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Knowledge, Innovation and Agglomeration: regionalized multiple indicators and evidence from Brazil

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ABSTRACT

This paper develops multiple indicators to map the geographical distribution of knowledge and scientific and technological capabilities as proxies of the geographical distribution of Science, Technology & Innovation activities, and applies such indicators to data and information from the state of São Paulo, Brazil. The overall view of the geographical distribution of S,T&I activities in the state is complemented by the analysis of the same activities in the perspective of a local production and innovation system: the case of information and communication technologies in the micro-region of Campinas. The results show a pattern for the regional distributions of S,T&I activities along the main highways of the state, around metropolitan areas such as São Paulo and Campinas, and in regions where educational, science and technology, and R&D institutions are strongly concentrated. Firms tend to agglomerate in these areas and regions, forming local production and innovation systems. The paper produces evidence on the adherence of the geographical distribution of those systems to the geographical distribution of S,T&I activities as shown by the indicators. This confirms the empirical findings of the literature about the relationship between geography and innovation.

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Introduction

This article is thematically linked to a body of literature that studies the relationships between geography and innovation, a field that has become increasingly multidisciplinary, combining elements of economic geography, industrial organization, innovation economics, international trade, and the economics of the firm.

The lines of research that have drawn most attention in this field include the application of innovation activity indicators for a number of purposes: measuring the occurrence of knowledge spillovers in delimited territorial spaces, assessing the technological efforts of firms, and proving that there is a correlation between geographical location and innovation, among others. The present paper follows this line of research by propounding a methodology based on multiple indicators that can be used to map the regional distribution of innovation activities, and applying it for the sake of illustration to Brazilian data for the state of São Paulo.

The logic of the argument is that the regional distribution of science, technology and innovation activities reflects the regional distribution of the knowledge that substantiates technical, scientific and technological capabilities. These capabilities in turn induce the localization of productive activities and the formation of agglomerations of firms, often leading to the creation of clusters or geographically circumscribed production and innovation systems. Thus the paper develops and applies a set of regionalized indicators based on: (1) the regional distribution of skilled jobs, innovative firms, patent and trademark applications, and published scientific articles; and (2) the regional network of higher education institutions, vocational and technical schools, research centers, laboratories and other service entities constituting the scientific and technological infrastructure that supports the innovation activities of business organizations.

The principle underlying our use of multiple indicators is that the technological efforts of firms depend on a far wider array of factors than can be captured by indicators based on only one type of information, such as patent citations, for example. However, the elaboration of several types of indicators evidently depends in the last analysis on the availability of databases with sufficient quality and detail to serve as a source of regionalized information. This is not always the case, owing to restrictions imposed by specific legislation designed to protect the confidentiality of personal data. These and other limitations of the databases involved are noted below.

The paper is organized as follows. The first section reviews the literature, focusing specifically on work that discusses the geographical distribution of innovation activities from the empirical standpoint. The second section presents a set of quantitative indicators, their respective methodologies and databases, and the results of their application to São Paulo State. The next section summarizes our survey of the network of scientific, technological and service infrastructure institutions that support firms in the state. The fourth part of the paper utilizes a vertical cross-section to analyze the results from the standpoint of clusters or local production and innovation systems. This is the basis for an assessment of the extent to which the localization of productive activities and the agglomeration of firms in clusters or local production and innovation systems correlate with the pattern of geographical distribution of knowledge and technological infrastructure institutions displayed by the indicators, as illustrated by the analysis of a specific case: the local production and innovation system in the Campinas micro-region. The conclusion presents some final thoughts and suggestions for enhancement of the system of data and information on science, technology and innovation.

1. The geography of innovation: spillovers, spin-offs, networks, and regional systems

The correlation between geography and innovation has been demonstrated empirically by several authors. Feldman (1993; 1994) and Audretsch & Feldman (1996), for example, show that there is a clear relationship between the localization of innovative activities, measured in terms of the number of patent citations, and the geographical concentration of innovative inputs such as R&D in universities, industrial R&D, the presence of related industries, and the presence of firms that provide specialized business services, demonstrating the importance of "geographically mediated spillovers". They also show that there is an important correlation between the location of innovation production and the location of industry value added, but that it is the presence of related industries that is most relevant to innovation activities, indicating the significance of regional innovation networks.

There are in fact several schools of thought with differing approaches to the theoretical and empirical explanation of the relations between geography and innovation, including the formation of geographically concentrated clusters of firms in many economic activities, but above all in technology-based industries. This is not the place for a detailed discussion of all these approaches.[1] Given the scope of this paper, it will suffice to summarize the key points that are common to several approaches and substantiate the findings presented here.

The foundation shared by all the approaches discussed here is the perception that geographical proximity facilitates the transmission of new knowledge characterized as complex, tacit, and specific to certain production and innovation systems and activities. This may seem paradoxical in the age of information and communication technology but, as noted by Audretsch & Thurik (2001), it is important not to confuse knowledge with information. While the marginal cost of transmitting information is not proportional to distance, the cost of transmitting knowledge, especially tacit knowledge, increases with distance. This type of knowledge is best transmitted through interpersonal contacts, frequent interaction, and mobility of workers from one firm to another. Hence the advantage of geographically concentrated configurations of production such as clusters.

However, although they have this common foundation, two groups of approaches can be distinguished by their emphasis on differing mechanisms of knowledge transmission. One group, comprising the innovation economics and innovative systems approaches,[2] attributes a key role to spillovers in the transmission of knowledge among neighboring firms. These spillovers are triggered by innovative firms or institutions that generate new knowledge. The other group, comprising approaches based on regional economics, seeks to explain what makes firms localized in clusters more innovative than isolated firms. In doing so these authors emphasize a different set of key factors in knowledge transmission. According to Breschi & Malerba (2001: 819-820), the main points of these approaches are as follows: (1) learning through networking and interacting, including user-producer relationships, formal and informal collaborations, interfirm mobility of skilled workers, and spin-offs of new firms from existing firms, universities and research centers; (2) the high-level embeddedness of local firms in a very thick network of knowledge sharing, supported by close social interactions and facilitated by shared norms, conventions and codes, and in institutions that build trust and encourage informal relations

[1] See Breschi & Malerba (2001) for such a discussion.

[2] The systems approach considers national, regional, sectoral and local innovation systems and technological systems.

among actors in a collective learning process; (3) the availability of a common set of resources, such as universities, research centers, technology centers, and a pool of specialized and skilled labor, all of which help reduce the costs and uncertainties associated with innovative activities.

These key components of the different approaches serve in the present paper as a foundation for the elaboration of a set of indicators for the geographical distribution of innovation activities. It should be stressed that these indicators are not designed to measure innovative activities or knowledge flows in regional terms, topics discussed by most empirical studies in the field of the geography of innovation,[3] especially with regard to the U.S. economy and based on statistics for patent citations and the location of R&D activities. The purpose of these indicators here is simply to map the geographical distribution of innovative activities by using as a proxy the geographical distribution of their inputs (knowledge and technological infrastructure) and outcomes (patents and trademarks).

In Brazil, previous research along these lines has been published by Albuquerque et al. (2002). Working with data on patents, scientific articles and researchers by municipality, the authors discuss indicators that describe the spatial distribution of scientific and technological activities in Brazil based on the hypothesis that spatial determinants are as important as factors relating to the innovation system in mediating the relationship between scientific production and technological production.

In this paper we set out to make progress by extending the scope of the indicators used. We recognize the limitations of patent statistics as indicators of innovative activities, since not everything that is patented is an innovation just as not all innovations are patented. Assuming that the relationship between geography and innovation is empirically proven, and therefore that some of the key elements of innovation have geographical determinants, we set out to map these geographical determinants represented by: (1) the tacit knowledge held by workers and specialists; (2) the number of innovative firms; (3) patent and trademark registrations; (4) scientific production; and (5) institutions providing scientific, technological and service infrastructure for innovative firms. In this sense the present paper differs from the literature in two ways: first, by proposing the use of multiple indicators,[4] albeit without taking the additional step of aggregating them into a single synthetic indicator; and second, by using these indicators not to measure innovative performance but to map the geographical distribution of innovative activities. The next section summarizes the methodology used to produce the indicators and describes their respective databases.

2. Regionalized quantitative indicators: methodology, databases, and application to São Paulo

Five types of regionalized quantitative indicators were produced: (1) the number of skilled workers, based on data from the Labor Ministry's employment survey (RAIS – Relação Annual de Informações Sociais) for 2002; (2) the number of innovative firms, based on regionalized tabulations of Brazilian Institute of Geography and Statistics (IBGE)'s Technological Innovation Survey (PINTEC) for 2000; (3) the number of patents and (4) marks registered with INPI (Brazil's industrial property office) and USPTO (United States Patent & Trademark Office); and

[3] See especially Clark, Feldman & Gertler (eds.) (2000), *The Oxford Handbook of Economic Geography*, Part IV – "The Geography of Innovation", with an excellent review of the literature on this subject by Maryann Feldman.
[4] Hagedoorn & Cloodt (2004) is an important benchmark study in the use of multiple indicators, albeit applied to the evaluation of firms' innovative performances.

(5) indicators of scientific production based on data from the Institute for Scientific Information (ISI) on the publication of scientific articles.[5]

The indicators for skilled workers derived from the 2002 RAIS database were classified in accordance with the categories of the Brazilian Classification of Occupations (CBO).[6] Taking the definition of a job as a set of tasks, operations and other activities that constitute the duties of a worker and result in the production of goods and services, we selected the categories in Level 3 of the CBO, "Basic Occupational Groups", with a technical and technical-scientific profile relating in some way to science, technology and innovation (ST&I). Thus the occupations were selected so as to include those relating to the generation and diffusion of new technical and scientific knowledge, such as engineer, physicist, chemist and biologist, as well as technical and operational occupations involving skills that are relevant to the innovation process. The rationale for choosing these occupations is the broad consensus in the specialized literature regarding the importance of tacit knowledge and the specific knowledge embodied in worker skills and routines for the generation and diffusion of innovations. We selected 63 Basic Groups from a total of 355.

The next step was to divide the selected groups into three subgroups in accordance with the type of occupation and the corresponding functions within firms: (1) technological occupations, such as engineer, physicist, chemist and biologist, involving a higher level of formal education and professionals who usually perform high-level functions in firms' innovative activities; (2) technical occupations, such as specialized technician in certain areas, requiring formal education to intermediate level but involving professionals who perform an important role in the firm's hierarchy and the more simple stages of new knowledge generation and diffusion; and (3) operational occupations, such as machine assembler or operator, requiring a low level of formal education but with a high tacit and specific skill content.

With regard to the third subgroup (operational occupations), it should be noted that the decision to select these was based on two complementary criteria. The first is the recognition, in congruence with the large body of research on ST&I in the literature, that the knowledge embodied in worker skills and operating routines plays a fundamental role in the generation and diffusion of innovations, characterized as a social and collective process. The second is that, especially in metalworking-machine manufacturing and electronics, both of which industries drive diffusion of technology throughout the economic system,[7] these operational occupations require a higher level of technical knowledge. Hence the importance given to them in the selection.

The results show the distribution of skilled occupations in São Paulo State by microgeographical region, as can be seen in **Map 1**. This makes it clear that the creation of technology-related jobs is stronger in industrially developed regions. It is possible to infer a close correlation between the number of jobs created in this category and ST&I activities in which firms are engaged in these regions, including service providers. It also shows that the São Paulo

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[5] Access to some of the databases was facilitated by the collaboration of the following people: Dr. Mariana Rebouças, IBGE, who supplied special tabulations of data from PINTEC; Prof. Eduardo Albuquerque, Federal University of Minas Gerais (UFMG), who supplied INPI's patent database and with whom it was possible to share a methodological discussion on the production of regionalized indicators for patents; and Prof. José Ângelo Gregolin, UFSCar, who provided data on scientific production.

[6] The CBO is subdivided into Major Groups, Subgroups, Basic Groups, and Occupations. The RAIS data can be disaggregated down to the Basic Group level, also termed Primary Group, Unitary Group or Occupational Family. This level covers occupations that are strictly related in terms of the type of work involved and the level of skill required. Altogether 355 Basic Occupational Groups (GBOs) are defined.

[7] This is the case, for example, with "electronic equipment assembler", an occupation that is typically operational but requires a significant level of technical knowledge.

micro-region (which includes the so-called ABC municipalities, i.e. Santo André, São Bernardo and São Caetano) accounts for a large proportion of jobs in the selected skilled occupations. This is hardly surprising. It is also worth noting the importance of the large area around the metropolitan region of São Paulo, which encompasses metropolitan São Paulo (Osasco, Guarulhos, Itapecerica da Serra, Mogi das Cruzes, Santo André, São Bernardo, São Caetano, Diadema and other municipalities), and the Campinas, São José dos Campos, Santos and Sorocaba regions. These are all industrially developed regions with significant networks of educational and research institutions, as discussed in Section 3. Ribeirão Preto is the only micro-region not located in this swathe of municipalities that centers on metropolitan São Paulo, although it is one of the ten largest in terms of its share of the number of jobs in technological occupations. Ribeirão Preto is also industrialized and accounts for some 2% of jobs in the selected occupations.

The data suggest that the São Paulo micro-region still displays a predominance of technology-related occupations over other types of occupation. This micro-region accounts for 56.6% of all jobs in technological occupations, 47.8% of jobs in technical occupations and 37.5% of those in operational occupations. This feature is confirmed by the data from Pintec presented below. However, the micro-regions in metropolitan São Paulo and the wider conurbation do not display this predominance although they are equally industrialized. Campinas, for example, accounts for only 7%, 7.6% and 8.7% of technological, technical and operational occupations respectively. This demonstrates the significance of the São Paulo micro-region in higher ST&I activities.

The main reason for this, besides the relative concentration of skilled occupations in the metropolitan area, seems to be the nature of the industrial deconcentration experienced by metropolitan São Paulo in recent decades. While there has been significant relocation of production facilities into the wider conurbation surrounding the metropolitan area and into more distant parts of the interior of São Paulo State (as well as other states), as part of a broader process of industrial restructuring, this process has not involved deconcentration of higher corporate functions: central administrative offices and departments of engineering and product development often remain in the former headquarters or main manufacturing facility even when the latter loses its share of production, employment and sales. This explains the high and more than proportional share of technological occupations in the São Paulo region.

In addition to absolute numbers, we also calculated the relative density of occupations for each micro-region in the state, defined as the total number of occupations per 1,000 jobs.[8] The data for the density of ST&I-related occupations highlight other micro-regions besides São Paulo. The greatest density of technological occupations is found in São José dos Campos, where there are just over 30 technological occupations per 1,000 jobs, followed by Osasco (27.9), São Paulo (26.6), and Campinas (25.5). It is no accident that these regions have the highest concentrations of technology-intensive industries and the largest number of innovative firms, as will be seen below.

The regions with the greatest density of technical occupations are São José dos Campos (43.1), Campinas (35.3), Sorocaba (32.2), Piedade (32), Osasco (31.9), and Jundiaí (31.3). The density of operational occupations is highest in São Carlos (155), São José dos Campos (107.3), Guarulhos (87.1), and Sorocaba (86). São Paulo displays relatively low density of both technical

[8] The corresponding data are not included in this paper, but can be obtained directly from the authors upon request. We also calculated Location Quotients for occupations, identical to the standard LQ of regional economics. The results were similar to those for the relative densities of occupations.

and operational occupations (28.3 and 42.6 respectively), reinforcing the significance of regional deconcentration of manufacturing plants and hence of technical and operational occupations.

The second type of indicator is designed to capture the tacit knowledge embodied in the routines of innovative firms. The regional distribution of this type of knowledge, which lies at the root of innovation activities, can be estimated using a breakdown of the number of innovative firms by region based on a special tabulation of data from Pintec, although it is difficult to regionalize this information.

The innovation rate for São Paulo State – defined as the number of innovative firms as a proportion of the total – is close to the averages for other parts of Brazil, which are only slightly higher. The differences between regions of the state are less significant in terms of these average rates than in terms of the innovation patterns characteristic of each region. In other words, the differences are more significant in terms of the sectors that innovate and the type of innovation occurring in each region. Thus although the innovation rates for the various regions of São Paulo State are relatively high by Brazilian and international standards, they are less significant in terms of the importance and scope of their results. The highlights among regions with innovations in both products and processes that are relevant for the market, and not just for the firms involved, are the Paraíba Valley region (with São José dos Campos as its hub), metropolitan São Paulo, the so-called macro-metropolitan region of the state, and Campinas (see **Chart 1**).

It should be noted, however, that one of the main limitations of the National and Regional Systems of Science, Technology & Innovation is the absence of comprehensive information regarding the numbers of skilled professionals occupying higher technical and technological functions. The Pintec statistics only partially address this important gap in the national and regional systems of statistics, since the Pintec database refers only to workers in firms that declare themselves innovative, a universe that does not coincide with that of firms engaged in technological activities. Hence the relevance of the data indicating a very high concentration of workers in technological occupations in a few regions, especially metropolitan São Paulo, Campinas, and the Paraíba Valley – data which illustrate the dissociation between technological activities and innovation. This observation confirms much of what is known about the distribution of economic activities in São Paulo State, showing that it is very uneven in terms of geographical location: production facilities and firms have advanced into the interior of the state while corporate functions requiring higher levels of skill and qualification are still relatively concentrated around one or two cities and along a few geographical axes.

The third type of indicator is based on information about codified knowledge, represented by patents registered with INPI and USPTO. Using these two databases we produced regionalized indicators for the number of patents per 100,000 inhabitants, technological specialization, and patenting of strategic technologies.[9]

According to the results for the numbers of patents per 100,000 inhabitants based on information from INPI for the period 1999-2001, as shown in **Map 2**, seven of the 63 micro-regions in the state stand out for having technological densities above 20 patents per 100,000 inhabitants. The São Paulo micro-region is the most important both in absolute numbers (5,105 patents, or 61% of the total) and in patents per capita (about 40 per 100,000 inhabitants). Next in order of density come the São Carlos, Campinas, Jundiaí, Limeira, Itapecerica da Serra, and Ribeirão Preto micro-regions. All the rest except Marília are located along the Anhanguera and

[9] The authors acknowledge the research assistance by Rogério Vicentim, M. A. student at UNICAMP, for calculating these indicators.

Washington Luiz highways, centering on municipalities with significant productive and university structures.[10]

The technological specialization indicator[11] identifies the technological areas in which each micro-region is strongest based on the International Patent Classification (IPC). A specialization index higher than 1 in a given technological area means the region's patenting activity exceeds the average for that specific area. The specialization indices calculated for micro-regions of São Paulo State are shown in **Map 3**, which highlights the main technological domain in each micro-region.

The indicator for patenting in strategic technologies by micro-region was calculated in a similar manner to the specialization index. Three technological domains were chosen for being relatively knowledge-intensive and because they are standard components of public policy in the areas of science, technology and innovation: information technology (IT), pharmaceuticals, and machine tools.[12]

In IT and related technologies, the Campinas, Sorocaba and Osasco micro-regions stand out as being strategically important. The Campinas micro-region accounted for about 20% of the 107 patents registered in this domain. São Paulo accounted for more than half in absolute terms, yet did not show above-average activity in this domain. The same reservation regarding the São Paulo micro-region applies to the other technological domains. In pharmaceuticals/cosmetics the Campinas, Osasco, Itapecerica da Serra and Presidente Prudente micro-regions concurrently displayed relative specialization as well as significance in absolute terms, with more than a third of the 116 patents registered in the period. In machine tools the leading micro-regions are Campinas, Ribeirão Preto, and São José do Rio Preto. With the reservation already mentioned, the São Paulo micro-region accounted for 82 of the 136 patents registered in this domain. It is noteworthy that the Campinas micro-region concurrently displayed specialized activity in all three technological domains considered strategic.

Lastly, the USPTO patent database was used to produce an indicator of international technological specialization. We identified 145 patents granted by USPTO between 1992 and 2001 to individuals and firms domiciled in São Paulo State. These patents were classified by technological domain and micro-region as an indication of the level of international technological specialization for each micro-region.

It was found that only 18 of the state's 63 micro-regions had patents registered abroad, especially in the technological domains of Housewares, Machinery, and Vehicles. Some of the micro-regions that stand out in terms of international specialization in their respective technological domains contain important innovative firms, as already mentioned. The Campinas micro-region is outstanding for international patents in IT, and in this case its technological dynamism is more extensive than can be represented by the fact that it contains one or several innovative firms. It reflects strong regional specialization in this domain, given that the region contains a large number of firms in the various segments of the production chain, alongside institutions of education and research, and specialized research labs and centers.

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[10] It should be noted that a significant proportion of patent registrations in specific micro-regions reflects the innovative dynamism of some firms in particular. A case in point is Marília, where the strong emphasis on transportation relates to patents registered by a single firm (Máquinas Agrícolas Jacto).

[11] The indicator used here is Revealed Technological Advantage (RTA), a standard feature in the literature relating to patent-based indicators. For a brief history of the RTA as well as the formula and methodology for this indicator and the corresponding variation coefficient, see Cantwell & Vertova (2004), and Vertova (2002).

[12] An example taken from public policy in Brazil is the Government's definition of "strategic options" in a key document on industrial, technological and trade policy guidelines: *Diretrizes de Política Industrial, Tecnológica e de Comércio Exterior* (MDIC, 2003).

The fourth type of indicator is based on the registration of marks. Besides patents, marks are an important means for innovative firms to protect the new knowledge embodied in their products and services. Marks too may be registered only in Brazil or internationally. Marks are increasingly a key asset, and in some cases the most important, in the competitive strategies of firms that command national and international networks of production and distribution. Indicators of specialization levels can be inferred from the number of marks registered with the USPTO. We identified 168 marks registered between 1998 and 2002 with the USPTO by individuals and firms domiciled in São Paulo State. This information was used to calculate specialization indices identical to the RTA (see n. 12) for each category in the Nice Classification.[13] The results are shown in **Map 4**, which displays the geographical distribution of the main categories of marks in the various micro-regions of São Paulo State.

It can be seen that 21 of the 63 micro-regions in the state have marks registered in the U.S. Most (eight micro-regions) are in Housewares. It is worth noting the commercial efforts of firms in Franca and Birigui in the categories Clothing and Footwear; Franco da Rocha and Guarulhos in Musical Instruments; Itapecerica da Serra in Tobacco & Smokers' Articles; Limeira in Jewelry; Mogi Mirim in Nonmetallic Building Materials; and Sorocaba in Toys & Sporting Goods. In many of these cases the level of specialization that can be verified from international registration of marks correlates closely with regional specialization in production, which is territorially concentrated in local systems of production and innovation.

The fifth and last type of indicator is based on data for scientific production. New knowledge generated in research activities is usually disseminated in the form of papers published by specialized periodicals. The database utilized was ThomsonISI, which systematizes this scientific production.[14] We retrieved journal articles published between 1998 and 2002 by authors affiliated to institutions located in São Paulo State. This indicator is identical to the RTA and was calculated for each of the major science areas so as to capture the type of scientific specialization in each region (see **Map 5**).

The scientific production indicators are significant for most micro-regions. Nevertheless, this production is clearly concentrated to a conspicuous extent. Roughly 80% of the citations were for São Paulo (49%), Campinas (18%), São Carlos (9%) and Ribeirão Preto (6%). Important university campi and research centers are located in all these micro-regions (see Section 3). The map also shows a degree of geographical concentration in scientific specialization. The most evident specializations are: (1) health, near metropolitan São Paulo, specifically in the Franco da Rocha, São Paulo and Santos micro-regions; (2) engineering, in the Araraquara and São Carlos micro-regions; and (3) human sciences, especially in the Sorocaba and Jundiaí micro-regions.

It is also necessary to mention certain scientific fields that are on the international knowledge frontier and usually targeted by public policy. The micro-regions with significant indicators of scientific specialization in such areas are as follows: computer science, Campinas, São Carlos and São José dos Campos; materials engineering, São Carlos, Araraquara, São José dos Campos and Guaratinguetá; molecular biology and genetics, Ribeirão Preto, Botucatu, Piracicaba, São José do Rio Preto, Bauru and Rio Claro. In all cases it is clear that these micro-

[13] Nice Agreement Concerning the International Classification of Goods and Services for the Purposes of the Registration of Marks - http://www.wipo.int/clea/docs/en/wo/wo019en.htm .

[14] More specifically, we used the Science Citation Index. To make the map easier to understand, the data were manipulated so as to ensure a match between this classification and the system used by CNPq. Scientific disciplines were grouped into six major areas (Grande Área CNPq): agrarian sciences, biological sciences, health sciences, exact & earth sciences, human sciences, and engineering.

regions contain important universities and research centers which account for a significant proportion of Brazil's scientific production.

3. Indicators of local capabilities: scientific, technological and support infrastructure institutions

Complementing the quantitative indicators, and as an additional step in the line of argument underlying this paper, we compiled data and information on the geographical distribution of the institutions in São Paulo State that provide firms with support in the form of a scientific, technological and service infrastructure. These institutions perform functions that enable firms to enhance their technical, technological and innovation capabilities. In particular, they are higher education and research centers, secondary-level technical and vocational training institutions, research labs, and technology centers.

The method was as follows: (1) use of the 2002 RAIS database on employment and numbers of establishments in R&D, higher education, and vocational education according to the National Classification of Economic Activities (CNAE); (2) direct collection of information on the São Paulo State system of education and training for all levels, from degree courses in engineering and other technological areas to industrial training courses; (3) direct collection of information on institutions providing firms with support infrastructure and services in technological areas and innovation support, mainly comprising technology centers and R&D labs.[15] It was not always possible to quantify this information in terms of budgets and numbers of employees, for example. Nor was it possible to appraise the extent to which firms actually made use of these institutions or the quality of the services provided.

Space limitations prevent us from presenting the results in detail on this occasion.[16] For this reason we will not discuss the findings based on the RAIS data, which anyway overlap to a considerable extent with the data collected directly. The following paragraphs contain a summary of the most important aspects of the regional distribution of the institutions comprising the scientific, technological and support infrastructure for innovation activities pursued by firms. Moreover, the information on the location of these institutions and the analysis of the role they play is more relevant to the vertical cross-section of local production and innovation systems discussed in this paper (see Section 4). It is in these systems that the role of support institutions is usually most relevant in terms of reinforcing the innovation capabilities of local firms.

3.1 Educational institutions offering technical, technological & vocational qualifications

Information was collected for educational establishments offering technical, technological and vocational qualifications at various levels, from university degrees to diplomas or certificates in different areas of technology via secondary-level technical courses and industrial training. The information was then broken down by micro-region to show the distribution of these courses throughout the state as part of the ST&I infrastructure.

With regard to undergraduate courses, information was collected on courses leading to bachelor's degrees in engineering, pharmacy, biochemistry, chemistry, biology, and agronomy. This was done using data supplied by INEP,[17] an agency of the Ministry of Education responsible

[15] Information was also collected on industry and professional associations, but these were not found to be very active in supporting innovation by firms. With a few outstanding exceptions, they confined themselves to providing services of a general nature.

[16] A detailed discussion of the results as well as the methodology is in Suzigan et al. (2004).

[17] Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira. The exam tests student achievement in the most widely followed courses (management, law, engineering, medicine etc). Students are not judged on their

for administering a national test for final-year undergraduates in selected subjects. Although the universe is limited to the courses assessed, the data from INEP is sufficiently comprehensive as it includes the numbers of graduates as well as an indication of the quality of each course based on the students' average scores. The main limitation of this data source is the omission of courses in some important subjects, such as production engineering, which are not assessed by INEP's test.

The results show that in 2002 there were 249 tertiary-level courses of a technological nature in São Paulo State and that almost 13,000 students graduated from them. Almost half were engineering courses (114), followed by biology (59), pharmacy (35), chemistry (27), and agronomy (14).[18] The regional breakdown shows a high level of concentration in the São Paulo micro-region, with 30% of the total number of courses and 38% of the graduates in 2002. Next comes the Campinas micro-region, with 17 courses and some 1,050 graduates. Third is Santos, with 10 courses and about 520 graduates. This regional distribution indicates the importance of the public higher education system but also suggests that the presence of large private universities in these regions is significant.

The qualitative indicator, on the other hand, shows a very different regional pattern from the one portrayed by the regional distribution of courses (**Table 1**). The number of students scoring A or B in the Provão is smaller in the São Paulo micro-region, certainly because of the larger quantity, diversity and heterogeneity of courses assessed. For similar reasons, the numbers in the important micro-regions of Campinas and São José dos Campos are only slightly above the average for the state. The micro-regions with the best performance in terms of the proportion of high-scoring students are Jaboticabal and Rio Claro (100%, with only one course); Andradina (100%, four courses); Botucatu (100%, two courses); São Carlos (69.4%, six courses); Limeira (68.6%, two courses); Araraquara (66.8%, two courses), and Piracicaba (65.2%, two courses).

Another point worth noting with regard to higher education is the existence of 46 tertiary-level technological courses, with 2,670 places, offered by 14 Fatec and Ceeteps state-run technology colleges, three Cefet federal technology colleges, and 29 schools run by Senai, the National Industrial Training Service. Although these technological courses and technical schools are concentrated in the São Paulo micro-region, which has almost half the courses and places offered throughout the state, it should be noted that in general they are linked to the productive activities that predominate locally.

As regards secondary-level technical and vocational courses, we collected data from the Senai, Cefet and Ceeteps systems. The results (**Table 2**) show the existence of 218 technical courses and 194 industrial training courses.[19] These are disseminated throughout the state, whereas technological courses are strongly concentrated in a few micro-regions, especially São Paulo. A regional breakdown of technical and industrial training courses shows concentration in São Paulo and adjacent micro-regions, especially Campinas, São José dos Campos, Sorocaba and Santos, but in this case concentration in these areas is far less intense than in that of the technological courses or even the tertiary-level courses. The greater degree of regional dispersion of technical and industrial training courses has to do with the regional distribution of industrial

individual performance but the average score for each institution is published as a proxy indicator of the quality of instruction in that course.

[18] Evidently, not all graduates of these courses can be considered directly employed in ST&I activities. The numbers merely serve to quantify the pool of skilled labor potentially available to the science, technology and innovation system in São Paulo State. In this sense it is worth noting that engineering courses train proportionally more professionals who will be employed in activities of a technological nature than biology, pharmacy and chemistry courses, where a large proportion of graduates go on to work in non-technological activities, mainly education (teaching).

[19] In this case, as in the case of technical courses, it was not possible to verify numbers of students or places.

activities and above all with the existence of local production and innovation systems, as shown by the Limeira, Ribeirão Preto, São Carlos, Jaú and Franca micro-regions, among others (Suzigan et al., 2003).

3.2 Technology centers and R&D labs

The data and information collected on technological centers and R&D laboratories included those belonging to the Senai system (some Senai units have labs that provide services to firms); labs and centers linked to public institutions for support to the innovative activities of firms, such as IPT (Instituto de Pesquisas Tecnológicas, subordinated to the São Paulo State Department of Science, Technology & Economic Development); and private labs maintained by members' contributions and revenue from the sale of services.

We set out to identify the services typically provided to firms, emphasizing support for innovative activities, and to find out whether these institutions provide services in areas such as technological information, product development, management of production processes, technical and technological assistance and consulting, testing, and laboratory trials. We also set out to quantify these labs and technology centers by size, but many institutions refused to furnish such information.

Here we collected data and information on labs and technology centers accredited by the Ministry of Science & Technology (MCT) and the National Institute of Weights & Measures (Inmetro), as well as other non-accredited institutions. Among those accredited by MCT are labs and technology centers entitled to tax breaks under the provisions of the Information Technology Act (Lei de Informática) if they carry out R&D under agreement with firms that market IT and automation-related goods or services. Those accredited by Inmetro include Senai's calibration and testing labs. Among the other labs and research centers, the highlights are those of Embrapa (Empresa Brasileira de Pesquisa Agropecuária, agronomy), IAC (Instituto Agronômico de Campinas, agronomy), ITAL (Instituto de Tecnologia de Alimentos, food), and INPE (Instituto Nacional de Pesquisas Espaciais, aerospace), especially their special technology labs and centers for integration and testing (**Table 3**).

In this case there is clearly a high level of concentration in the São Paulo micro-region, which has 45 labs and technology centers, or almost half the total in the state. It is worth noting the large number (15) of MCT-accredited labs in the Campinas micro-region. As will be discussed in Section 4, this infrastructure of labs and research centers relates to the regional agglomeration of firms and education and research institutions that develop activities in the area of information and communication technologies, especially the production of telecommunications and IT equipment and software.

4. Clusters or local production & innovation systems

What drives the formation of clusters or local systems of production and innovation is the existence in the locality or region of specialization knowledge that generates productive, technical or technological capabilities specific to a given product or economic activity. Firms and institutions are attracted because of the importance of geographic proximity to the transmission of this tacit and specific knowledge. Once the process has begun, the system evolves mainly through the emergence of new firms as spin-offs from existing local firms or institutions.

Previous work by the present authors[20] has dealt with these territorial agglomerations of firms and institutions, which we have identified and mapped, as well as characterizing their

[20] See Suzigan et al. (2003; 2004).

production structures. With regard to São Paulo State, this has enabled us to create a typology for use in the formulation of public policy. Four basic types of clusters or local systems are suggested: (1) c*enters of sectoral or regional development*, which stand out for their great importance both to local or regional development and for the respective sector or class of industry; (2) *advanced vectors*, which are highly important to the sector but diluted within a far larger and more diversified economic fabric and therefore less relevant to local or regional economic development. This is the case with local production and innovation systems located in densely industrialized metropolitan areas; (3) *vectors of local development*, which are important for a region but do not play a significant role in the main sector to which they relate. Most are regional poles in geographical dispersed activities; (4) *embryos of clusters or local production systems*, which have little importance to their sector and, because they coexist with other economic activities in the same region, are not yet especially important to the local economy. The results can be seen in summary form in **Maps 6**, **7**, **8** and **9**.

Combining the results of the mapping and regionalized indicators of ST&I activities, including the local capabilities of institutions that provide firms' scientific, technological and service infrastructure, we can see a reasonable correlation between the localization of clusters or local production and innovation systems and the geographical distribution of ST&I activities. In particular, it is worth drawing attention to the localization patterns in the vicinity of major metropolitan areas such as those of São Paulo and Campinas, and on certain geographical axes, especially along major arterial roads, the Paraíba Valley and the Anhanguera and Washington Luiz highway axes.

This factual observation can be empirically proven by analyzing a vertical cross-section, so that the evidence produced by an overview of regionalized indicators is analyzed from the standpoint of each identified case of a cluster or local production and innovation system. However, there is no space to do so in this paper.[21] The following paragraphs therefore present an illustrative discussion of one case of an advanced vector: the information technology and communication activities in the Campinas micro-region.

The Campinas metropolitan area ranks second only to metropolitan São Paulo among the areas that most generate innovations in Brazil.[22] Like São Paulo, Campinas is one of the most advanced regions in the country in terms of industrialization. Thus there are numerous local production and innovation systems within these large areas, but they are diluted in a highly diversified and wide-ranging production structure. Many may be relevant as objects of study. For the present purpose, we have chosen the various activities relating to information and communication technologies (ICT).

Using the OECD definition of ICT activities, i.e. including software production and services as well as hardware manufacturing, we found that the Campinas micro-region contained 610 establishments with more than 14,500 workers in these activities, according to the 2002 RAIS database. The following segments accounted for the largest shares of total employment in São Paulo State in the ICT sector: manufacturing of basic electronic material (13.1% in 2002), telecommunications equipment (33.9%), and telephone handsets and communication systems (47.7%).

These industries are among the largest employers of workers in skilled occupations. In 2002, the numbers employed by manufacturers of telephone handsets and communication systems in the region accounted for 65.4% of the total number employed in technological occupations in this industry throughout the state. The proportions were 45.4% for the

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[21] For a more detailed discussion, see Suzigan et al. (2004).
[22] For details, go to www.inova.unicamp.br.

telecommunications equipment industry and 24% for the basic electronic material industry. Similar proportions were found for technical occupations. As a result, the Campinas micro-region has the fourth-largest density of technological occupations in the state, with 25.5 technology-related jobs per 1,000 jobs, falling short only of São José dos Campos (30.8), Osasco (27.9) and São Paulo (26.6), and the second-largest density of technical occupations (35.3), after São José dos Campos (43.1). This in turn is reflected in outstanding technological density: 563 patents were registered with INPI in the period 1999-2001, resulting in the fourth-largest density of patents per 100,000 inhabitants (25), beaten only by São Carlos (29), Marília (29) and São Paulo (40). Furthermore, Campinas has 22 patents registered with USPTO. Five of them were registered under the technological domain Information Technology, indicating the relative importance of innovation in local ICT activities.

One of the most important factors in attracting these industries to the Campinas region is the availability of skilled workers. This results from the excellent installed base of education and research institutions, with strong scientific specialization in the various branches of engineering and in exact and earth sciences. The region has five higher education institutions, led by the University of Campinas (Unicamp); several institutions that manage technical schools, including Ceeteps, Cotuca, Fatecs and Senai, with an ample supply of technical courses in electronics, microelectronics, telecommunications, information technology, mechatronics, automations, mechanics and chemistry, among others; and vocational training courses offered by Senai in these same disciplines.

The Campinas region also has a sizable network of labs and R&D centers. Some of these labs are very large and considered national benchmarks in their respective areas. A good example is ABTLuS, which has 180 full-time professionals as well as trainees and interns, and provides services to firms and institutions in research involving synchrotron light, nanostructures, microcomponents, construction of scientific equipment, and proteins; CenPRA, with 230 researchers and 12 labs, offering services in ICT product and process quality, and ICT prototype and product engineering, among others; CPqD, with more than 1,000 professionals and 20 labs for product testing, field measurement of systems, fiber optic measurement, and lab management; Embrapa, with 16 labs and experimental fields; and IAC and ITAL, each with nine R&D and analysis centers. There are also several smaller centers with testing and essay labs, research facilities and service providers in areas such as electro-electronics, telecommunications and teleinformatics; software and hardware design and development; industrial design and product engineering; quality in software, experiments with optical devices etc.

Both the education and research institutions and the R&D centers frequently generate new firms as spin-offs from their ST&I activities. The most noteworthy example is that of Unicamp, which at the start of 2004 registered the existence in the region of 78 firms originating in the university's research activities (see the website of Unicamp's Innovation Agency www.inova.unicamp.br). Of these 78 firms, 42 are engaged in ICT-related activities. One of the most noteworthy examples is AsGa, which produces optoelectronic components for use in digital data transmission systems.[23]

[23] AsGa originated with groups of researchers from Unicamp, CPqD and Elebra. It won an outstanding reputation for its ability to adapt to the new competitive environment of the second half of the 1990s, following the major privatization wave in Brazil, when it succeeded in conserving a significant internal capacity for innovation (13% of sales in 2002). Commanded by entrepreneur José Ripper, a former professor at Unicamp, the firm seems to have found a promising market niche in the production and marketing of optoelectronic components and optical modems. It ships to practically every new telecommunications service provider and equipment vendor in Brazil. The firm's success in today's competitive environment and its ability to maintain a significant market share in its segment can also be explained by its effective use of the facilities offered by governmental development agencies: it has

Last but not least, the Campinas region also has an excellent transportation infrastructure including the country's largest cargo airport and efficient road links to markets and suppliers. This represents another important locational factor for ICT-related activities in the region.

Conclusion

This article presents a set of indicators that map out the geographical distribution of knowledge and of scientific and technological capabilities as proxies for the geographical distribution of ST&I activities and applies them to the analysis of data and information for São Paulo State. An overview of the geographical distribution of ST&I activities by micro-region throughout the state is complemented by an analytical view of these activities in a vertical cross-section to identify local production and innovation systems. One specific case is discussed in some detail: information and communication technology activities in the Campinas micro-region.

The results display a pattern of regional distribution for ST&I activities along the main highways of the state and in and around metropolitan areas, especially those of São Paulo and Campinas, as well as highlighting the existence of regions that concentrate educational institutions, research centers, and science & technology development hubs. The tendency for firms to agglomerate in these areas and regions, forming local production and innovation systems, is evidenced by the adherence of the mapping of these systems to the mapping of the geographical distribution displayed by the quantitative indicators and the indicators of institutional capabilities. This reinforces the assertion found in the literature that innovative activities by firms have strong determinants relating to geography. However, it does not entirely explain the regional distribution of production and innovation activities. There are many other factors – historical, institutional, productive (linked to the primary economic activities in the regions), social, cultural, political etc – that influence the determination of the economic vocation of the regions and are not covered by the scope of this article.

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developed several projects with support from Finep, BNDESPar and Fapesp. Another noteworthy point is its strategy of cooperation with local agents, as illustrated by an ongoing project in partnership with CPqD to develop the Horus call management system with funding from Funttel.

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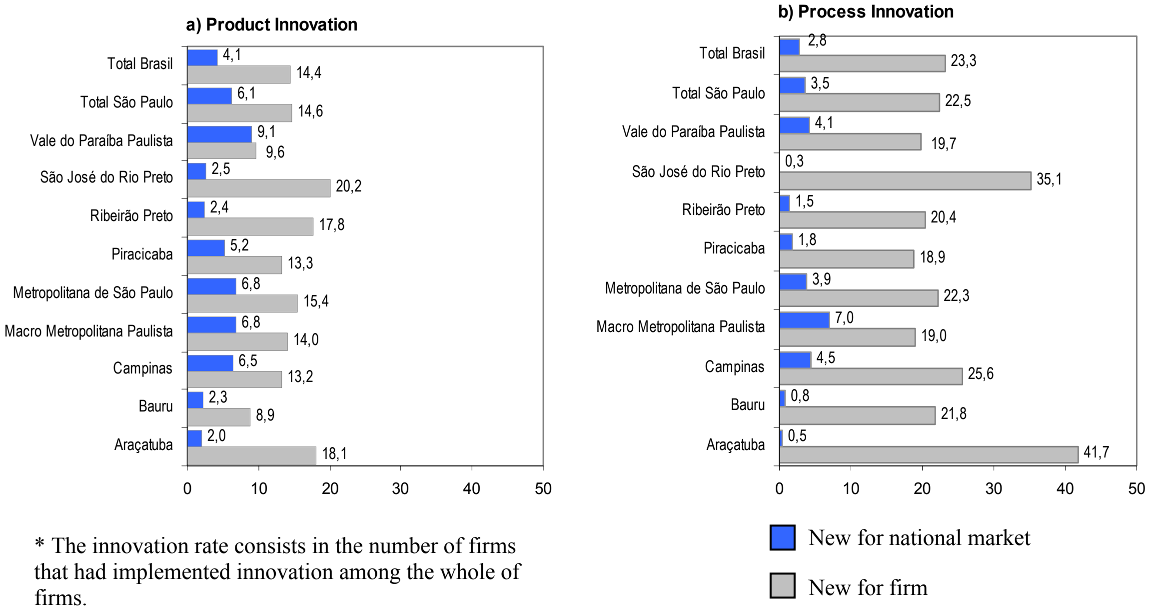
Chart 1. Innovation rate* of the firms, meso-regions, 2000.



* The innovation rate consists in the number of firms that had implemented innovation among the whole of firms.

Source: IBGE/PINTEC, 2000. Authors own elaboration.

Table 1. Regional distribution of well-evaluated courses, by micro-region, State of São Paulo, 2002.

Micro-region	N° of courses	Graduated Students		Share of students in well-evaluated courses by micro-region
		N°	%	
São Paulo	15	1.315	38,7	27,1
Campinas	6	421	12,4	39,9
Piracicaba	2	277	8,2	65,2
São Carlos	6	229	6,7	69,4
Bauru	3	158	4,7	45,7
Araraquara	2	155	4,6	66,8
Botucatu	2	127	3,7	100,0
Andradina	4	116	3,4	100,0
São José dos Campos	4	115	3,4	29,6
Guaratinguetá	3	95	2,8	37,4
Jaboticabal	1	94	2,8	100,0
Rio Claro	1	75	2,2	100,0
Limeira	2	70	2,1	68,6
São José do Rio Preto	1	50	1,5	19,2
Sorocaba	1	31	0,9	10,2
Marília	2	30	0,9	21,9
Santos	1	21	0,6	4,0
Assis	1	15	0,4	22,4
Others	0	0	0,0	0,0
Total	**57**	**3.394**	**100**	**26,5**

Source: MEC/INEP. Authors own elaboration.

Table 2. Regional distribution of Industrial Training, Technical and Technological Courses, by micro-region, State of São Paulo, 2003.

Micro-region	N° of Industrial Training Courses	N° of Technical Courses	Technological Courses	
			N° of Courses	Vacancy
São Paulo	46	62	23	1.400
Campinas	17	20	3	160
São José dos Campos	11	11	0	0
Sorocaba	8	8	2	240
Limeira	8	8	0	0
Santos	7	8	4	280
Ribeirão Preto	12	7	0	0
Marília	3	5	0	0
Jundiaí	6	4	1	80
São Carlos	5	4	0	0
Jaú	4	4	6	150
Franca	3	4	0	0
Assis	0	4	0	0
São João da Boa Vista	0	4	0	0
Bauru	8	3	0	0
Piracicaba	8	3	0	0
Araraquara	5	3	0	0
Others	43	56	7	360
Total	**194**	**218**	**46**	**2.670**

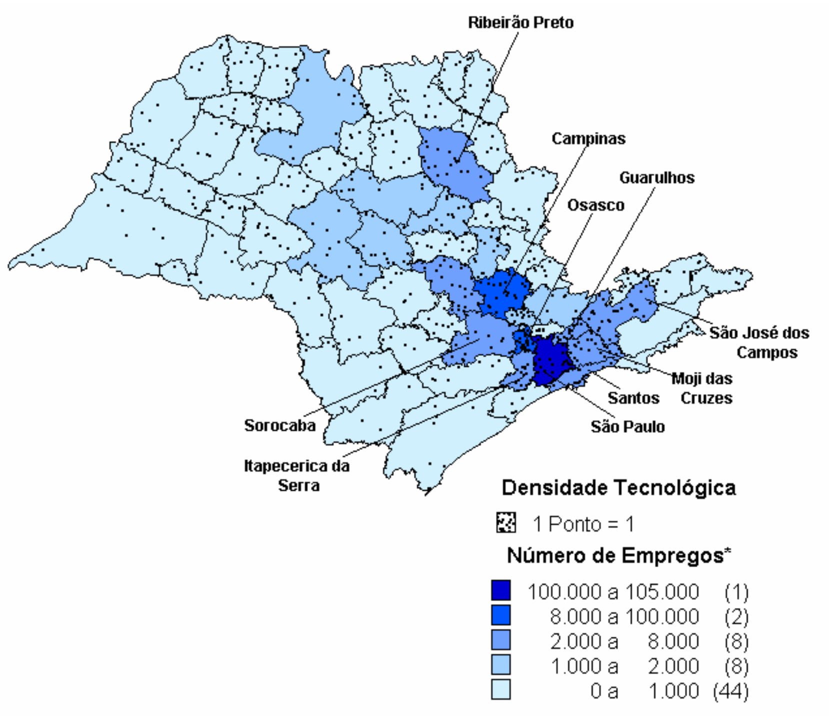
Source: Data collected from the systems CEETEPS - Centro Estadual de Educação Tecnológica Paula Souza, CEFET - Centro Federal de Educação Tecnológica de São Paulo and SENAI - Serviço Nacional de Aprendizagem Industrial, 2003. Authors own elaboration.

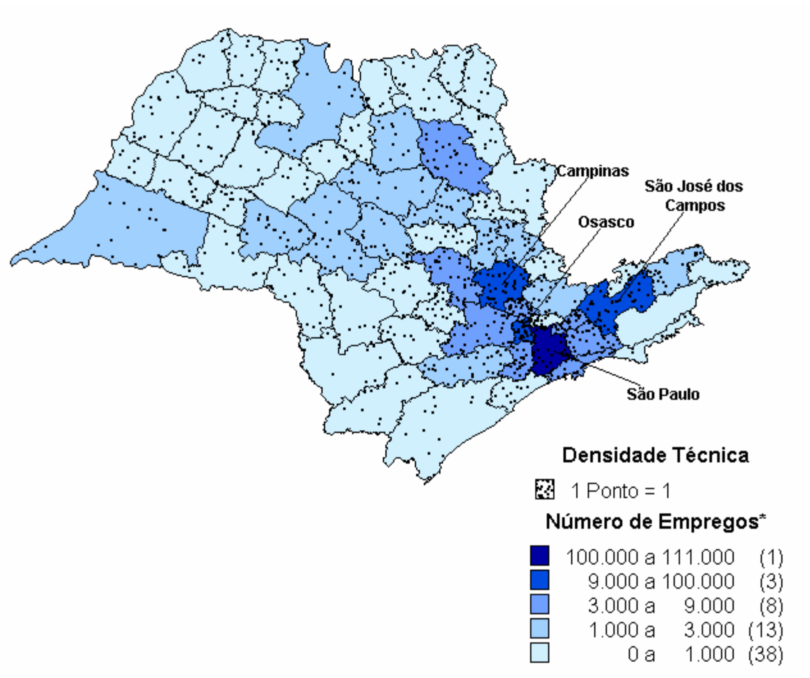
Table 3. Regional distribution of labs and technology centers, by micro-region, State of São Paulo, 2004.

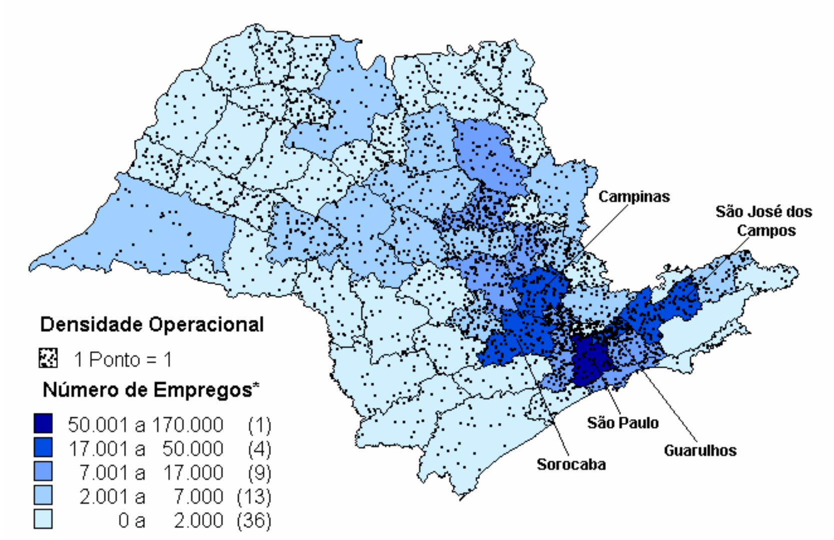
Micro-region	Accredited		Non-Accredited					Total
	MCT	INMETRO	Embrapa	IAC	ITAL	INPE	Others	
Campinas	18	0	18	9	9	0	0	**54**
São Paulo	22	8	0	0	0	1	13	**44**
São Carlos	1	0	23	0	0	0	1	**25**
São José dos Campos	2	1	0	0	0	4	3	**10**
Sorocaba	3	1	0	0	0	0	0	**4**
Jundiaí	0	0	0	0	2	0	0	**2**
Osasco	1	1	0	0	0	0	0	**2**
Bauru	0	1	0	0	0	0	0	**1**
Araraquara	1	0	0	0	0	0	0	**1**
Bragança Paulista	0	0	0	0	0	1	0	**1**
Franca	1	0	0	0	0	0	0	**1**
Guaratinguetá	0	0	0	0	0	1	0	**1**
Guarulhos	1	0	0	0	0	0	0	**1**
Limeira	0	0	0	0	1	0	0	**1**
Pirassununga	1	0	0	0	0	0	0	**1**
Ribeirão Preto	0	0	0	0	1	0	0	**1**
Tatuí	1	0	0	0	0	0	0	**1**
Total	**52**	**12**	**41**	**9**	**13**	**7**	**17**	**151**

Source: Data and information collected from labs and technology centers accredited by the Ministry of Science & Technology (MCT) and the National Institute of Weights & Measures (INMETRO), labs of EMBRAPA, IAC, ITAL, INPE and others, 2004. Authors own elaboration.

Map 1. Distribution of skilled occupations in São Paulo, by micro-region, State of São Paulo, 2002





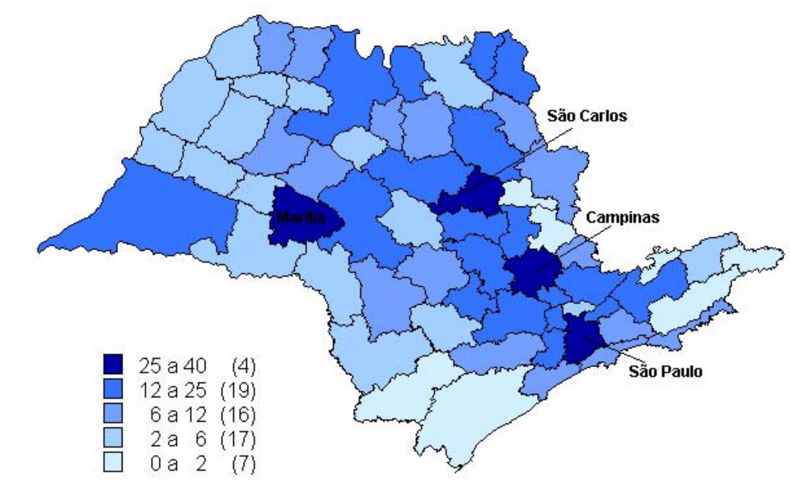


* The intervals refer to values ≥ to the minimum value and < than the maximum.

** The numbers between parentheses mention the number of micro-regions in that interval.

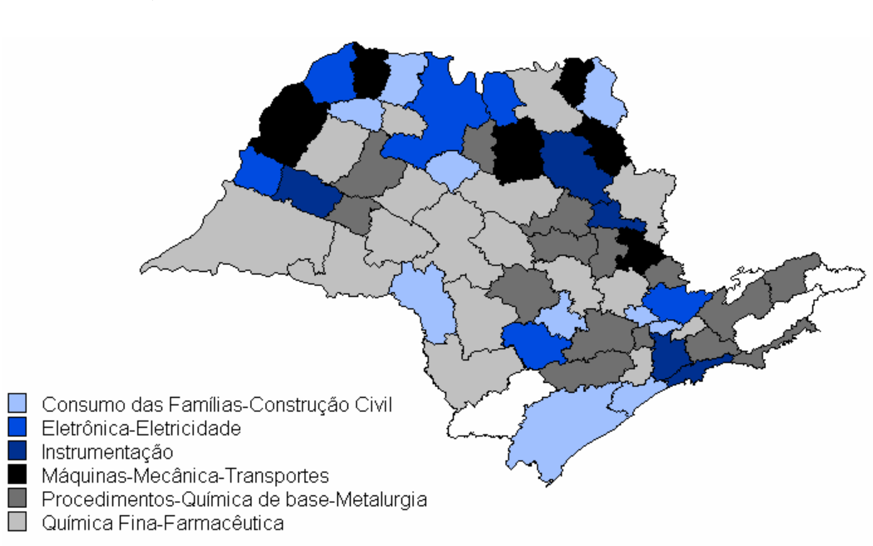
Source: RAIS/MTE. Authors own elaboration.

Map 2. Number of patents per 100,000 inhabitants, by micro-region, State of São Paulo, 2002*



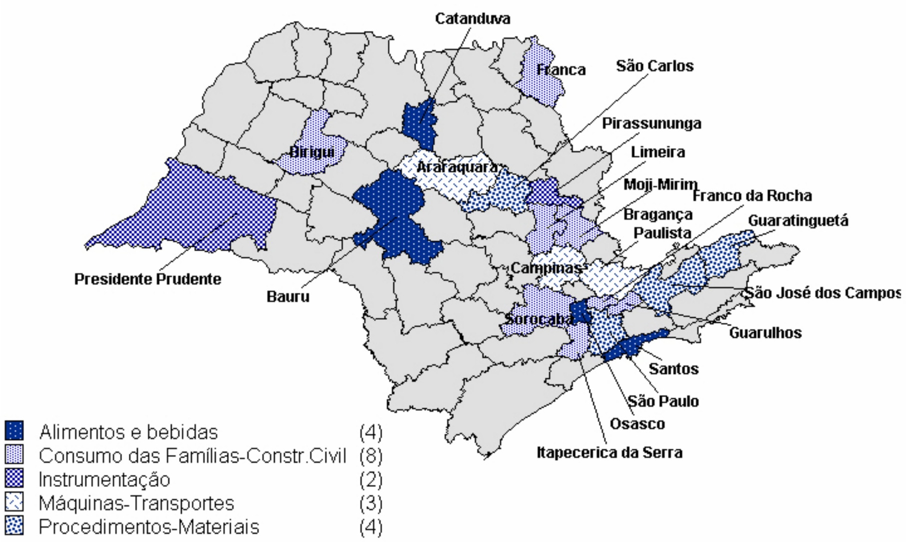
* The numbers between parentheses refers to the number of micro-regions in that interval. **Source:** INPI. Authors own elaboration.

Map 3. Technological specialization, by micro-region, State of São Paulo, 1999-2001



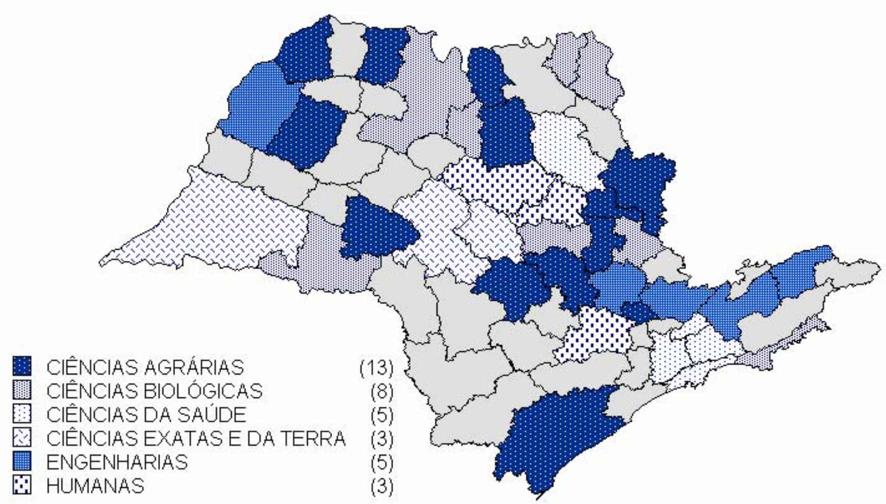
Source: INPI. Authors own elaboration.

Map 4. International commercial specialization, by micro-region, State of São Paulo, 1998-2002*



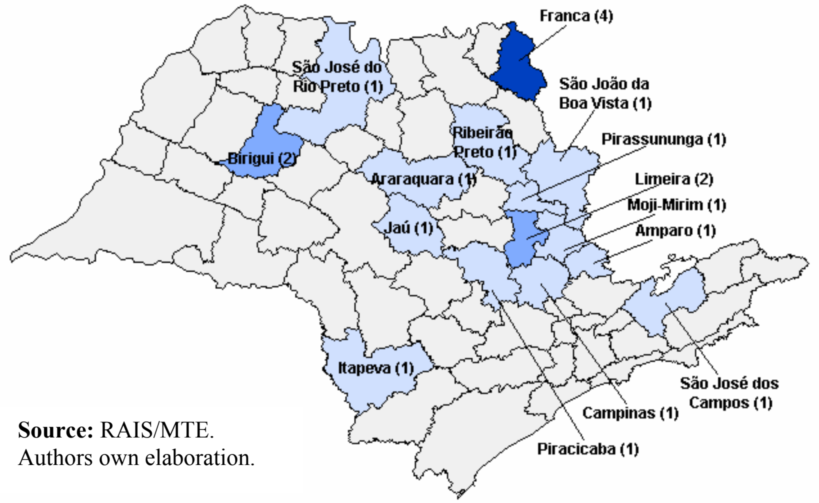
* The numbers between parentheses refers to the number of micro-regions in that interval. **Source:** USPTO. Authors own elaboration.

Map 5. Scientific specialization, by micro-region, State of São Paulo, 1999*



* The numbers between parentheses refers to the number of micro-regions in that interval. **Source:** ISI. Authors own elaboration.

Map 6. Number of four-digit industries located in each micro-region of the type "centers of industrial-regional development", State of São Paulo, 2004.

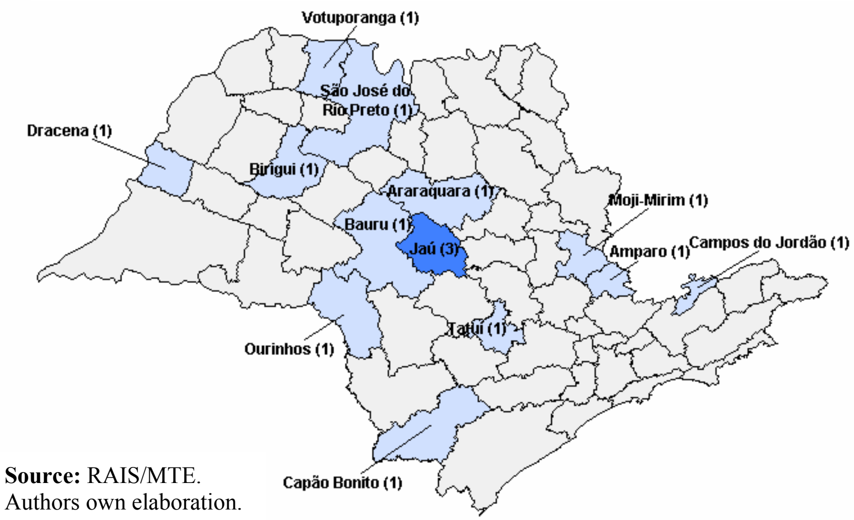


Source: RAIS/MTE.
Authors own elaboration.

Map 7. Number of four-digit industries located in each micro-region of the type "advanced vectors", State of São Paulo, 2004.

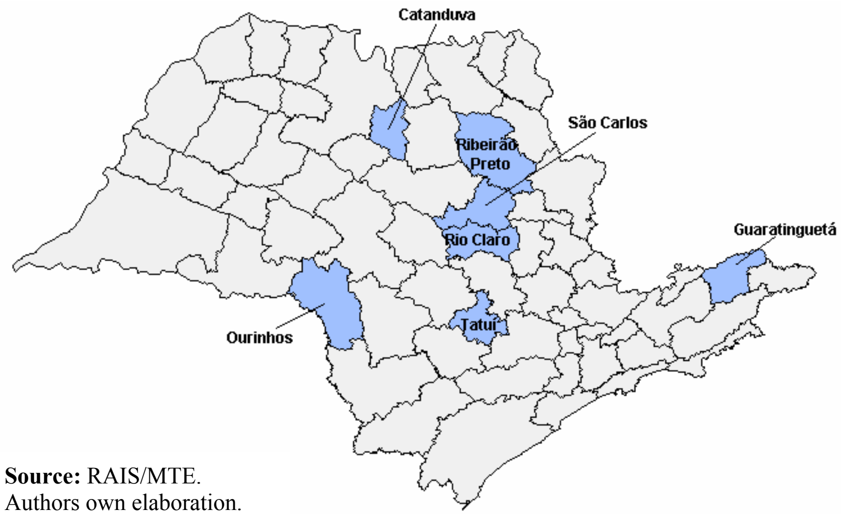
Source: RAIS/MTE.
Authors own elaboration.

Map 8. Number of four-digit industries located in each micro-region of the type "vectors of local development", State of São Paulo, 2004.



Source: RAIS/MTE.
Authors own elaboration.

Map 9. Number of four-digit industries located in each micro-region of the type "embryonic local production system", State of São Paulo, 2004.



Source: RAIS/MTE.
Authors own elaboration.