications indexed by the databases is small (Figure 4.24; Detailed Table 4.18).

In regional terms, collaboration between São Paulo and the Northeast, South, Central West and North increased, largely owing to research groups and collaborative networks in which São Paulo has a significant share and which are supported by research programs and projects. For example, São Paulo-based institutions play a leading role in national research networks established in recent years in such areas as nanotechnology, climate change, sugarcane genomics, "Omics" and biophotonics (more details are given in the boxes below). FAPESP has many research programs that foster collaboration and contribute to the advance of science beyond the borders of São Paulo State, in particular: technological innovation programs (BIOTA, BIOEN, Genoma, CEPID, Research in Public Policies, Technological Parks in São Paulo, PITE (Research Partnership for Technological Innovation), ConSITec, PIPE (Innovative Research in Small Businesses), PAPI/Nuplitec, Smolbnet, Tidia and VGDN, among others); special programs (Rede ANSP Academic Network, Young Investigator awards and Scientific Journalism, among others); grants and thematic projects etc. Scientific collaboration is also significantly furthered by CNPq, with such programs as Pronex and Millennium Institutes, and CAPES, with Minter (Interinstitutional Master's), Dinter (Interinstitutional Doctorate) and Procad (Programa Nacional de Cooperação Acadêmica) (CAPES, 2007a).

Figure 4.24
SCIE- and SSCI-indexed publications by São Paulo authors with co-authors in other states of Brazil – São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

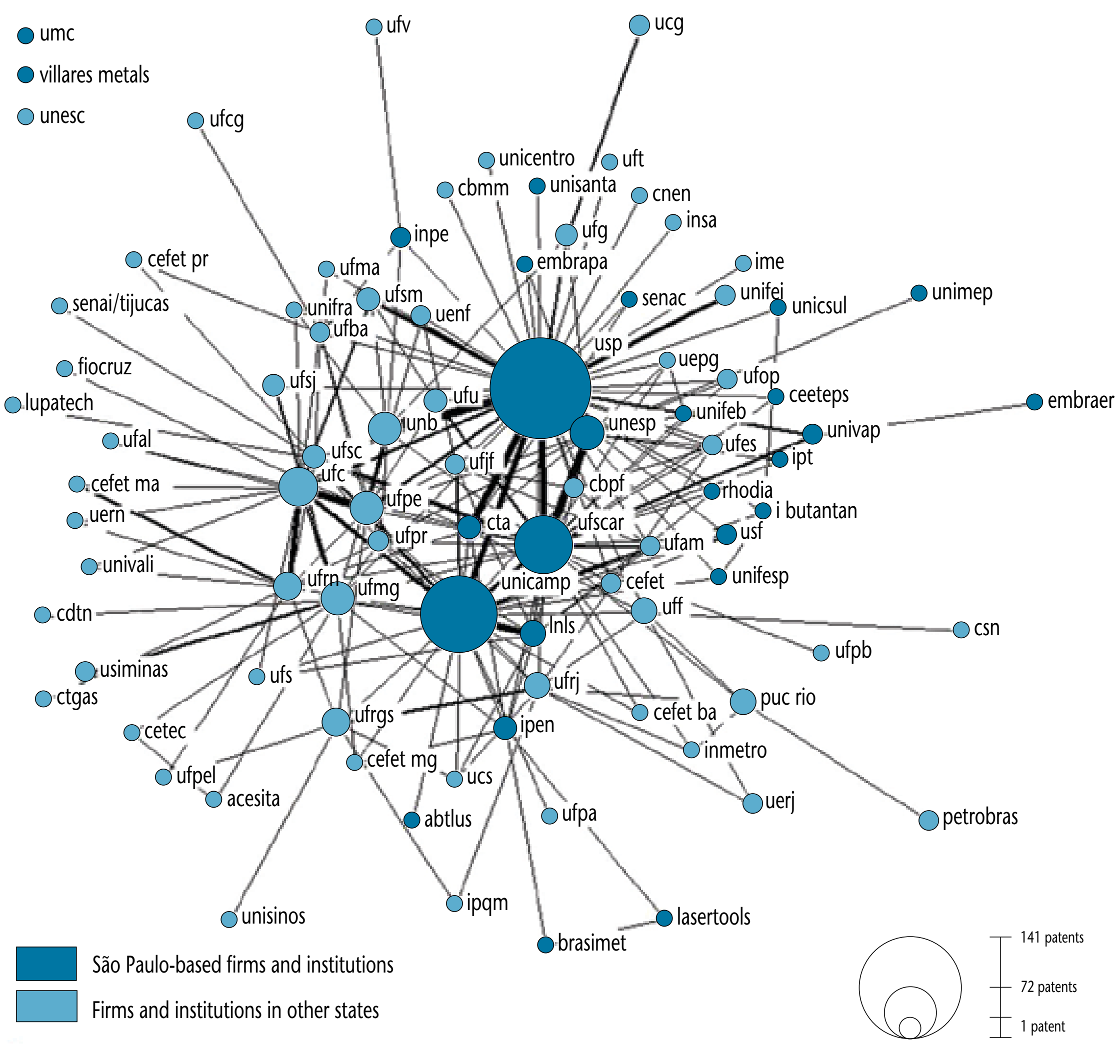
Note: See Detailed Table 4.18

Box 4.2 Nanotechnology research networks

Nanotechnology is one of the main drivers of S&T development today, with impacts in many economic sectors (Galembeck & Rippel, 2004). It necessarily involves new knowledge acquisition or creation for application in innovative products and processes.

In Brazil, this area displays three patterns of organization. The first involves academic researchers and results mainly in new knowledge embodied by scientific articles without explicit links to innovation. The second involves personnel employed by industrial and service firms which explicitly or implicitly use nanotechnology tools and concepts to create new products and processes. The third involves teams of academic researchers and firms working in close contact, creating knowledge, mastering knowledge created by others and developing innovations.

Chart 4.1
Nanotechnology scientific collaboration network based on SCIE and SSCI-indexed publications – Brazil, 2002-2006 (cumulative)



Source: Thomson Reuters (2008). SCIE e SSCI via *Web of Science*.

Note: Links between organizations are represented by lines. Each organization's contribution is proportional to the radius of the respective circle (Detailed Table 4.31).

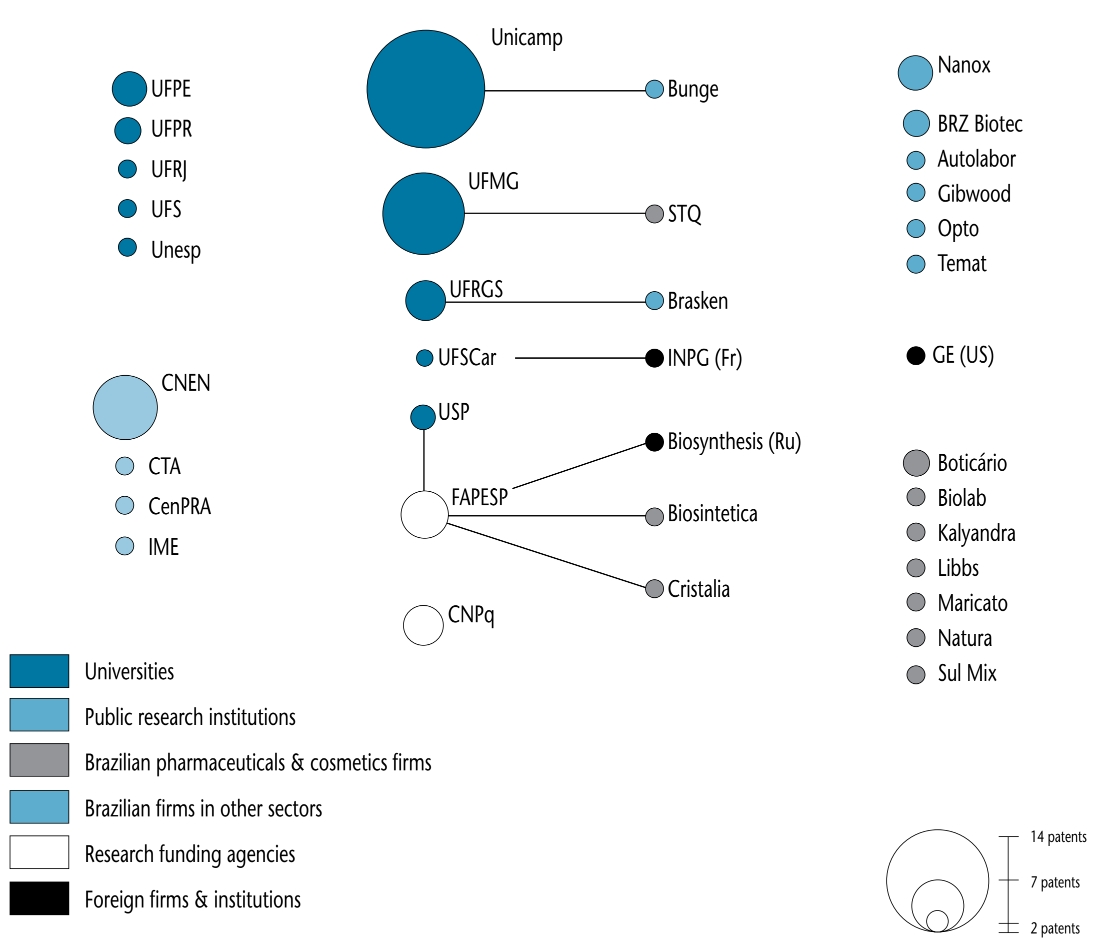
The network made up of academics* produces a significant amount of scientific articles, as shown by Chart 4.1. Public universities in São Paulo State are the most important nodes of this network. On the other hand, it is auspicious that 13 firms also participate, ten of them privately or publicly held.

Chart 4.2 shows that the activities of professionals employed by firms that file for patents, jointly with academic groups or independently, is also significant, albeit more modest.

It is particularly disturbing that the number of articles published and patent applications filed between 2004 and 2006 did not increase (Figure 4.25) even though nanotechnology was expanding rapidly in other countries during the period.

With regard to nanotechnology-related themes covered by scientific articles and patents, firms are mainly interested in metallic materials and chemicals, including cosmetics and pharmaceuticals. Sectors linked to information technology (semiconductors, magnetic materials, displays, lasers etc.) participate little, no doubt owing to their relatively negligible size in Brazil.

Chart 4.2
Nanotechnology interfirm collaborative network based on patents generated in Brazil and indexed by *Derwent Innovations* – Brazil, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), Derwent Innovations Index (2008) <http://thomsonreuters.com/products_services/legal/legal_products/intellectual_property/derwent_innovations_index/>.

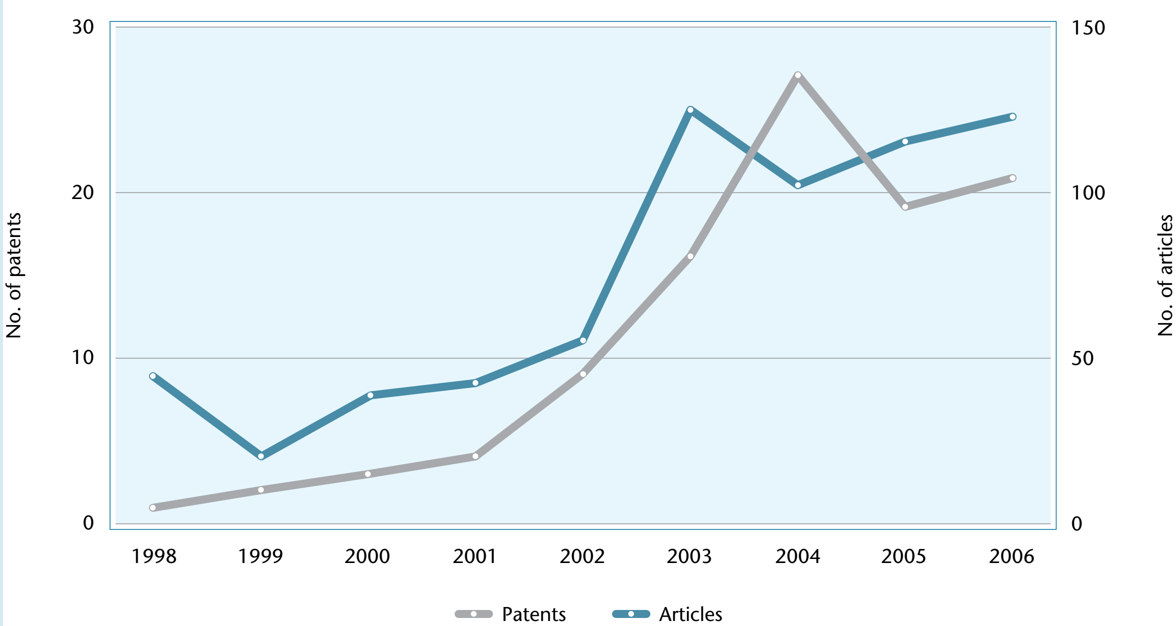
Note: Links between organizations are represented by lines. Each organization's contribution is proportional to the radius of the respective circle (Detailed Table 4.32).

*For details of the methodology used in this box, see the Methodological Annex to this chapter.

The outlook for nanotechnology in Brazil shows signs of improving. The sector displays considerable economic and social potential. One of these positive signs is the recent formation of networks coordinated by major industrial corporations such as Oxiteno, Braskem and Petrobras. In particular, Petrobras's nanotechnology network could become genuinely important owing to a circumstantial but very significant abundance of financial resources.

In sum, these nanotechnology networks reproduce the strengths and weaknesses of Brazil's scientific organization, displaying academic vigor alongside limited knowledge of the real force of the business R&D system. To transcend this situation, it will be necessary to bring together people and organizations, planning and definition of objectives and strategies. This effort cannot be delayed.

Figure 4.25
Patents in nanotechnology generated in Brazil and indexed by *Derwent Innovations,* and SCIE- and SSCI-indexed publications – Brazil 1998-2006



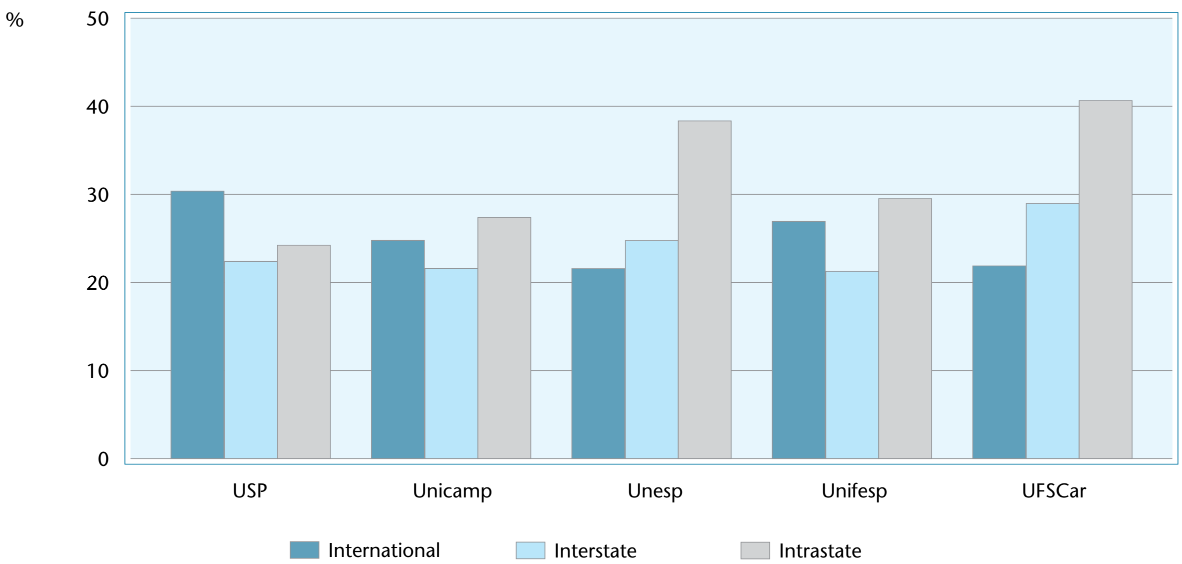
Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science* and *Derwent Innovations* Index.

Note: See Detailed Table 4.33.

5.3 Scientific collaboration by institutions in São Paulo

Institutions in São Paulo State collaborated actively in science during the period 2002-06, both within the state and with institutions in other states and countries. Among public universities, USP's collaboration was mostly international, followed by intrastate and interstate collaboration. In the case of Unicamp and Unifesp, intrastate collaboration moderately surpassed international collaboration, with interstate collaboration ranking third. Unesp and UFSCar stood out for intrastate collaboration, followed by interstate collaboration, with international collaboration ranking last (Figure 4.26; Detailed Table 4.19). These patterns of collaboration in aggregate point to USP as the leader in international scientific collaboration, followed by Unicamp and Unifesp, with Unesp and UFSCar focusing more on national and regional collaboration. Interstate collaboration grew most in the period for all public universities in the state except Unifesp. International collaboration grew least (or not at all in some cases).

Figure 4.26
Public universities' collaborative SCIE- and SSCI-indexed publications by type of collaboration – São Paulo State, 2002-2006



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.19.

Box 4.3 Climate change research networks

What is the contribution of developing countries, especially Latin America and Brazil, to first-class scientific production on climate change? In the Brazilian case, how does this production break down by research institution? Is Brazil's production in this important and topical knowledge area increasing?

Twenty international journals were analyzed in an attempt to answer these questions. The journals in question are very widely read and cover most of the many disciplines involved in climate change research, although some are multidisciplinary (*e.g.*, *Science*, *Nature* and *PNAS*) while others are not.

Selected journals: *Science, Nature, Climatic Change, Journal of Geophysical Research, Journal of Geophysical Research Atmospheres, Journal of Geophysical Research Biogeosciences, Journal of Geophysical Research Oceans, Journal of Geophysical Research Oceans and Atmospheres, Geophysical Research Letters, Proceedings of the National Academy of Sciences of the USA, Proceedings of the National Academy of Sciences of the USA Biological Sciences, Proceedings of the National Academy of Sciences of the USA Physical Sciences, Journal of Climate, Global Change Biology, Global Biogeochemical Cycles, Anais da Academia Brasileira de Ciencias, Tellus, Tellus Series A Dynamic Meteorology and Oceanography, Tellus Series B Chemical and Physical Meteorology and International Journal of Climatology*

Data for scientific publications on climate change were analyzed using *Science Citation Index Expanded (SCIE) and Social Science Citation Index (SCI)*, both part of *Web of Science*, which is available via the CAPES Journals Portal (Portal de Periódicos). The search query used the expression "climate change" and was restricted to the 20 selected journals for the period 1998-2007 and publications of the following types: *article, letter, note* and *review*. Altogether, **3,729 bibliographic records were collected, treated and** quantified using Vantage-Point bibliometric software, generating a breakdown of publications by geographic area and year of publication (Table 4.5). A co-occurrence matrix of institutions to which the authors of the publications in question were affiliated was produced using Ucinet and NetDraw to map collaborative networking links, as shown in Chart 4.3.

Developing countries accounted for 12.1% of publications in 1998-2007, with Latin America and the Caribbean contributing 2.5%. About half this contribution (1.2%) came from Brazilian institutions. Of the articles on climate change co-authored by Brazilian institutions, 61% involved institutions in São Paulo State, equivalent to 0.8% of the world total. The evolution of Brazilian contributions over time is particularly interesting. In the first five years of the period (1998-2002), Brazilian institutions featured in 0.64% of the publications (8 out of 1,248), while in the last five years (2003-07) the proportion rose to 1.53% (38 out of 2,481). This growth in Brazil's share can be attributed to the maturing of the research groups that focus on climate change and to international collaboration in major research projects such as the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA).

Chart 4.3 presents the collaborative network of Brazilian institutions that focus on climate change. Two institutions in São Paulo State (INPE and USP) account for a significant share of the contributions (circles), collaborating intensely with each other and working with 21 other institutions (lines). Only four of the 25 institutions covered are not linked to INPE and/or USP. Two (Ibama and UnB) collaborate with each other, and two others (IAC and Cria) publish independently. With regard to the volume of publications on climate change, the size of the nodes reaffirms the importance of INPE and USP, which together account for 52.2% of the Brazilian total.

The creation of strong structured programs to support this type of research in 2008 (including the Science & Technology Ministry's Brazilian Climate Change Research Network and FAPESP's Global Climate Change Research Program, among others) should radically change this situation, increasing both the number of articles by Brazilian authors published in SCIE- and SSCI-indexed journals and the amount of collaboration among institutions in Brazil.

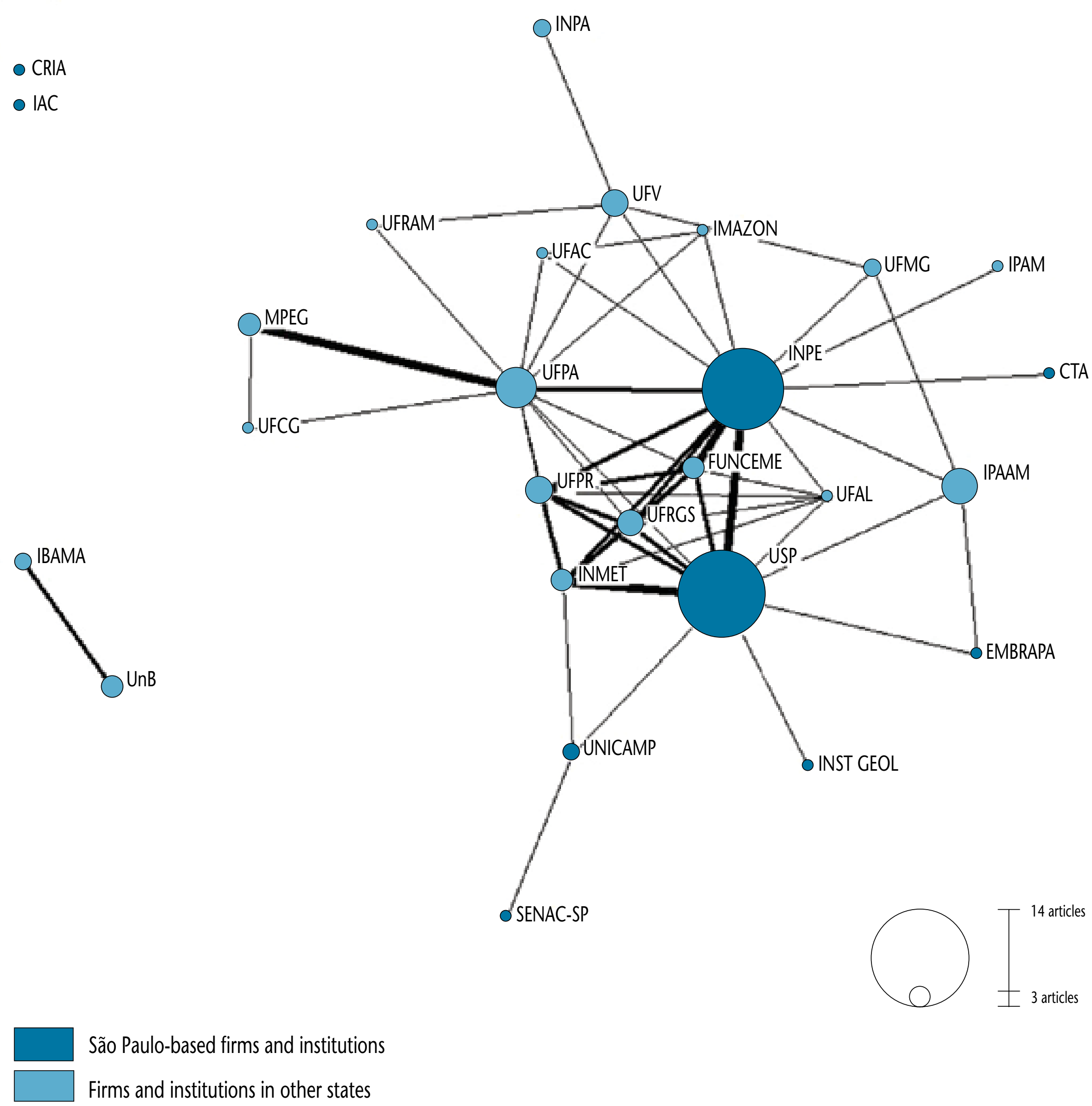
Table 4.5
SCIE- and SSCI-indexed publications on climate change by geographic region – 1998-2007

Geographic region	SCIE- and SSCI-indexed publications on climate change											
	1998 (Abs. nos.)	1999 (Abs. nos.)	2000 (Abs. nos.)	2001 (Abs. nos.)	2002 (Abs. nos.)	2003 (Abs. nos.)	2004 (Abs. nos.)	2005 (Abs. nos.)	2006 (Abs. nos.)	2007 (Abs. nos.)	1998-2007	
											Abs. nos.	%
World	190	234	267	286	271	378	396	482	592	633	3,729	100.0
Developing countries (1)	14	20	19	26	43	43	56	74	73	82	450	12.1
Latin America & Caribbean (2)	4	4	5	6	6	9	11	13	14	21	93	2.5
Brazil	1	1	1	2	3	4	9	7	7	11	46	1.2
São Paulo State	1	1	0	1	1	2	6	6	5	5	28	0.8

Source: Thomson Reuters, *Web of Science* (available via CAPES, Portal de Periódicos).

(1)) According to the International Monetary Fund: <http://www.imf.org/external/pubs/ft/weo/2008/01/weodata/groups.htm#oem>.
(2) According to the World Bank: <http://go.worldbank.org/K2CKM78CC0>.

Chart 4.3
Climate change scientific collaboration network based on SCIE- and SSCI-indexed publications – Brazil, 1998-2007 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science.*

Note: Links between organizations are represented by lines. Each organization's contribution is proportional to the radius of the respective circle (Detailed Table 4.31).

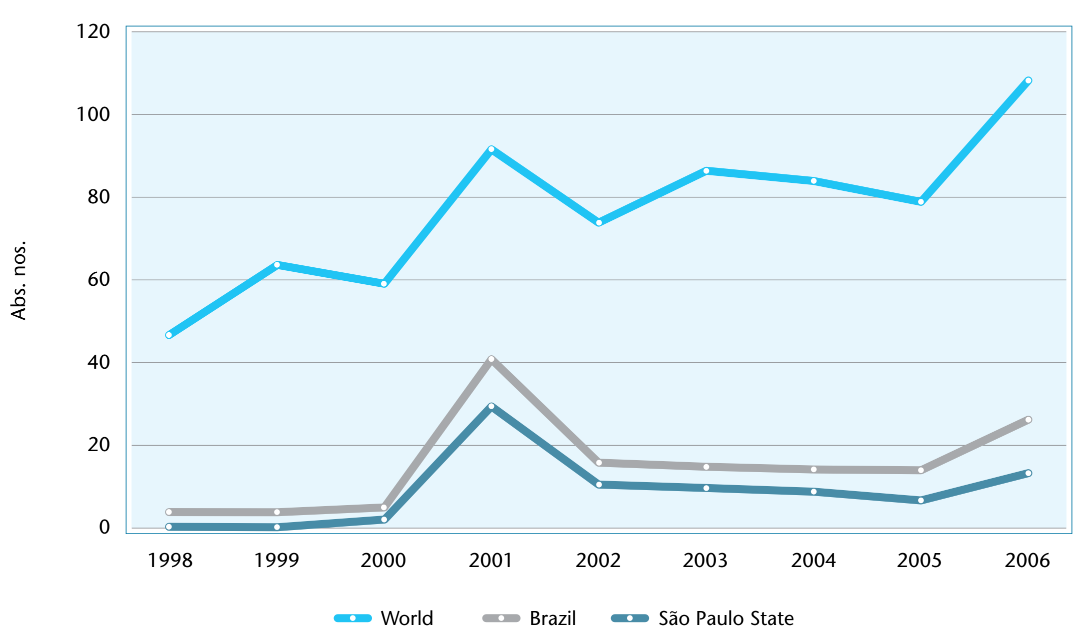
Box 4.4 Sugarcane genomics and breeding scientific cooperation network

Project SUCEST (short for "Sugarcane Expressed Sequence Tag"), funded by FAPESP as part of its Genome Program and ONSA Network (short for "Organization for Nucleotide Sequencing & Analysis"), was dedicated to sequencing and analyzing expressed sequence tags (ESTs) of sugarcane genes for a functional study of the sugarcane genome and transcriptome. With some 200 researchers affiliated to 50 labs, the project identified 238,000 ESTs. The findings were described in 37 articles (edited by Arruda, 2001) and the sequences were published in 2003.

Brazilian scientific production in sugarcane genomics, hitherto insignificant by world standards, increased substantially after the initial SUCEST findings were published in 2001 and reached 20% of world publications on average in the period 1998-2006 (Figure 4.27). Research in sugarcane genomics and breeding by the São Paulo State network contributed strongly, with 17 institutions participating in 58% of publications in the period. This effort was led by USP in terms of numbers of publications (47 out of 139 articles published by Brazil), followed by Unicamp (Figure 4.27).

The collaborative network of sugarcane genomics and breeding research organizations is presented in Chart 4.4, which highlights the intensity of collaboration among USP, Unicamp, UFSCar, Unesp and the Center for Sugarcane Technology (Centro de Tecnologia Canavieira, CTC). It is also important to note the contributions of UFRJ and Embrapa to the formation of a national net-

Figure 4.27
SCIE- and SSCI-indexed publications on sugarcane genomics and breeding – world, Brazil & São Paulo State, 1998-2006



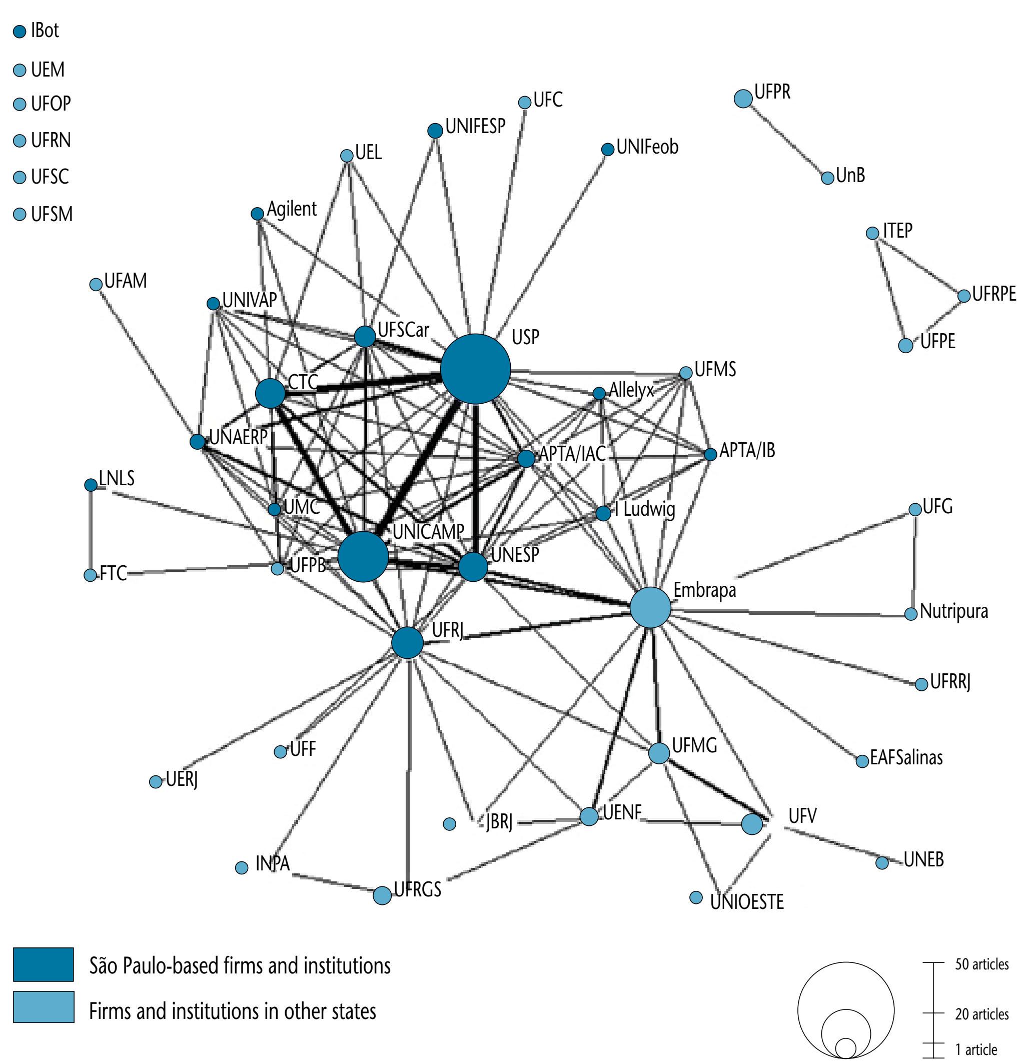
Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Notes: 1. See Detailed Table 4.36.
2. For details of the methodology, see the Methodological Annex to this chapter.

1. *Sugar Cane Expressed Sequence Tag.*
2. *Organization for Nucleotide Sequencing and Analysis.*

work, reflecting their large scientific production and collaboration with institutions in São Paulo and other states. The outputs of the SUCEST-FUN research network (http://sucest-fun.org/en/overview/overview) include identification of the genes associated with sucrose content and stress response. Members of the network recently joined federal universities associated with the Sugarcane Breeding Program (PMGCA) of the Inter-University Network for the Development of the Sugar & Ethanol Industry (Ridesa) and the Campinas Institute of Agronomy (IAC). The genomics group expanded to include BIOEN, which comprises researchers from 20 universities and research institutions in Brazil and 17 in other countries (http://bioenfapesp.org).

Chart 4.4
Sugarcane breeding scientific collaboration network based on SCIE- and SSCI-indexed publications – Brazil, 1998-2006 (cumulative)

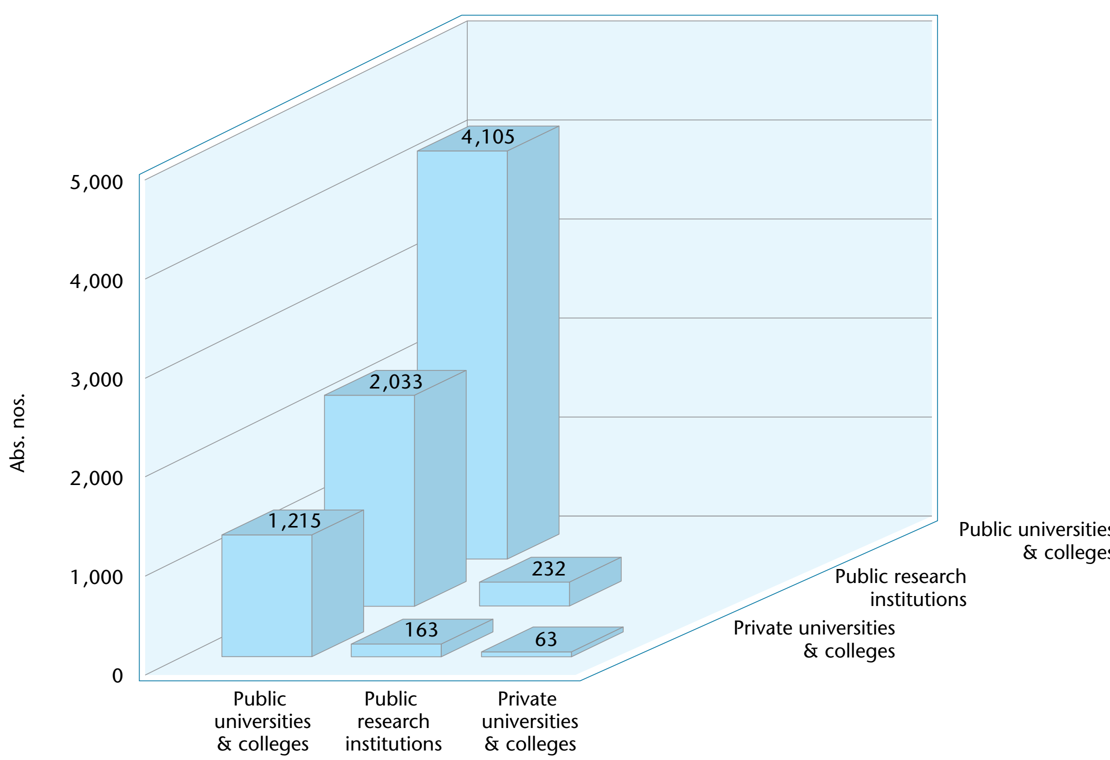


Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: Links between organizations are represented by lines. Each organization's contribution In the period 1998-2006 is proportional to the radius of the respective circle (Detailed Table 4.35).

With regard to collaboration by institutions in São Paulo State (intrastate collaboration in the period 2002-06), it is worth noting collaboration among public universities and colleges: 4,105 out of 35,594 publications by public universities, or 11.5% of the total, were the product of collaboration among these institutions. Intrastate collaboration by universities and research institutions involved 2,033 publications, or 46.2% of the total (4,400). With regard to collaboration between public and private universities or colleges in São Paulo State, the number of co-authored publications totalled 1,215, or 68.6% of all publications by private institutions (1,770). Others were less significant. For example, publications by private universities and colleges in collaboration with research institutions accounted for 9.2% of the total number of publications by the former, while collaboration among research institutions accounted for 5.3% of the total published by these institutions (Figure 4.28; Detailed Table 4.21).

Figure 4.28
Collaboration among universities, colleges and research institutions embodied in SCIE- and SSCI-indexed publications – São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*.

Note: See Detailed Table 4.21.

Box 4.5 Innovation networks in 'Omics' – *genomics, proteomics* and *lipidomics*

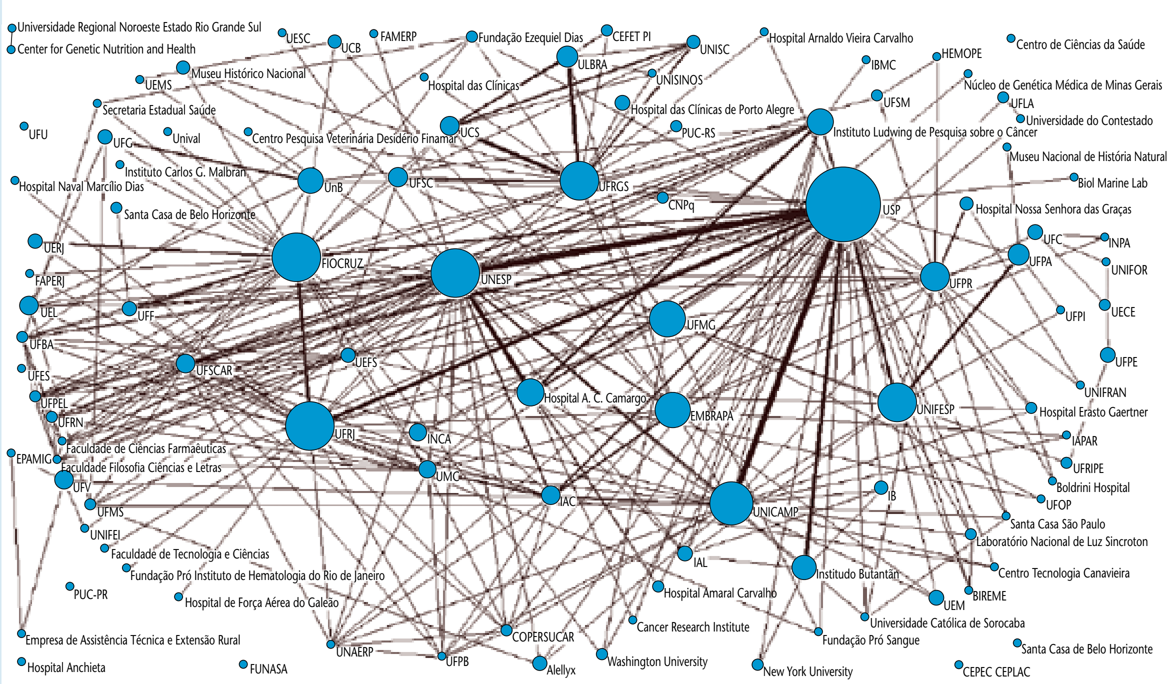
This box discusses two research networks that focus on molecular biology and genetics, or "Omics", an umbrella term for genomics, proteomics and lipidomics. One network revolves around co-authorship of articles indexed by the two main *Web of Science* databases, SCIE and SSCI, in the period 1997-2006 (Chart 4.5). The second network (Chart 4.6) is based on citation links from a patent to other patents, which enable the technological interests of patent-holding groups – firms or R&D institutions – to be analyzed.

The relationships among actors in a network can be expressed visually, or in algebraic form using indicators. In a visual representation, a chart (such as Chart 4.5 below) displays the strength of the link between one institution and another by the thickness of the connecting line, while the content of the collaborative content created by each institution is shown in circular form.

Algebraic indicators of scientific networks, such as network density and group centrality (see the Methodological Annex for definitions and the calculation procedure), can be used to understand the strength of the linkages between co-authors within one and the same institution or in different institutions.

Technology appropriation networks, such as the one shown in Chart 4.6, can be analyzed using the patent co-citation approach based on citation of patents by later patents. Frequently cited patents form networks with a high intensity of interaction, evidencing the clustering of market interests and the emergence of new technological trajectories. A patent-based analysis of the biotechnology appropriation network (Chart 4.6) shows one- and two-link categories (with one or two citations) accounting for over 92% of the total and the eight-link category accounting for 97% of all citations.

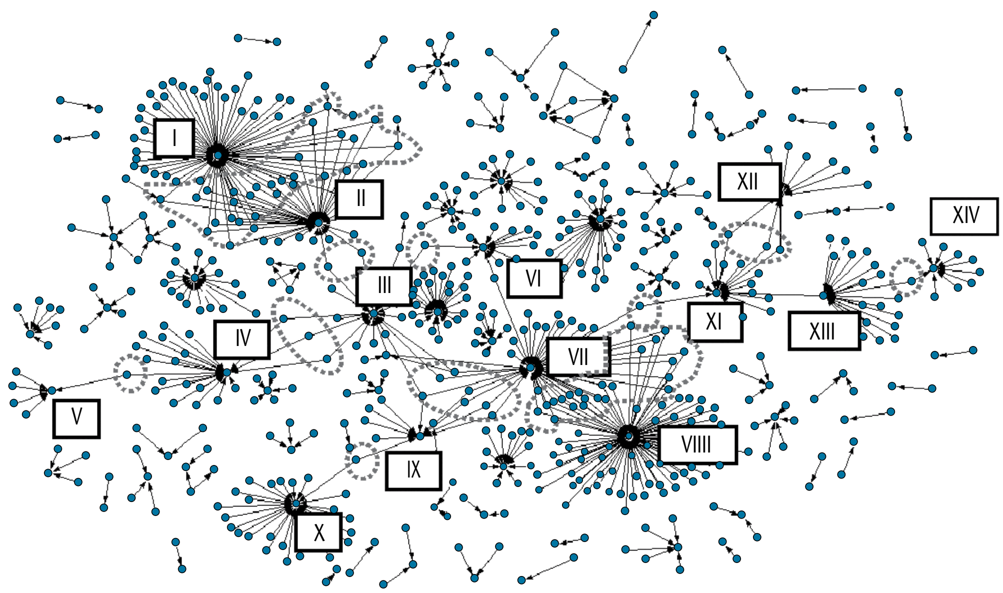
Chart 4.5
Omics scientific collaboration network based on SCIE- and SSCI-indexed publications – Brazil, 1997-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science.*

Note: See Detailed Table 4.29.

Chart 4.6
Network of USPTO agricultural biotechnology patents – Brazil, 1976-2004



Source: USPTO (2004). Dal Poz (2006).

Notes: 1. The analysis covered patents belonging to subclass C12N or group C07H-21, according to the International Patent Classification. See http://pesquisa.inpi.gov.br/ipc/index.php/ [Site inactive]

2. See Detailed Table 4.30.

Patent citation indices are economic indicators of development and typical of knowledge-based economies because they can be used to infer R&D investment by countries and firms that hold patents (Hall, Jaffe & Trajtenberg, 2005). The highest citation scores in this area are also indicators of high technological value for innovation systems and of high market value.

Patents I and II, the most frequently cited and with the highest centrality, protect technologies essential to changing the development trajectories of pharmaceuticals and medical drugs. No Brazilian firms are part of these nodes.

Patent I, held by Diversa Corp. (Glaxo Wellcome), protects intellectual property rights to simulated genetic alteration and gene expression processes that facilitate scale-up in R&D for new drugs and medications.

Patent II, held by Rutgers University, protects biotechnology R&D processes such as gene expression tools and selective gene markers used to develop pharmacogenomics-based biotech based on knowledge of the functions of the genes and molecules they encode.

The approach presented here is often itself innovative, since it translates the analysis of citation intensity into a method for identifying the importance of innovation paths, using networks as technological prospecting tools for the formulation of ST&I and economic development policies.

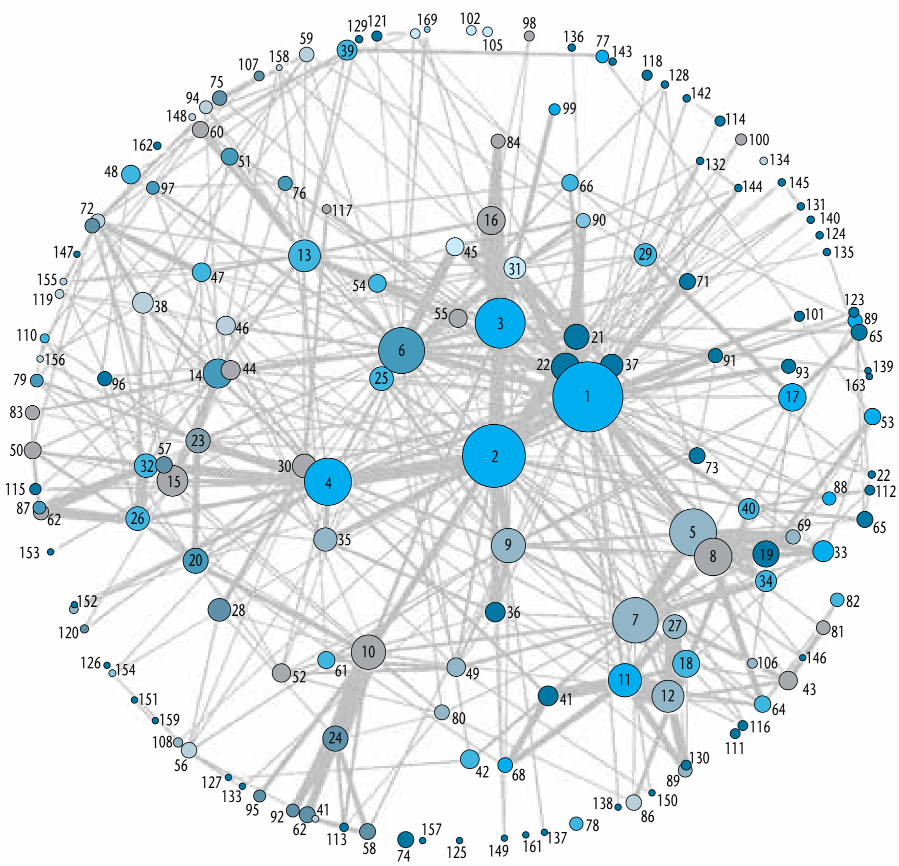
Box 4.6 Biophotonics research networks

Biophotonics is intrinsically multidisciplinary and therefore requires the formation of collaborative networks. Its embryonic stage of development in the world and the breadth of possible applications contribute to the growth of such networks, which are discussed here.

Chart 4.7 illustrates the network of co-authorships in biophotonics generated by Pajek social network analysis software based on a set of selected keywords (the methodology is described in the annex to this box, which includes a detailed legend to Chart 4.7). In this figure the area of the circle that represents an institution is proportional to the number of publications, while the thickness of the lines linking institutions is proportional to the number of co-authorships between them.

The network centers on São Paulo City's great medical schools, triangulating with Unicamp's

Chart 4.7
Biophotonics collaborative network by institution and co-author unit – Brazil, 1983-2006



Simplified legend

- Schools of medicine
- Institutions with complementarity to medicine
- Institutions & departments of chemistry
- Institutions & departments of bioengineering
- Private institutions
- Institutions & departments of physics, biophysics, engineering, biomedicine, IPEN etc.

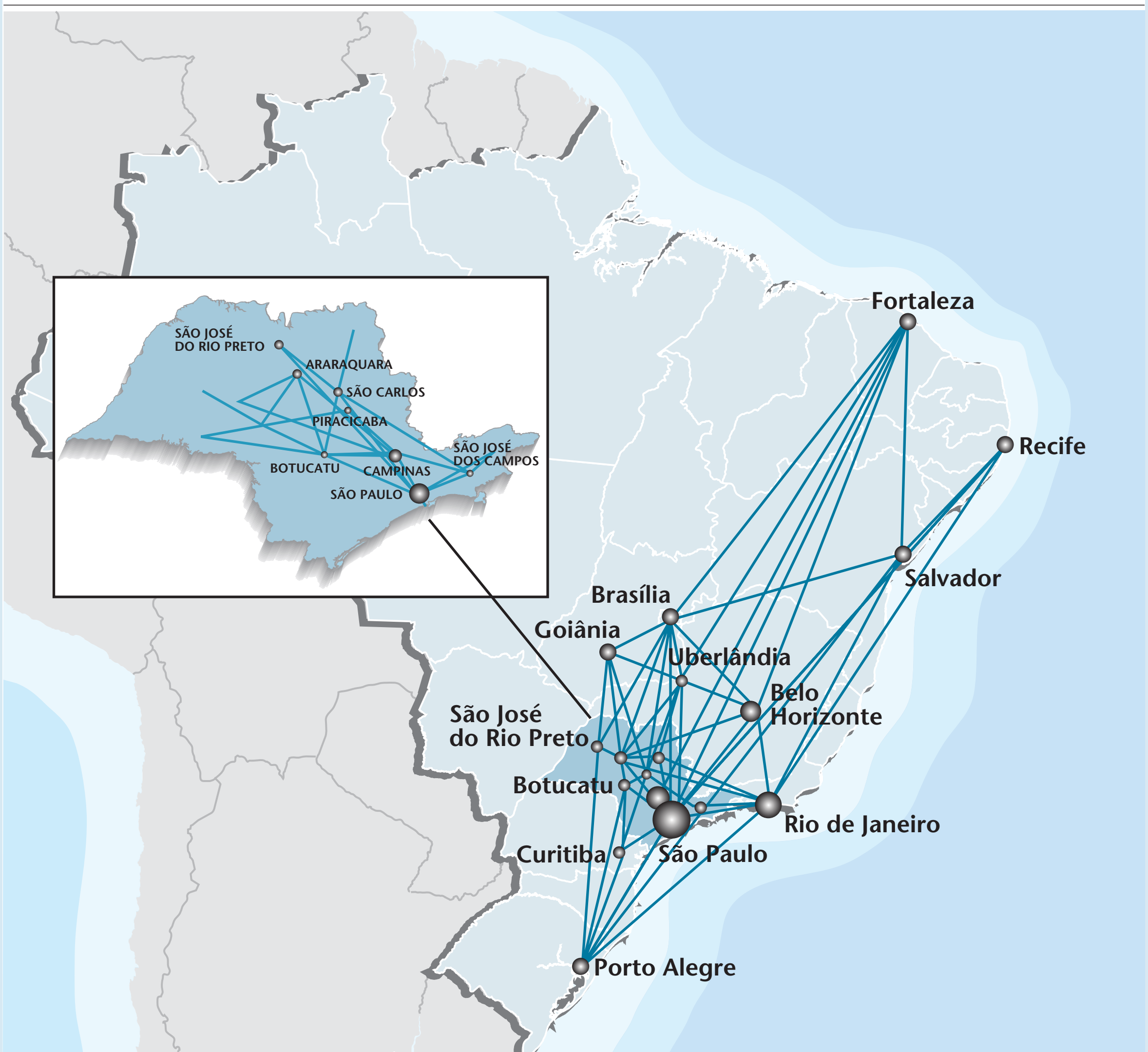
Source: Thomson Reuters (2008), *Web of Science*.

Notes: 1. A detailed legend can be found in the Methodological Annex to this chapter.
2. See Detailed Table 4.37.

school of medicine and slightly distanced from the medical school at USP's Ribeirão Preto campus. USP's Institute of Chemistry, which includes biochemistry, is very close to the center. Gravitating around the center are schools of biomedicine (ICBs), biology, physics and mathematics (because of bioinformatics in genomics and proteomics), the National Synchrotron Light Laboratory (LNLS) and hospitals.

The distance between institutions is not geographical but is determined by "intellectual" proximity reflected in co-authorship. However, it can be seen from the figure that there is a close correlation between "intellectual" and geographical distance. The São Paulo cluster, centering on the great medical schools (1, 2, 3, 4, 21, 22, 37) is distant from the Rio de Janeiro cluster (5, 7, 8, 19). The School of Medicine (33) at the Federal University of Rio de Janeiro (UFRJ) is small because most of the institution's medical research is done by the biomedical school (ICB), which also delivers the basic undergraduate course in medicine. The same applies in part to USP's School of Medicine in São Paulo, which has transferred part of its research to the ICB (9). Unifesp is totally concentrated in the medical school. Institutions in Minas Gerais (11, 12, 18, 27, 43) are closer to the Rio de Janeiro cluster than to the São Paulo cluster.

Map 4.1
Biophotonics co-authorship network – Brazil, 1983-2006



Source: Thomson Reuters (2008), *Web of Science.*

Notes: 1. Excludes co-authorship with researchers affiliated to foreign institutions.
2. See Detailed Table 4.37.

Map 4.1 illustrates the geographical relations more clearly. It is interesting to note the absence of the Amazon from the Brazilian biophotonics network. Considering the region's biodiversity, this gap should be corrected by means of incentives for research projects in collaboration with the network center. Biophotonics expertise is strongly concentrated in São Paulo State.

The pullout in Map 4.1 magnifies São Paulo State to show its many links with other states and within the state itself, comprising nodes in the cities of São Paulo, Campinas, Ribeirão Preto, São Carlos and São José dos Campos. These figures and an analysis of the data show the existence of a multidisciplinary network involving the areas of medicine, biology, physics, chemistry and engineering, as well as private institutions such as Hospital A.C. Camargo, Hospital Israelita Alberto Einstein and Laboratório Fleury (a chain of clinical analysis laboratories), demonstrating a strong natural connection between the academic and productive sectors. This network, which formed naturally, has huge innovative potential if the links are strengthened by the action of well-directed forces.

6. Citations of scientific articles published by selected countries

Research funding agencies and higher education institutions in Brazil and elsewhere see citation-based indicators as important metrics for evaluating the relevance or impact of scientific publications (NSB, 2006; European Commission, 2003; CAPES, 2007b; Mugnaini, 2006; Zanotto, 2006). Citation-based indicators are designed to reflect the impact, influence and/or visibility of articles within the scientific community, assuming that articles are cited because they are useful to researchers. However, the construction and applicability of citation-based indicators entail certain limitations and they should be used with care. Although citation may be associated with quality, it should be understood as a complex parameter that is not equivalent to or unequivocally correlated with the scientific quality of a published article, as exemplified in item 4 of the Methodological Annex (Leydesdorff, 2008). Moreover, few databases are available that enable citation-based indicators to be produced on a global scale.

In 2002-06 Brazilian publications received 214,431 citations or 1.1% of the world total (19,494,964 citations), according to *Essential Science Indicators*.[14] Between 1998-2002 and 2002-06 citations rose 26.7% worldwide and 79.6% for Brazilian publications (Figure 4.29; Detailed Table 4.22). The average number of citations per publication worldwide rose 11.5% from 3.9 to 4.4. The Brazilian average remained much smaller (2.8, up from 2.2) but rose 23.8%, more than double the rate of worldwide growth (Figure 4.30).

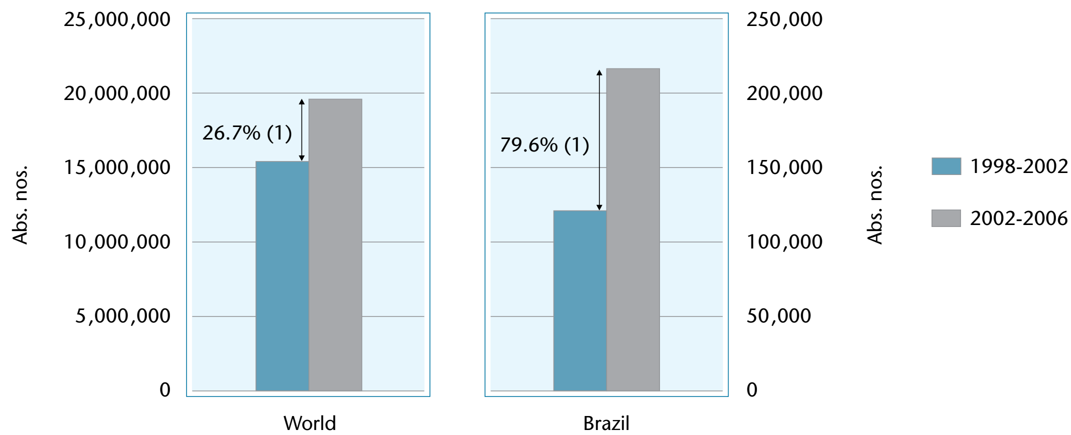
As shown by the ranking of citations received by publications in 2002-06 presented in Figure 4.31, the leading countries in terms of scientific production also lead in terms of worldwide citations (United States, Germany, England, Japan and France). Brazil ranks 23rd in citations and 17th in scientific production, displaying more concentration in citations than most other countries that rank relatively highly in terms of scientific production.

Numbers of citations and publications correlate for the leading countries, as can be seen from Figure 4.32. Citations per publication are below the average for the selected group in the case of countries below the correlation curve, such as Japan, China and Brazil (very close to the average), among others, and above average for countries above the curve, such as England, the Scandinavian countries, Mexico and Chile.

Figure 4.33 plots citations for selected countries in specific years between 1990 and 2003, using data from the National Science Foundation (NSB, 2002, 2004, 2006). The U.S. is both the leader in worldwide indexed scientific production and the country with the largest share of citations, but its share has systemati-

14. See item 2 of the Methodological Annex for details.

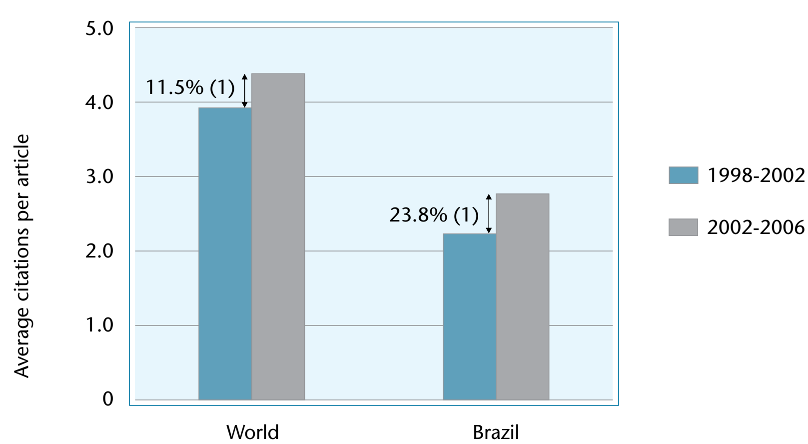
Figure 4.29
Citations of world and Brazilian publications quantified in *Essential Science Indicators* and growth rates (1) – World & Brazil, 1998-2006



Source: Thomson Reuters (2008), *Essential Science Indicators*.

Note: See Detailed Table 4.22.
(1) Growth of citations in 2002-06 compared with 1998-2002.

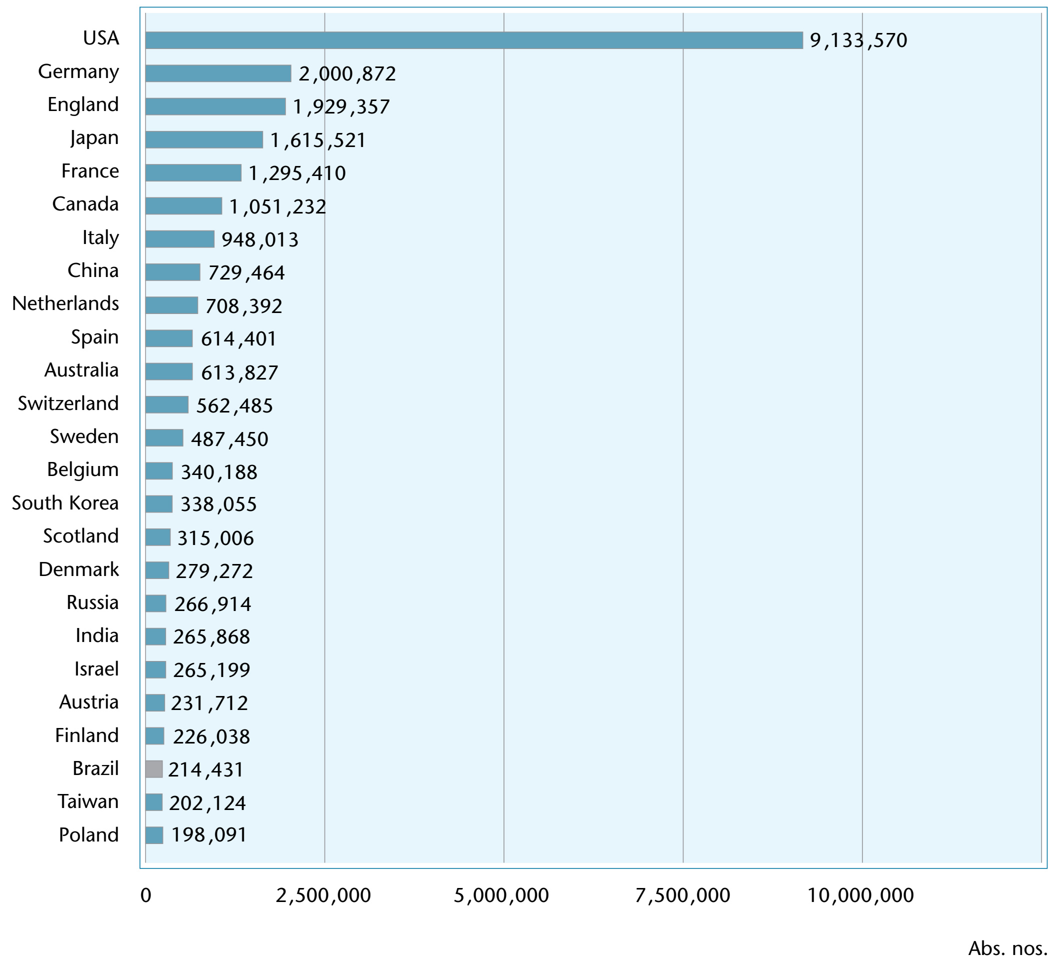
Figure 4.30
Average number of citations received by world and Brazilian publications quantified in *Essential Science Indicators* and growth rates (1) – World & Brazil, 1998-2006



Source: Thomson Reuters (2008), *Essential Science Indicators*.

Note: See Detailed Table 4.22.
(1) Growth of citations in 2002-06 compared with 1998-2002.

Figure 4.31
Ranking of citations quantified in *Essential Science Indicators* – selected countries, 2002-2006 (cumulative)



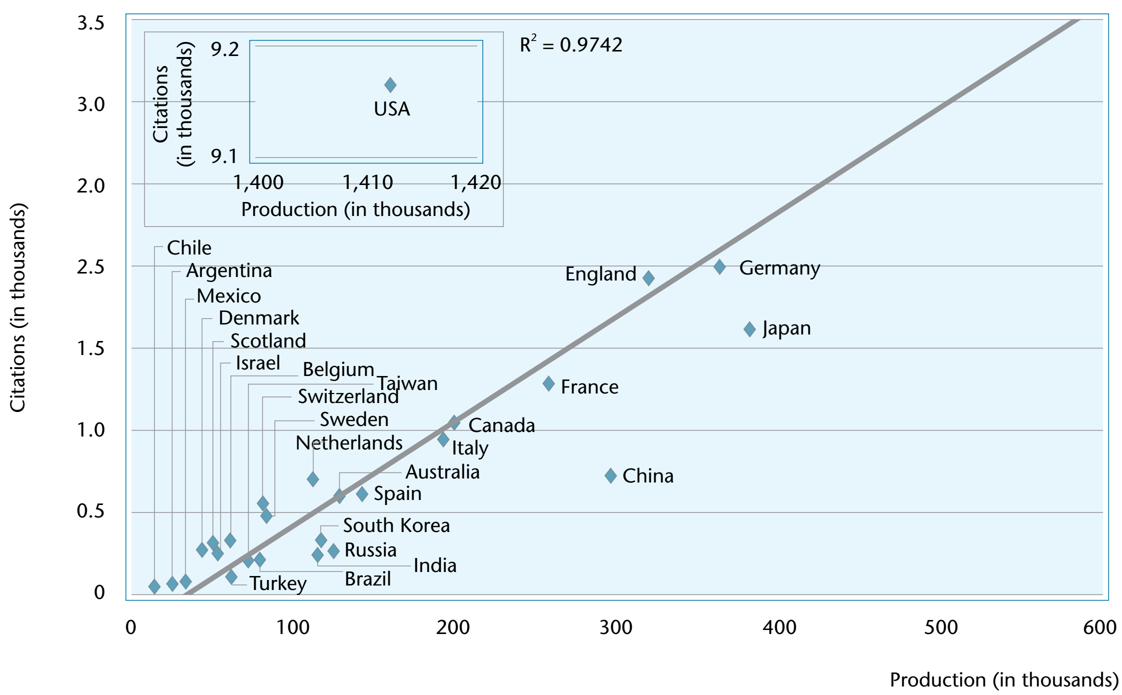
Source: Thomson Reuters (2008), *Essential Science Indicators*.

Notes: 1. IEngland, Scotland, Wales and Northern Ireland are treated as separate entities and it is impossible to aggregate publications for the United Kingdom accurately.
2. Data refer to citations received in 2002-06 by publications in 2002-06
3. See Detailed Table 4.23.

cally fallen, possibly reflecting a relative decrease in the influence of U.S. science on that of other countries, due partly to growth of investment elsewhere, initially in the European Union and now above all in Asian countries such as China, South Korea, Taiwan and Singapore (Shelton, 2008). The U.S. share fell from 52.1% in 1990 to 42.4% in 2003, and the same downtrend occurred for England, the territory with the next largest number of citations, whose share fell from 8.5% to 8.1%, with fluctuations during the period. Meanwhile, the shares of Japan, France and Germany rose in the period, reaching 7.3%, 7% and 4.7%, respectively, in 2003. With regard to China, which joined the group of countries with more than 5% of world scientific output only recently (in 2003), the number of citations received also grew rapidly in the period, from 0.2% of worldwide citations in 1990 to 1.5% in 2003. However, China's share of citations did not reach the same level as the countries with more than 5% of world scientific output (Figure 4.33a; Detailed Table 4.24).

In the group of countries with 2%-5% of world scientific output included in the study, Canada's publica-

Figure 4.32
Publications versus citations quantified in *Essential Science Indicators* – selected countries, 2002-2006 (cumulative)



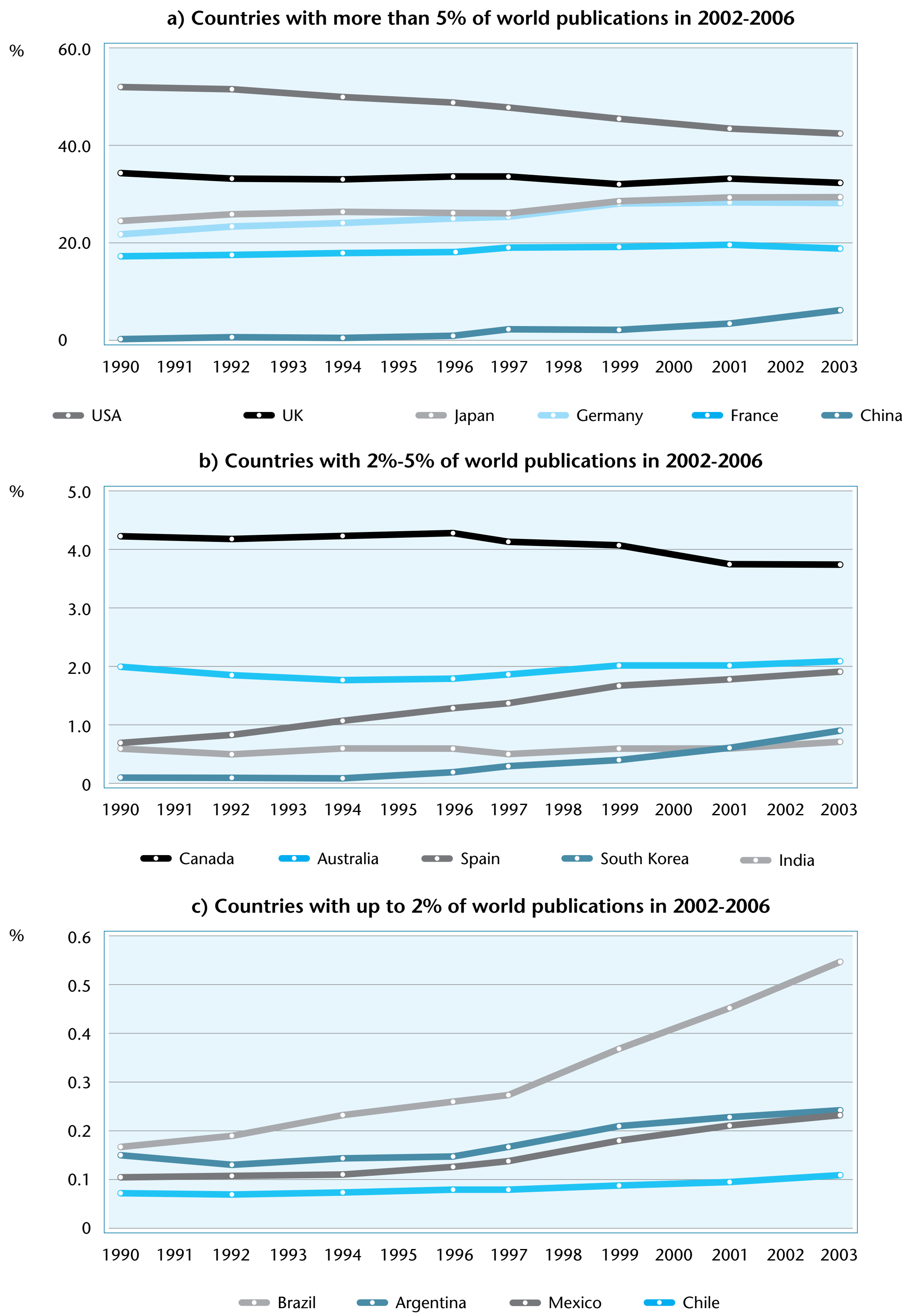
Source: Thomson Reuters (2008), *Essential Science Indicators*.

Notes: 1. England, Scotland, Wales and Northern Ireland are treated as separate entities and it is impossible to aggregate publications for the United Kingdom accurately.
2. Data refer to citations received in 2002-06 by publications in 2002-06
3. See Detailed Tables 4.2 & 4.23.

tions received a large share of citations in 1990-2003 but its share fell from 4.2% to 3.7% of the world total during the period (Figure 4.33b). Citations received by the publications of Spain, Australia and India increased, as did those received by those of South Korea, whose share was well below Brazil's in 1990 (0.06% versus 0.16%) but by 2003 had jumped to 0.94%, almost twice that of Brazil, which was 0.55% in 2003 (Figures 4.33b and 4.33c). Although Brazil's citations lagged those of China and South Korea, they rose strongly, in step with the growth of its scientific output. Brazil stands out among the Latin American countries selected for this study: Mexico's and Argentina's share of citations was 0.24% in 2003, while Chile's was 0.11%. A key element in Brazil's results was use of impact factors in Qualis assessments of journal publications by Brazilian post-graduate programs (CAPES, 2007b). It is also important to note the influence of SciELO, a Brazilian database established in 1996 to promote visibility and credibility for Latin American and Caribbean scientific production. This influence is evidenced by growth in the region's SCIE- and SSCI-indexed publications (Meneghini, Mugnaini & Packer, 2006; Alonso & Fernández-Juricic, 2002; Meneghini, 2002).

A breakdown of citations by knowledge area shows that although a large proportion of Brazilian areas accounted for a significant share of worldwide citations received in the period 2002-06, when this period is compared with 1998-2002, a majority of citations also grew more than the world total for the same area, with physics, biology and botany, and agrarian sciences in the lead. It is also worth noting that the average number of citations per publication in 2002-06 for physics in Brazil was 3.4, close to the world average of 3.9. The average for engineering was 1.7 both in Brazil and worldwide (Figure 4.34; Detailed Table 4.22).

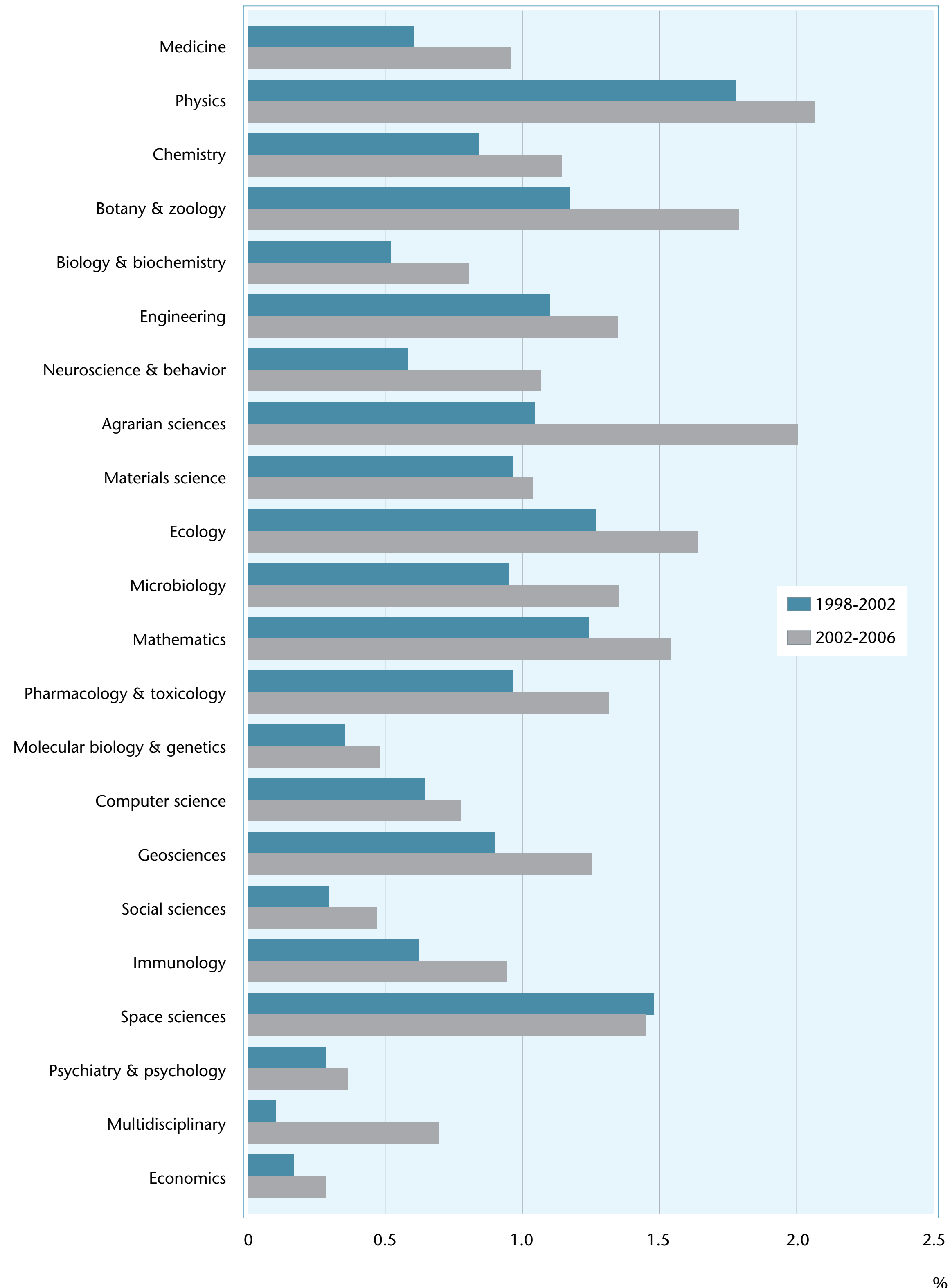
Figure 4.33
Contributions of selected countries to world citations of SCIE- and SSCI-indexed publications – 1990-2003



Source: NSB (2002, 2004, 2006).

Note: See Detailed Table 4.24.

Figure 4.34
Brazilian contributions (1) to world citations quantified in *Essential Science Indicators by knowledge area – Brazil, 1998-2006*



Source: Thomson Reuters (2008), *Essential Science Indicators*.

Note: See Detailed Table 4.22.
(1) Contributions measure citations to Brazilian publications in a given knowledge area in proportion to total world citations to publications in the same area.

7. Using additional databases to analyze scientific production

The main databases used in this study were SCIE and SSCI, owned by Thomson Reuters (formerly ISI) and available from *Web of Science*. Although these databases are used worldwide for the macroanalysis of scientific production, some characteristics of Brazil's and São Paulo State's scientific production are measurable only by using other databases, given the limitations and weaknesses inherent in the construction of indicators for countries with a small share of world scientific output.

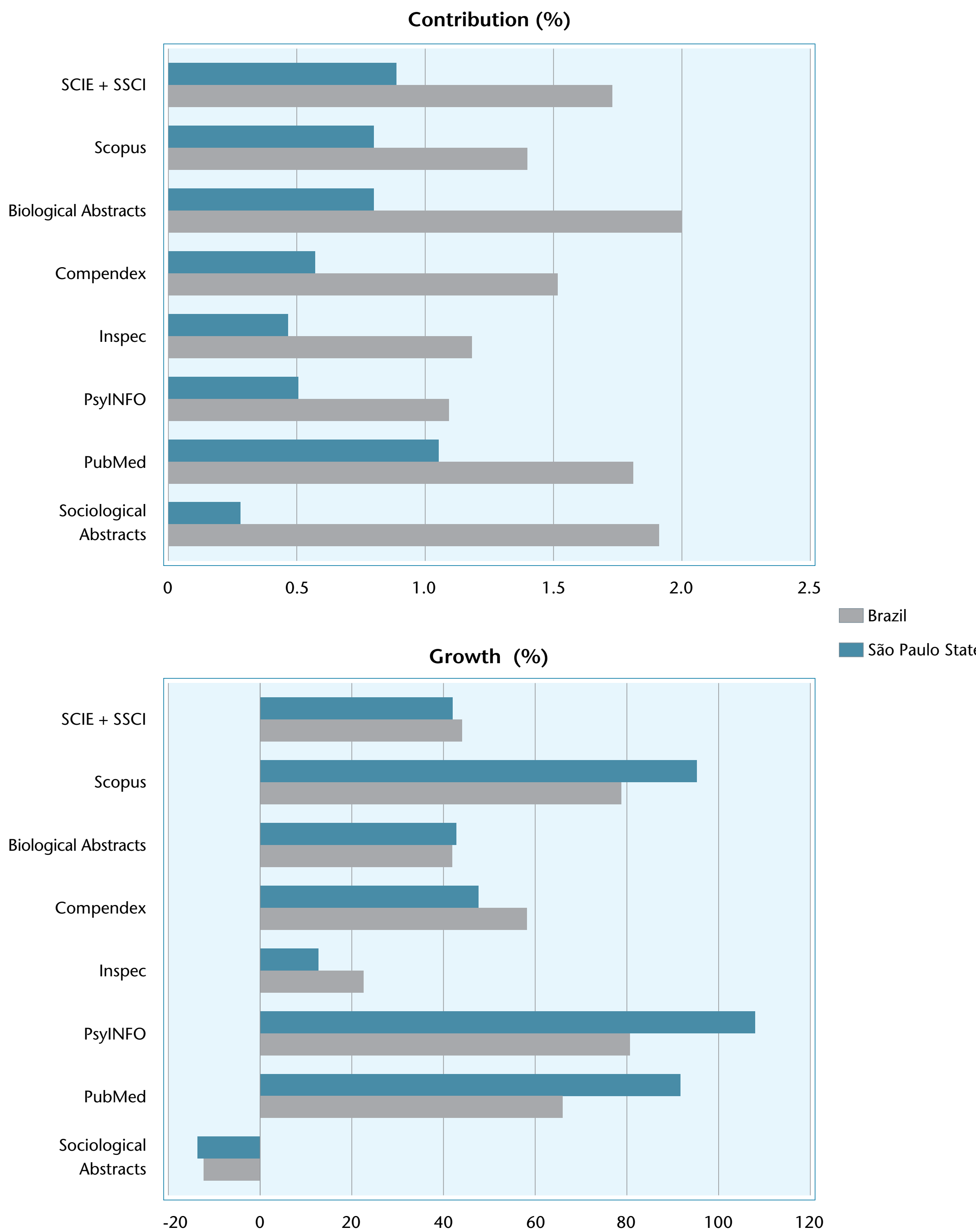
According to the multidisciplinary databases SCIE and SSCI, Brazil's contribution to world production in 2002-06 was 1.7% and São Paulo State's was 0.9%. The following international databases were used for a comparative study with the data from SCIE and SSCI: the multidisciplinary database Scopus, according to which Brazil's contribution was 1.4% and São Paulo's was 0.8%; and the specialized databases Biological Abstracts with 2% and 0.8%, respectively, Compendex with 1.5% and 0.6%, Inspec with 1.2% and 0.5%, PsycINFO with 1.1% and 0.5%, PubMed with 1.8% and 1.0%, and Sociological Abstracts with 1.9% and 0.3% (Figure 4.35a; Detailed Table 4.25). The multidisciplinary database SciELO displayed percentage contributions and proportions between Brazil and São Paulo that closely resembled those displayed by SCIE and SSCI. The findings were also fairly similar to those from the databases that specialize in health sciences, exact sciences and technology. The greatest difference was found in the case of Sociological Abstracts, according to which São Paulo's share was significantly smaller than Brazil's compared with the results from other databases. These results reflect differences in the contents of the various databases and possibly also differences in Brazil's and São Paulo's contributions in the knowledge areas on which each database specializes. As for growth of Brazil's and São Paulo's publications indexed by the specialized databases, the highest percentages were for PubMed and PsycINFO, while growth was negative for Sociological Abstracts (Figure 4.35b). Brazilian scientific production has been found to have grown by previous studies (Leta & Cruz, 2003; FAPESP, 2005).

With regard to the selected international multidisciplinary databases, Scopus shows stronger growth in Brazil's and São Paulo's indexed output than SCIE and SSCI (Figure 4.35b; Detailed Table 4.25). This may reflect differences between the databases in terms of maturity, policy and criteria for accepting and retaining journals. On one hand, they may favour a concentration of publications by mainstream journals; on the other, publications by countries with a smaller share of world output may predominate. The recent creation of Scopus (in 2004) introduced an important new component for the construction of indicators, given the possibility of comparing and contrasting databases, whereas hitherto Thomson Reuters has been hegemonic. Competition among these databases could lead to changes in the strategies according to which they select content, at least partially hindering analysis based on historical comparisons.

With regard to specialized databases, their use in studies of scientific production is pertinent and recommendable, but there are serious reservations regarding their use to analyze indicators based on scientific collaboration and citations (see item 3 of the Methodological Annex). The large volume of records contained by the various databases makes them sufficiently representative for bibliometric research despite the biases that may exist (Okubo, 1997). As found in a previous study by this institution (FAPESP, 2005), in line with the findings of Okubo (1997), a macroanalysis focusing on a specific knowledge area represented in a multidisciplinary database identifies similar trends and closely correlated growth and proportionality in scientific production when compared with a specialized database. While the existence of alternatives is stimulating, prudence is essential since there is no guarantee of representativity or convergence of databases in specific respects. They have different contents and entry criteria. The multidisciplinary databases are intentionally less comprehensive in certain knowledge areas and specializt disciplines. This diversity can create quite different and even incompatible results in one and the same study, and there is no objective means of knowing which database provides a more accurate reflection of reality in the scientific field analyzed. For quantitative mesoanalysis and microanalysis, and for the analysis of certain qualitative aspects, multidisciplinary databases may lack sufficient sensitivity for the required depth or level of detail, especially when analyzing the scientific output of countries like Brazil with a small share of the total volume in world databases and widely differing levels of scientific development across knowledge areas, regions and institutions. It is therefore desirable to complement multidisciplinary databases with specialized databases whenever possible in bibliometric and citation-based research on scientific production.

In research on collaboration, multidisciplinary databases record the affiliations of all co-authors whereas specialized databases identify only the first author's affiliation. In the absence of all co-author affiliation data it is impossible to analyze scientific collaboration based on co-authored publications using specialized databases. Moreover, only some of the publications

Figure 4.35
Brazil's and São Paulo State's contributions to publications indexed by selected databases and growth rates – Brazil & São Paulo State, 2002-2006 (cumulative)



Source: Thomson Reuters (2008), SCIE & SSCI via *Web of Science*; Scopus (2008); *Biological Abstracts* (2008), Inspec e PsycINFO via *WebSpirs*; Compendex via *Ei Engineering Village* (2008); *Sociological Abstracts* (2008).

Notes: 1. For SCIE, SSCI and Scopus, the types of publication considered were articles, letters, notes and reviews. All types were considered for other databases.
2. For *Biological Abstracts*, Compendex, Inspec, PsycINFO, MEDLINE/PubMed and *Sociological Abstracts*, the publications considered were those originating in São Paulo State and with the following expressions in the "author's affiliation" field: (a) "sao paulo"; (b) "SP"; (c) the name or acronym of a public university in the state or of a public research institution in the state, or the name of one of the ten cities with the largest numbers of publications in the state (São Paulo, Campinas, São Carlos, Ribeirão Preto, São José dos Campos, Araraquara, Piracicaba, Botucatu, Jaboticabal, Rio Claro).

originating in certain countries or institutions and indexed by specialized databases can be retrieved or identified by affiliation. The data treatment necessary to enable such an analysis would typically be complex, slow and susceptible to errors, not to mention prohibitively expensive because it would involve skilled labor. Specialized databases may therefore not offer the desired conditions or representativity even for mesoanalysis and microanalysis, although they are valuable as complementary sources to multidisciplinary databases and for the analysis of specific aspects.

Specialized databases cannot be used for the purpose of constructing citation-based indicators either, since they do not index citations, as do multidisciplinary databases. The latter are indispensable when the object of research is the impact, relevance and visibility of scientific production. It is important to bear in mind, however, that citations refer only to the contents of a given owner's database system and do not encompass sources external to that specific system. In order to extend the analysis beyond scientific production to indicators of collaboration and citations, it is essential to use international multidisciplinary databases (those of Thomson Reuters, especially SCIE, SSCI and A&HCI, and/or Elsevier's Scopus) or the Brazilian multidisciplinary database SciELO.

The SciELO Brazil database, which contributes to the visibility of Brazilian production by indexing citations to publications held by the database itself, can also be used to analyze collaboration by country. The data can be disaggregated by institution but not by state. The number of publications indexed by SciELO Brazil rose 78.9% to 60,204 in the period 2002-06. Brazil's and São Paulo State's contributions were 77.3% and 32.5%, respectively, in 1998-2002, and 73.6% and 26.2% in 2002-06, with the Brazilian contribution growing significantly faster (Detailed Table 4.25). Also according to publications indexed by SciELO Brazil, Brazilian collaboration with selected countries in the same period was strongest with the U.S., U.K., Germany, France, Canada, Spain, Argentina and Chile (Figure 4.36; Detailed Table 4.26). Collaboration with Japan, China, India, Australia, South Korea and Mexico was not significant. In most cases collaboration grew very strongly in the period.

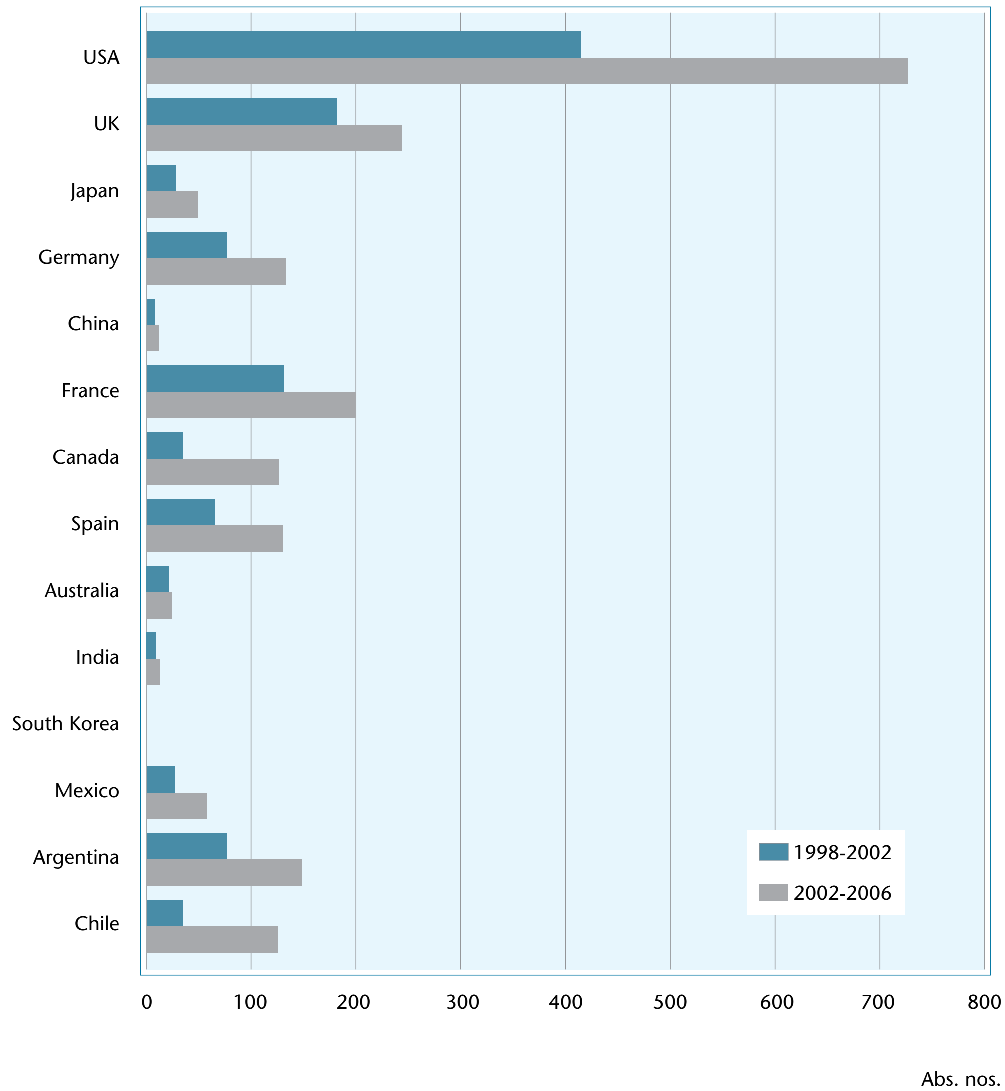
It is worth mentioning that despite SciELO's usefulness for the construction of citation- and collaboration-based indicators of scientific production, and its important contribution to enhancing the visibility of Brazil's publications, international multidisciplinary databases must be used when the analysis focuses on Brazil's bibliometric indicators.

SCIE and SSCI are international multidisciplinary databases that have existed for some time. Scopus, established more recently, is an important alternative or complement for studies of citation-based indicators and research focusing on scientific production and collaboration. Journal, country and institution rankings produced by SCImago on Scopus (scimagojr.com and scimagoir.com) can be used, for example, to analyze the correlations between publications and citations in 2002-06 for selected countries (Figure 4.37; Detailed Table 4.27). The resulting correlation curve, which can be considered the per publication citation rate, closely resembles the plot presented in Figure 4.30, which was constructed using data from *Essential Science Indicators,* extracted from SCIE and SSCI. The procedure used to construct Figure 4.37 was also similar to that used to construct Figure 4.32. In the case of Figure 4.37, for example, the U.S. is slightly above the curve, whereas in Figure 4.32 the U.S. is on the curve. Japan is below the curve, and China is well below, as also shown by Figure 4.32. Brazil is slightly above the curve, whereas in the previous result it was slightly below.

Another important citation-based indicator, the h-index,[15] can be obtained aggregately, by country, institution or researcher from SCImago, which is based on base Scopus. In the period 2002-06 the countries with the highest h-indices were among the leaders in terms of scientific production (Figure 4.38; Detailed Table 4.28), with the U.S., U.K., Germany, Japan and France at the top, followed by Canada, Switzerland, Italy, Netherlands and Sweden, among others. Brazil ranked 24th, ahead of India, Ireland and other Latin American countries.

15. The Hirsch index (h) is defined as the number of articles published by a researcher to which the number of citations is equal to or greater than *h*. Thus an author with an index of *h* has published h papers each of which has been cited by others at least *h* times.

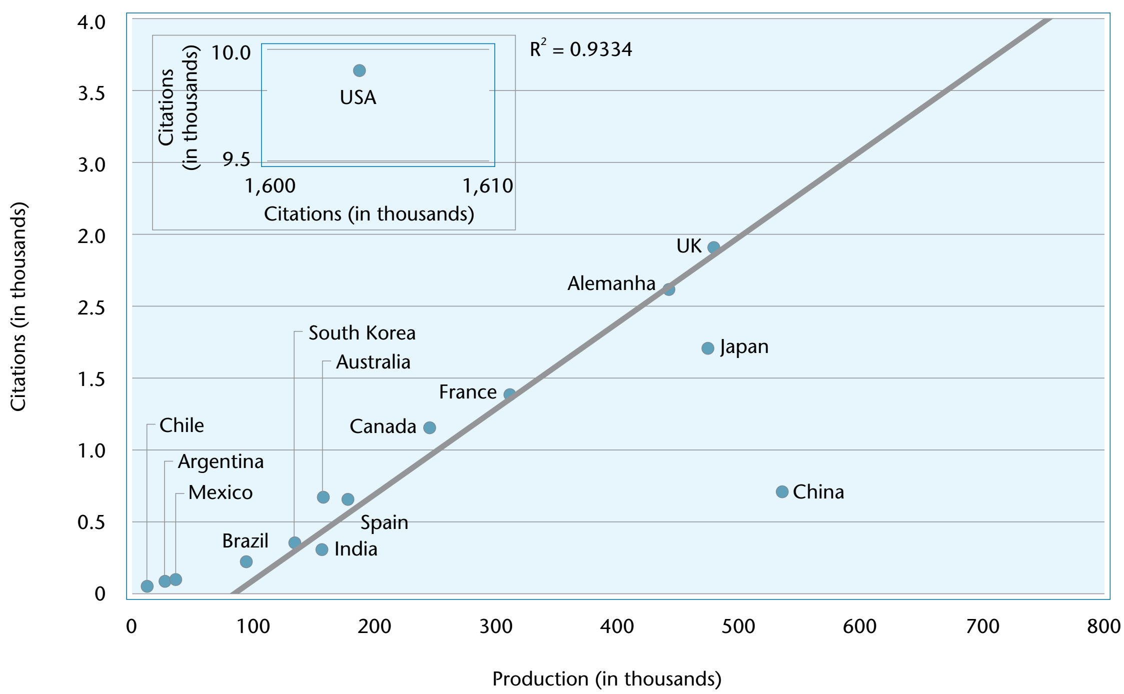
Figure 4.36
SciELO-indexed Brazilian publications with international co-authors – selected countries, 1998-2006



Source: SciELO (2008).

Note: See Detailed Table 4.26.

Figure 4.37
Publications versus citations quantified by SCImago – selected countries, 2002-2006 (cumulative)



Source: Scopus, quantification by SCImago (2008).

Note: See Detailed Table 4.27.

8. Conclusions

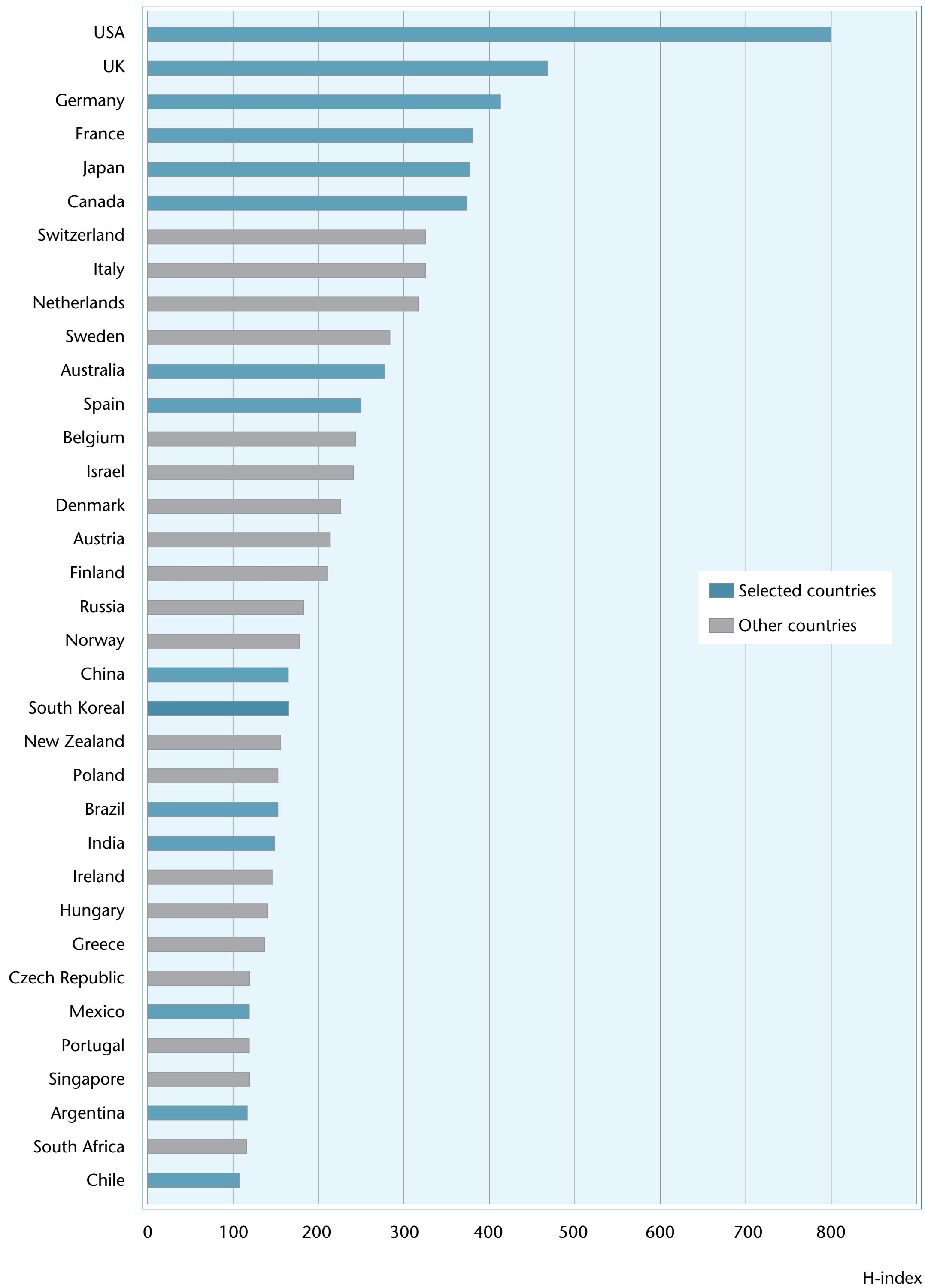
The analysis of scientific production presented in this chapter, based on surveys with retroactive adjustments where necessary and using bibliometric indicators and procedures in accordance with international practice, shows significant growth in publications and citations for both Brazil and São Paulo State in the period 2002-06.

The number of SCIE- and SSCI-indexed Brazilian publications increased significantly in 2002-06, reaching 18,915 in 2006, and Brazil's contribution to indexed world production rose from 1.6% to 1.9% in the period. One of the key drivers of this growth was the maturing of post-graduate programs and growth in the numbers of post-graduate students, programs and degree holders in Brazil. The Southeast contributed more than any other region to national scientific production, thanks mainly to the presence of more higher education and research institutions, to a larger supply of human and financial resources, and to the infrastructure installed in the region. However, all other regions displayed more growth, possibly owing to federal and local policies to decentralize national ST&I capabilities.[16]

São Paulo State's scientific production measured in publications rose from 6,764 in 2002 to 9,564 in 2006. Its contribution to Brazilian production rose from 49.9% in 1998-2002 to 51.0% in 2002-06. This growth was due mainly to the magnitude of scientific production by public universities and by the state and federal research institutions present in São Paulo, and to the human resources involved in post-graduate programs (see Chapter 3 of this publication). The dis-

16. Some institutions in states without a significant track record in science performed strongly owing to the fact that researchers who graduate from leading Brazilian universities, especially in São Paulo State and Rio de Janeiro State, end up working elsewhere, and also owing to state ST&I policy measures, such as the establishment of research development agencies in several states. The Ministry of Science & Technology (MCT) has also taken steps to strengthen ST&I infrastructure in the regions.

Figure 4.38
H-index quantified by SCImago – selected countries, 1996-2006 (cumulative)



Source: Scopus, quantification by SCImago (2008).

Notes: 1. The *h*-index is defined as the number of articles published by a researcher to which the number of citations is equal to or greater than *h*. Thus an author with an index of *h* has published *h* papers each of which has been cited by others at least *h* times. In this figure, based on data from Scopus, *h* refers to the period 1996-2006.
2. Data were collected for the top 35 countries ranked by their respective *h*-indices, thereby assuring the inclusion of all 15 selected countries. The other 20 in the top 35 were non-selected countries.
3. See Detailed Table 4.28.

tribution of São Paulo's scientific production between the capital and the interior of the state was balanced and stable in the period, with the interior contributing 54.7% and the capital 51.8%. The fact that three cities in the interior – Campinas, São Carlos and Ribeirão Preto – as well as the state capital ranked among Brazil's top ten cities in numbers of publications strengthened the importance of the interior as an engine of scientific development. The interior of São Paulo State has this importance because units of public universities and research institutions are located in several cities across the state.

Brazil's international scientific collaboration measured by the number of co-authored publications grew 30.4% in the period, but its contribution to total scientific production decreased from 33.1% in 2002 to 30.0% in 2006. This downtrend has been in progress for some years, as noted in previous studies (FAPESP, 2002, 2005). On the other hand, interstate collaboration rose 79.4%, outpacing Brazil's scientific production, which grew 43.5% in the period. The maturing of post-graduate studies in Brazil, a reduction in grants and scholarships for overseas study and policy measures designed to foster the decentralization of research, to which collaboration also contributes, were probably the factors that led collaboration to rise faster than overall production. São Paulo's international collaboration was similar to Brazil's in that the number of co-authored publications rose in absolute terms but fell as a share of total scientific production. Brazil's and São Paulo's leading partners in this field were essentially the same, comprising the U.S., France, the U.K., Germany, Spain, Canada and Argentina. However, in São Paulo's case it is important to note strong growth in collaboration with South Korea (313.3%), India (184.8%), Mexico (126.8%), China (107.0%), Argentina (82.8%) and Australia (77.6%). The fact that Brazil has technical and scientific cooperation agreements with all these countries probably helps explain the strong growth in collaboration in the cases concerned.

In São Paulo, state universities (USP, Unicamp and Unesp) and federal universities (Unifesp and UFSCar) accounted for a significant share of international and domestic scientific collaboration, as well as playing a key role in collaboration with other institutions in the state. Collaboration between public universities and research institutions accounted for 46.2% of total publications by these institutions, while collaboration between public and private institutions accounted for 68.6% of the latters' production. São Paulo's institutions collaborate intensely with each other, and to a lesser extent with institutions in other states, possibly because competencies are more concentrated in the state and owing to geographical proximity and economic benefits, although they collaborate with all states with varying degrees of intensity.

Growth in research collaboration is important for scientific and technological development, given the increasing complexity of the challenges of scientific research and the multidisciplinarity required to surmount them. Research support programs can play a fundamental role in fostering the formation of collaborative networks, so as to achieve more significant scientific and technological results while at the same time enhancing the visibility and recognition of national science. A study of research networks that focus on nanotechnology, climate change, sugarcane genomics, "Omics" and biophotonics produced important findings for science policy planning, such as the leading role played by institutions located in São Paulo State in structuring these networks (see, for example, the case study of climate change research networks in Box 4.3); the decisive importance research support projects and programs can have for the formation of research networks (see, for example, the case study of sugarcane genomics research in Box 4.4); the growing number of publications associated with these networks (e.g. the nanotechnology and sugarcane genomics research networks); the creation of numerous and intense relationships of scientific collaboration (see, for example, the case study of the Brazilian "Omics" research network in Box 4.5); and the inclusion of private institutions in research networks, which is of vital importance to leverage the knowledge created by business and industry and which needs to be intensified (see, for example, the case studies of the nanotechnology and biophotonics research networks in Boxes 4.2 and 4.6, respectively).

Despite the limitations of the procedures and difficulties of interpretation that explain reservations on the part of some members of the scientific community, citation-based analysis is increasingly accepted as valid around the world. New tools to characterize scientific production are under development and will certainly contribute to more in-depth knowledge and understanding of science while helping to identify themes and issues on the scientific frontier.

Although the number of citations to Brazil's SCIE- and SSCI-indexed publications is relatively small, it is rising strongly. Between 1990 and 2003, for example, it rose from 0.16% of total world citations to 0.55%. This growth in citations is due in part to the growth of Brazil's SCIE- and SSCI-indexed publications. It is also worth mentioning the role of the Brazilian database SciELO in enhancing the visibility and recognition of publications in Brazilian journals. Its commitment to electronic international dissemination of Brazil's scientific production has demonstrably driven a rise in citations to the journals it indexes and will no doubt continue to do so as the database grows.

It should be stressed that there are limitations and weaknesses in the information sources used to analyze Brazilian science, such as the small participation of Brazilian publications in SCIE and SSCI. This chapter includes the findings of an exploratory study covering several databases, showing that they can viably be used to construct additional indicators. It is also advisable to upgrade national databases so as to foster the dissemination of knowledge and their use for the construction of indicators. Important initiatives under way in Brazil and requiring enhancement include SciELO, CNPq's Lattes Platform and IBICT's Digital Library of Theses & Dissertations, among others.

A final recommendation is that systematic efforts continue to improve the databases and techniques available for use in constructing and analyzing bibliometric indicators tailored to Brazil's needs in policymaking and to increase society's awareness of national science.

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