TECNOLOGIA & INOVAÇÃO

Universities as knowledge producers for economic development: how is Brazil allocating resources in the production of new relevant knowledge for innovation?†

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Abstract: Universities have broadly similar functions in the innovation systems of most industrial and industrializing countries; however the relevance of their role alters substantially. In Brazil, universities are the most important knowledge producers. Departing from the evidence that they do not form a homogeneous group (which is corroborated using the T-Theil index of inequality), a possible classification is then suggested: 'leader universities', 'threshold universities' and 'unveiling universities,' which are in turn divided into two different subclasses: 'catching-up universities' and 'embryonic universities'. This paper demonstrates that even though the largest allocation on financial resources goes to 'hard sciences', there is a large allocation of human resources within humanities, applied social sciences and linguistics, arts and literature (soft sciences). This distortion in the distribution of researchers with a relative high concentration in humanities and applied social science may directly affect the countries innovation capacity. Brazil may not be producing the quantity of pertinent human resources expected to compete in the world's technological advanced markets.

Key-words: Universities; Knowledge Production; Innovation System.

JEL code: O33; I23; I28.

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Policies for science and technology
must always be a mixture of realism and idealism.
Chris Freeman (1921-2010)

1 Introduction

This paper starts from the idea that knowledge has become a competitive factor and a *sine qua non* component for innovative and development capacity, both regionally and nationally. Social, political, cultural and institutional characteristics have an active role in shaping an innovative environment and there are many agents that should be taken into consideration, beyond their potentially tangled relationships, for an effective pro-development policy.

One of these agents is the university, understood here as an institution whose social role goes beyond simply forming a more 'enlightened' society, but to produce scientific and technological knowledge. Universities are then understood as knowledge producers responsible for fostering economic development.

Although universities meet broadly similar functions in the innovation systems of most industrial and industrializing countries, the relevance of their role varies considerably. Furthermore, knowledge production does not have the same intensity in every economy. This variability is influenced, for instance, by the structure of domestic industries, the size and structure of other publicly funded research performers, and numerous other factors (Mowery; Sampat, 2005). In Latin American economies, for example, the incentive regime for research is misaligned; there is little expectation that publicly generated knowledge will be transferred for commercial application in order to realize productivity gains and expenditure is also not geared toward cost-effective, output-oriented research (Rodrígues *et al.,* 2008). Despite existing efforts in making a more comprehensive research system, there is still a gap between scientific production and the amount of technological innovation in those countries and this is a peculiar feature of the region's development process. Unfortunately, Brazil is no exception.

Studying universities may then shed new light in the interpretation of the National System of Innovation. The objective of this paper is to describe the main features of the most important knowledge producers in Brazil, namely the universities. It will be shown that despite the great effort in allocating financial resources for research in specific areas that fit the priority industrial sectors and scientific and technological policies of the country, there is a misaligned allocation of human resources in other fields that are not engineering-intensive.

The paper is structured around three sections: the first presents a synthesis of universities' role for economic development which will serve as a reference throughout the paper. Section 2 succinctly underlines that even though the Brazilian tertiary education system is relatively recent, it has been growing rapidly. It will be also shown that the title of 'new emergent scientific

nation' granted to the country does not mean it has overcome structural problems usually attributed to Latin American economies.

There is a lack of synchronization between the incentive regimes of science and technology policies that on the one hand define areas that are important for playing technological and economical catch-up and on the other hand do not have a well-defined policy to allocate human resources to those areas. Section 2 also identifies that not all universities in Brazil are committed to research as this is a role normally attributed to the public ones. Thus the focus of analysis is on the federally funded universities plus the three state funded universities of São Paulo State. The analysis will involve numerous detours into the role of universities to support innovation for the country's development.

Departing from the evidence that those universities do not form a homogeneous group (which is corroborated using the T-Theil index of inequality), a possible classification is then suggested in section 3: 'leader universities', 'threshold universities' and 'unveiling universities' which are then divided into two subclasses: 'catching-up universities' and 'embryonic universities'. This is a first attempt classification which is an original contribution made by this study that may encourage fresh discussions.

Our hypothesis is that Brazil is not appropriately allocating resources to produce new techno-scientific knowledge with which to compete in the world's technological advanced markets and to act on 'windows of opportunities.' It may therefore not be ready to enter an internationally competitive environment. The results presented in section 3 show that despite the financial resources allocated in strategic fields of knowledge, there is a large allocation of human resources (researchers) within humanities, applied social sciences and linguistics, arts and literature (soft sciences) and that most of the students enrolled in post-graduate programs in the Brazilian Higher Education Institutions (HEIs) are in the same fields of knowledge. This means that in the coming years the country will put in the market work force about two times more Masters/Doctors specializing in 'soft sciences' than in engineering. The importance of the latter is obvious for scientific research and technological innovation as science and technology research are as close to industry and markets as never before (Schwartzman *et al.*, 1995).

Finally this papers ends with some final considerations for public policies.

2 Universities' role for economic development

Countries' innovation efforts are not homogeneous. Some, especially those in the Global North, have shown greater innovation efforts in research and development (R&D) over the past decades when compared to those in the Global South. The importance of R&D lies in the fact that it is a driver for the process of both knowledge and technological accumulation enabling development from what was called 'windows of opportunities' (Perez, 2001). Thus, chances for development depend on each of the opportunity achievements made in previous

phases, indicating the path dependency of the development process. These achievements should reflect a sound understanding of the technological paradigm, the new knowledge and ability to absorb/produce new technologies, and the existence of available infrastructure.

The new knowledge and technologies production reflects the importance of investment in R&D, education and training, which are considered essential for capital accumulation, economic growth, technological know-how and socio-economic development. However, investment in human capital is not the single solution for development *per se*. In a knowledge-based economy, not only is the creation of knowledge relevant, but also the creation of relevant knowledge.

In Latin American countries, the main *locus* of knowledge production is the university (Arocena; Sutz, 2001). Eight different functions (or outputs) of modern research universities that may lead to economic development impacts can be identified: creation of knowledge, human-capital creation, transfer of existing know-how, technological innovation, capital investment, regional leadership, knowledge infrastructure production and influence on the regional milieu. Each one of the outputs mentioned may cause a different pattern of effects on the economy, ranging from the direct and indirect effects of university spending to productivity gains in private companies, from the creation of spin-off enterprises, and the capacity to sustain long-term development and growth (Goldstein; Drucker, 2007).

In other words, universities play an important role in the process of creating and disseminating new scientific knowledge and new technologies through basic research, applied research, development and engineering. They also have the role of supplying skilled labor to meet the demand of the productive sector. Within universities, research staff are renewed and knowledge is updated (Marcovitch, 1999).

Moreover, universities can be seen as strategic agents for 'catching-up' once they contribute to the scientific and technological development of the country. These are the major drivers able to ensure innovation and lead to economic and social changes. Scientific-technological development is a dynamic process and is the result of a collective interaction among different economic agents, especially since the new technological paradigms are permeated by a scientific knowledge which is close to the knowledge frontier; hence it is strategic to promote an active role of the universities and to tighten the university-industry-government network.

The symbiosis between these three agents, was accounted by Sabato and Botana (1968) and gained new prominence with the 'triple helix' approach (Leydesdorff; Etzkiwitz, 1998; Leydesdorff, 2000; Etzkiwitz *et al.*, 2000; Etzkiwitz, 2003; Leydesdorff; Meyer, 2006; Leydesdorff, 2010) which recognizes that these actors can play the role of each other, so that the innovative system works properly, complementing the framework proposed by the Innovation System (IS).

3 Brasilian university system

The Brazilian university system is relatively recent and it has been in existence for less than a century (Mello *et al.*, 2009; Maculan; Mello, 2009). Compared to other Latin American countries, Brazil started relatively late on establishing universities (Suzigan; Albuquerque, 2009). While in some Latin American countries the first universities were established in the 16th century (as in Mexico and Peru) or in the 17th century (as in Bolivia), in Brazil colleges of medicine, law or engineering emerged only in the first half of the 19th century (Mello *et al.*, 2009) and the first university was established solely in 1920, in Rio de Janeiro by the Federal Government. It was 1934 before the state of São Paulo created its own university (Maculan; Mello, 2009), namely São Paulo University (USP), which was Brazil' first fully-fledged university (Schwartzman, 1979).

It is clear that the Brazilian university system had a late development and the history of the country's economy and society had a long-lasting influence, which is embedded in Brazilian higher education institutions' (HEIs) features: small in scale, concentration in humanities and applied social science, weak links to production activities, and applied research circumscribed to some fields such as agronomy, mining/metallurgy, and health sciences. Engineering fields germinated even later in Brazil, and graduate courses linking teaching and research activities were ushered in only in the 1960s, nurtured by federal government (Suzigan; Albuquerque, 2009).

Examining the number of scientific and engineering articles published in some particular fields, that is to say, physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences, Brazil is ranked 15th in the world, contributing 1.59% of all those articles issued (Figure 1) which demonstrates the modest performance of the country *vis-à-vis* the research done in more industrialized countries.

Figure 1 – Scientific and technical journal articles per selected country, %, 2007.
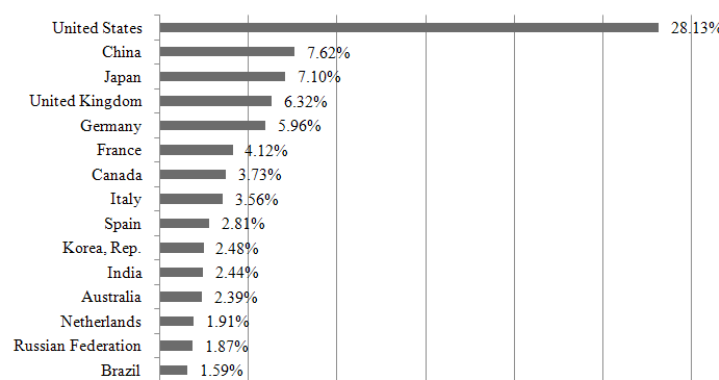
Source: Authors' own. Data sourced from the World Bank Data Catalog. Note: Scientific and technical journal articles refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

Even with this modest performance and considering that Brazil has an immature Innovation System (Albuquerque *et al.*, 2005; Suzigan; Albuquerque, 2008) once characterized by weak links between scientific infra-structure and technological activities (Albuquerque, 2004), science activities in the country are striking with investment and scientific productivity outperforming general trends of growth making the country a new emergent scientific nation (RS, 2011). Nonetheless, the question that should be addressed is: what are the main institutions responsible for science activities and knowledge production in Brazil? Private HEIs are specialized in the teaching mission and those that are dedicated to research are rare exceptions in the country, thus the great amount of scientific knowledge production is accredited mostly to public HEIs (Chiarini; Vieira, in press), more precisely federally funded universities.

A particularity of the Brazilian university system is that most private HEIs seem to be specialized in teaching and in some well-defined fields of knowledge (such as management, law, human sciences), with their research activities being almost entirely residual (Maculan; Mello, 2009). This is corroborated by taking into account the number of articles[1] published in national and international journal: Brazilian federally funded universities contribute to 45% of total article publications, in 2008, and if we sum up to this percentage the publications of the three São Paulo state funded universities – State University of Campinas (UNICAMP), State University of São Paulo (USP) and Paulista State University (UNESP) – the total percentage reaches nearly 66%.

According to the Brazilian Ministry of Education and Culture (MEC) in 2009 there were 186 Brazilian universities of which approximately 53% were public (federally, state or municipal funded) and about 47% were private. Nevertheless, if all HEIs (universities, university centers and colleges) are considered, there were 2,314 institutions of which only about 10% were public (Table 1). In 2010 three more federal universities were legitimized and established, accounting for a total of 58 federally funded universities, which are unequally distributed throughout the Brazilian territory (Table 2). 33% of those universities are concentrated in the Southeast region while only 9% are in the Central-west region. The former region has 4.75 federally funded universities per state whereas the latter has 1.25.

Table 1-Total Brazilian HEIs and Universities, 2009.

	HEIs Total	Universities Total	HEIs %	Universitie %
Brazil	2,314	186	100	100
Public	245	100	10.59	53.76
Federal	94	55	4.06	29.57
State	84	38	3.63	20.43
Municipal	67	7	2.90	3.76
Private	2,069	86	89.41	46.24
North	147	14	6.35	7.53
Northeast	448	35	19.36	18.82
Southeast	1,090	80	47.10	43.01
South	386	43	16.68	23.12

Source: Authors' own. Data sourced from Brazilian Ministry of Education.

1 Here we are considering all fields of knowledge, not only the scientific and engineering articles as the data available by the World Bank.

Table 2 -Total Federally funded Universities, Percentage of Federally funded University per region, and Federally funded University per state, Brazil, 2010.

Brazil (26 States and a F.D.)	Total	%	Federal Public per State (*)
	58	100	2.14
Southeast Region (4 States)	19	33	4.75
Northeast Region (9 States)	15	26	1.66
South Region (3 States)	11	19	3.66
North Region (7 States)	8	14	1.14
Central-west Region (3 States and a F.D.)	5	9	1.25

Source: Authors' own. Data sourced from Brazilian Ministry of Education. (*) Brazil is currently divided into five regions by the Brazilian Institute of Geography and Statistics (IBGE) and into 26 States and a Federal District (F.D.). For simplification we considered 27 States.

It is worth mentioning that the title of new emergent scientific nation (RS, 2011) granted to Brazil does not mean it has overcome structural problems associated with Latin American countries, such as illiteracy. One crucial difficulty faced by those countries is to raise the number of undergraduate students, especially in some specific areas as engineering. In 2008, for instance, there were 5,958 millions of enrolments in Brazilian tertiary education compared to the 18,248 million in the USA or 3,939 million and 3,204 million in Japan and Republic of Korea (much smaller than Brazil) respectively[2].

4 Knowledge production in federal universities

In order to describe Brazilian HEIs, this section starts by measuring the degree of inequality among federally funded universities. This measure is important as a starting point to characterize these institutions in Brazil and will shed new light on the interpretation of the Brazilian National System of Innovation and how they are capable of supporting the country's development. The choice to analyze only some HEIs in Brazil- the federally funded universities- is due to the fact that they are not only engaged in teaching, but also in research activities and in commercializing the results of their research activities (Maculan; Mello, 2009; Chiarini; Vieira, in press). Therefore, the following analysis will consider 55 federally funded universities (excluding three universities[3] legally established only in 2010 as they do not have any observable and comparable data because the analysis here is based on 2008 data).

4.1 T-Theil index as a measure of Brazilian university inequalities

From an index capable of measuring inequalities in a statistical distribution, we can quantify how unequal the Brazilian federally funded universities are, regarding their researchers, research groups, their bibliographic production and their technical production.

2 Global Education Digest 2010, from Unesco.

3 Universidade Federal da Fronteira Sul (UFFS), Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB) and Universidade Federal da Integração Latino-Americana (UNILA).

Albuquerque *et al.* (2001) calculated the Gini coefficient of inequality for scientific and technology production for Brazilian municipalities in 2000 coming to a value of 0.9873 for production technology (proxy patents), 0.9958 for scientific production (proxy articles) and 0.9937 for researchers, which shows that the spatial distribution of innovative activities in Brazil is highly concentrated. Our objective is therefore aligned to the work of Albuquerque *et al.* (2001), but is distinguished by its method.

Unlike Albuquerque *et al.* (2001), we used the Theil-T inequality index for measuring inequality, which can be mathematically deduced by assuming a population with n elements where each element has a non-negative fraction of a given variable, say Y ($Y_i \geq o$, with $i = 1,..., n$): if the distribution mean of Y is μ and X_i is the value of the i-th element, $Y_i = \dfrac{X_i}{n\mu}$ and, therefore, $\sum_{i=1}^{n} Y_i = 1$.

Considering that $H(Y)$ is defined as the entropy of the distribution, we have $H(Y) = \sum_{i=1}^{n} Y_i Log \dfrac{1}{Y_i}$, which can range from $0 \leq H(Y) \leq Log(n)$. If $H(Y) = 0$, there is perfect inequality, and on the contrary if $H(Y) = Log(n)$, there is perfect equality. The Theil-T inequality index is the maximum possible entropy of the data minus the observed entropy and it is the same as redundancy in information theory (Theil, 1967 *apud* Hoffmann, 2006), as it follows:

$$T = Log(n) - H(Y) \tag{1}$$

$$T = \sum_{i=1}^{n} Y_i Log(n) Y_i \tag{2}$$

$$T = \sum_{i=1}^{n} Y_i Log \dfrac{Y_i}{1/n} \tag{3}$$

Thus for the variable of Brazilian research groups, we have the following analysis. The population is comprised of 55 members, n, (all federally funded universities of Brazil, not considering the UFFS, UNILA and UNILAB because there is no observable data, since they were legally established only in 2010). Each member has a fraction of the total number of research groups ($Y_i \neq 0$). The average number of research groups is given by μ and X_i is the volume of research groups in the i-th institution.

So we calculate the Theil-T inequality index for the year 2008. The closer to 0, the more perfect the inequality among the considered universities and the closer to 1.74036, which is exactly the $Log(5)$ value, the more equal are the universities. The same is done for the other items, as shown in Table 3.

Based on the information displayed in Table 3, we can infer that the federally funded universities in Brazil do not make a homogenous group, as there is a high degree of inequality in all these four variables presented. The highest inequality occurs when considering technical production. If we considered three more universities, which were excluded due to not being federally funded, but which are significant in the Brazilian National Innovation System (USP, UNESP and UNICAMP) as suggested on section 2, then we get following results.

Table 3 - Theil-T inequality index of researchers, research groups, bibliographic production and technical production of the Federally funded Universities of Brazil, 2008.

	Researchers	Research Groups	Publication of research articles (*)	Technical Production(**)
Theil-T	0.163764	0.191423	0.216472	0.34456

Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). (*) Articles published in nationally and internationally indexed journals; (**) Technical Production here refers to the sum of the production of software and technology products which had patent registration.

The population now is comprised of 58 members, n, (all federally funded universities of Brazil, not considering again the UFFS, UNILA and UNILAB, but this time including UNICAMP, USP and UNESP). Once again each member has a fraction of the total number of research groups ($Y_i \neq 0$). The average number of research groups is given by μ and X_i is the volume of research groups in the i-th institution. Once more we calculate the Theil-T inequality index for the year 2008. The closer to 0, more greater the inequality among the considered universities and the closer to 1.763428, ($Log(\mathbf{8})$), the more equal the universities are (Table 4).

Table 4 - Theil-T inequality index of researchers, research groups, bibliographic productionand technical production of the Federally funded Universities of Brazil and theState funded Universities of São Paulo State, 2008

	Researchers	Research Groups	Publication of research articles (*)	Technical Production(**)
Theil-T	0.229384	0.23291	0.315712	0.38172

Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). (*) Articles published in nationally and internationally indexed journals; (**) Technical Production here refers to the sum of the production of software and technology products which had patent registration.

We find now a higher degree of inequality and again the biggest inequality happens when considering the technical production. This justifies once again the reason why the three São Paulo state funded universities must be included in the analysis even though they are not federally funded ones. After demonstrating the inequality among those institutions in Brazil, we ask whether there is any correlation between bibliographic production and the number of researchers and/or research groups. Our analysis shows that there is a high correlation: see Figures 2 and 3 below.

Figure 2 - Correlation between Researchers and Publication of research articles
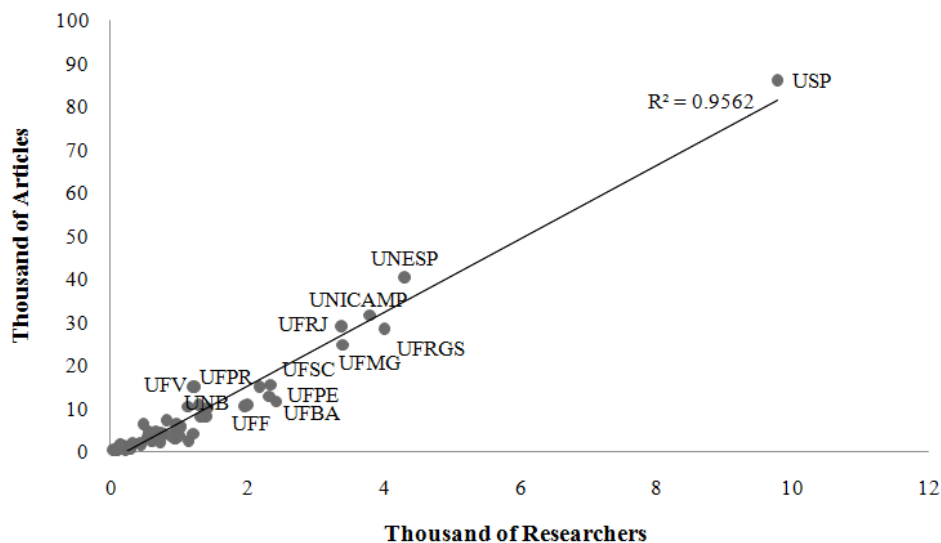
Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). Note: Articles published in nationally and internationally indexed journals.

Figure 3 - Correlation between Researchers and technical production

Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). Note: Technical Production refers to the sum of the production of software and technology products which had patent registration.

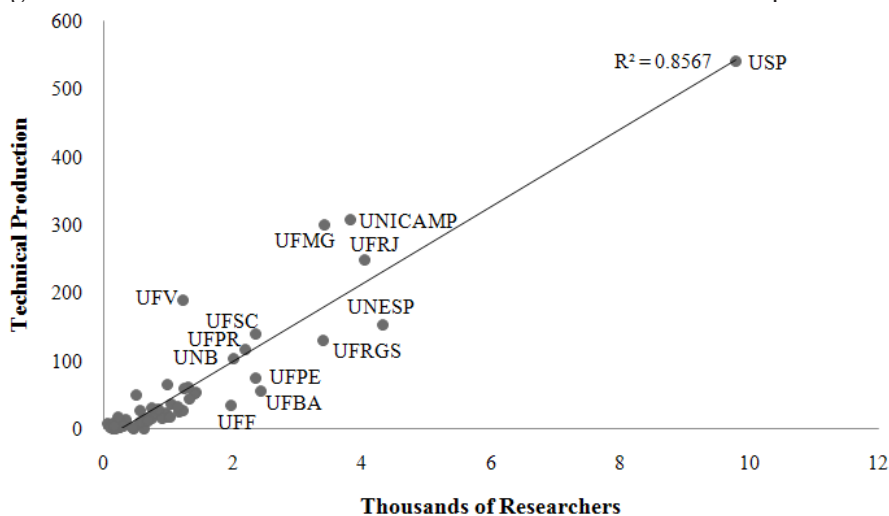As it is shown in figure 2, there is a relationship between researchers and the total amount of articles published (correlation coefficient is 0.97784) and three classifications can be identified: 'leader universities' (formed only by USP), 'threshold universities' (constituted by UNESP, UNICAMP, UFRJ, UFRGS and UFMG) and the 'unveiling universities' which are clearly divided into two different subclasses: 'catching-up universities' (UFPE, UFSC, UFBA,

UFF, UFPR and UNB) and 'embryonic universities' (the rest). Figure 3 shows there is a link between researchers and total amount of technical production and the same classification of universities may be identified (correlation coefficient is 0.92521).

Now we analyze the different features of those institutions considering that they are unequal and they are classified into three types ('leader universities', 'threshold universities' and 'unveiling universities') and then understand their role in shaping the Brazilian System of Innovation.

4.2 Fields of knowledge in the Brazilian HEIs

By fields of knowledge we refer to the subject areas or disciplines into which knowledge is frequently classified according to the categories proposed by the Coordination of Improvement of Higher Education Personnel (CAPES), which is a Foundation within the Ministry of Education and Culture in Brazil. The following large areas are identified: agricultural science; biological sciences; exact and earth sciences; health sciences; humanities; applied social sciences; engineering; and linguistics, arts and literature.

Analyzing the research groups according to the classification proposed by CAPES, it is possible to note that the highest percentage of research groups registered within the National Council for Scientific and Technological Development (CNPq) is in humanities (almost 19%), followed by exact and earth science (nearly 17 %) and engineering (13%). If we examine the distribution of Brazilian researchers by fields of knowledge, once again the biggest concentration is in humanities (19.56%), followed by health sciences (17.97%). The biggest concentration of article publications taking into account all Brazilian HEIs is in health science (24.69%) and engineering accounts only for almost 9% of total publications in the country (table 5).

It is worth acknowledging that in Brazil there is a large allocation of human resources to humanities, applied social sciences and linguistics, arts and letters (which together account for almost 37% of researchers) and only 13% of researchers are allocated in engineering. Brazil may not be producing the quantity of relevant human resources required to compete in the world's hi-tech markets. This distortion towards humanities and applied social science in the distribution of researchers by area of knowledge may be directly related to the predominance of HEIs offering a number of course openings that demand little investment in equipment such as management, law and other human sciences (MELLO *et al.*, 2009). The same conclusion can be made if the federally funded universities plus USP, UNESP and UNICAMP are analyzed: the number of researchers allocated in humanities, applied social sciences and linguistics, arts and letters account for almost 35% (figure 4).

Table 5 - Distribution of research groups, researchers, articles, post-graduation Programs, post-graduation student, by fields of knowledge, all Brazilian HEIs, %, 2008

	Research Groups	Researchers	Publication of research articles	Technical production	Post-graduation programs*	Post-graduation student*
Agricultural Science	9.55	10.37	15.72	4.02	10.98	9.44
Biological Science	11.83	11.33	18.14	21.17	8.10	7.62
Health Science	17.38	17.97	24.69	18.09	16.86	14.43
Exact and Earth Science	11.03	10.03	13.23	18.62	10.09	9.63
Humanities	18.51	19.56	10.05	3.98	14.25	16.99
Applied Social Science	12.08	12.23	6.50	2.54	12.69	12.64
Engineering	13.28	12.88	8.96	30.80	11.02	14.83
Linguistics, Arts and Literature	6.35	5.63	2.70	0.78	5.41	6.45
Multidisciplinary	n/a	n/a	n/a	n/a	10.59	7.98
Total	100	100	100	100	100	100

Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). *Data sourced from GeoCapes (Statistical Data from the Coordination of Improvement of Higher Education Personnel - CAPES). Note: Here we considered all public and private HEIs in Brazil. Note: Post-graduation programs refer to the number of master and doctoral programs. Bibliographic production refers to articles published in nationally and internationally indexed journals; technical production here refers to the sum of the production of software and technology products which had patent registration.

Figure 4 - Distribution of researchers by fields of knowledge, Brazilian federally funded universities and USP, UNESP and UNICAMP, 2008
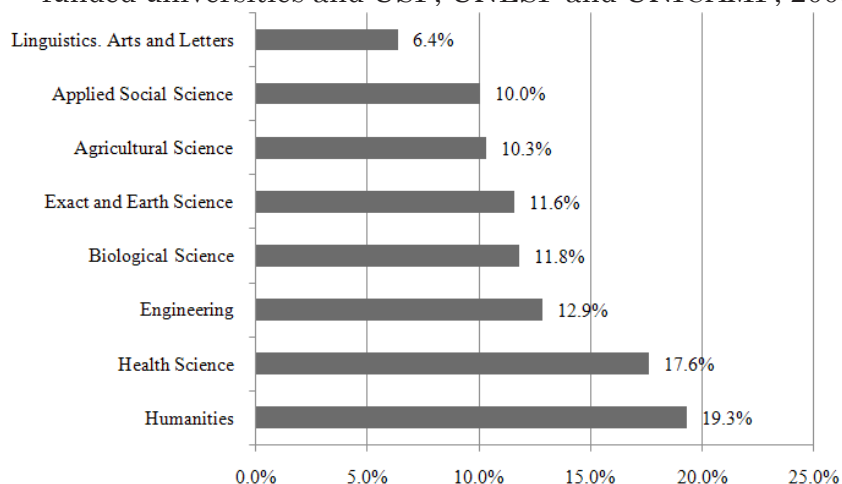
Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq).

A peculiarity of the Brazilian tertiary education is that, as already mentioned in section 2, the public HEIs are the main supporter of the public system of research, especially thanks to the post-graduate programs sustained

by those institutions. In 2008, the Coordination of Improvement of Higher Education Personnel (CAPES) had 2,718 registered programs that were offered in the country; humanities, applied social sciences and linguistics, arts and letters corresponded to nearly 32% of all programs. About 46.000 students were enrolled in post-graduate programs in the Brazilian HEIs in the same period: 36% of whom matriculated in humanities, applied social sciences and linguistics, arts and letters. Over the next few years the country will put in the market work force about 54 thousand Masters/Doctors from the aforementioned areas while only less than half of it will be made of engineers (Table 5).

It has been ascertained that not every type of research conducted by Brazilian HEIs is destined for strategic sectors defined by the industry and the country's development. We identify strategic sectors that can help the country's development taking the sectors defined by the Brazilian Industrial, Technological and Foreign Trade Policy (PITCE) as software, biotechnology, nanotechnology, biomass, capital goods, semiconductors and pharmaceuticals[4]. Accepting the aforementioned areas as strategic and 'leading to the future,' we propose that they have the potential radically to change processes/products, which is why there should be a better allocation of resources to these sectors. It is possible to cur across these sectors with the fields of knowledge proposed by CAPES referred before (Box 1). Although a direct correlation between fields of knowledge (CAPES) and strategic areas (PITCE) may be identified, nothing prevents research on a specific strategic area being conducted by researchers from other fields of knowledge. Chiarini and Vieira (in press) show that although 'software' belongs to Physical and Earth Sciences, there are researches related to software performed in other fields such as Agricultural, Engineering, Health Sciences, Social Sciences, Humanities, and even linguistics, Arts and Letters; the same may happen to other strategic sectors.

Box 1 - Fields of knowledge versus strategic sectors of PITCE

Fields of knowledge - CAPES	Strategic sectors - PITCE
Exact and Earth Sciences	Software
Engineering	Semiconductors, Capital goods
Health Sciences	Pharmaceuticals
Agricutural Sciences	Biomass
Life Sciences	-
Applied Social Sciences	-
Humanities	-
Linguistic, Arts and Letters	-
Multidisciplinary	Biotechnology, Nanotechnology

Source: Chiarini; Vieira, in press.

It is not the intention of this paper to suggest or to advocate the exclusion of research lines that do not fit the priority sectors of industrial and scientific and technological policies of the country. It is understood that they are important

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4 The Industrial, Technological and Trade Policy (PITCE) was launched in 2004, under President Lula da Silva as a way of valuing innovation as a means of development, influenced by the evolutionary school. The PITCE recognizes that certain knowledge-intensive areas are 'future carrier' and strategic and therefore they should be encouraged, as a result of joint efforts. Thus, this policy aims to guide public action in pursuit of dynamic comparative advantages and productivity increase. (CAMPANARIO, et al., 2005).

tools for understanding the regional, historical, cultural, economic and social dynamics (Chiarini; Vieira, in press). Nevertheless, we want to emphasize the importance that needs to be given to studies focused on the HEI priority areas for scientific development and technology as these are in line with the themes of Innovation Systems and is supported by the experience of countries that encouraged academic background in science and technology. This is the case in India which has stimulated the formation of qualified personnel in science and technology with emphasis on areas such as exact sciences and engineering.

4.3 Public investments in the Brazilian HEIs

Federal agencies like the Coordination of Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) in Brazil foster research through non-recoverable funds. State agencies have the same objective and the Research Support Foundation of São Paulo State (FAPESP) is by far the most important of them.

When we look at the non-recoverable funds granted by FAPESP, there was a real growth of 22.32%, between 2006 and 2010. In 2010, FAPESP investments that supported researches in Brazilians HEIs located in São Paulo State amounted to US$ 443.1 million and 11.06% of FAPESP resources to support research were directed to research in technological innovation. Considering CAPES investments, there was a real growth of 30.9%, between 2006 and 2008. In 2008, this investment was US$ 447.2 (Table 6)

Table 6 - Financial resources to research, CNPq, CAPES and FAPESP (2006-2010), U$ million

	CNPq	CAPES	FAPESP
2006	408.6	260.3	239.8
2007	617.5	308.7	282.1
2008	635.7	447.2	347.7
2009	665.2	n/a	340.2
2010	900.0	n/a	443.2
2006-2008 Real growth	-	30.9%	-
2006-2010 Real growth	46.02%	n/a	22.32%

Source: Authors' own. Data sourced from CNPq, CAPES and FAPESP.

Note: To calculate the real growth we used the IPCA inflation series from IPEAdata to deflate the R$ values.

Between 2006 and 2010, there was a real growth of 46.02% of investments in research of CNPq in Brazilian HEIs. The distribution of resources for research in Brazilian HEIs shows that about only10% of financing goes to areas of knowledge that have no relation to the strategic technological sectors of PITCE presented previously, as Humanities, Applied Social Sciences and Linguistics, Art and Letters.

In 2008, Agronomy, Medicine, Engineering; Physics; Chemistry and Pharmaceuticals; and Computer Science received together 43,3% of US$ 635.7 million that CNPq invested in research projects, events and post graduate scholarships (in Brazil and abroad) (Figure 5).

Figure 5 - Distribution of investments in research per specific fields of knowledge, Brazilian HEIs, 2008
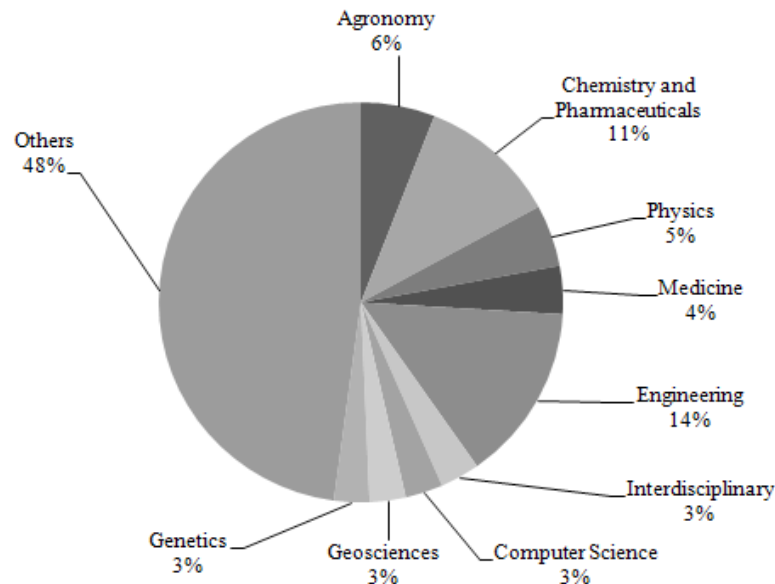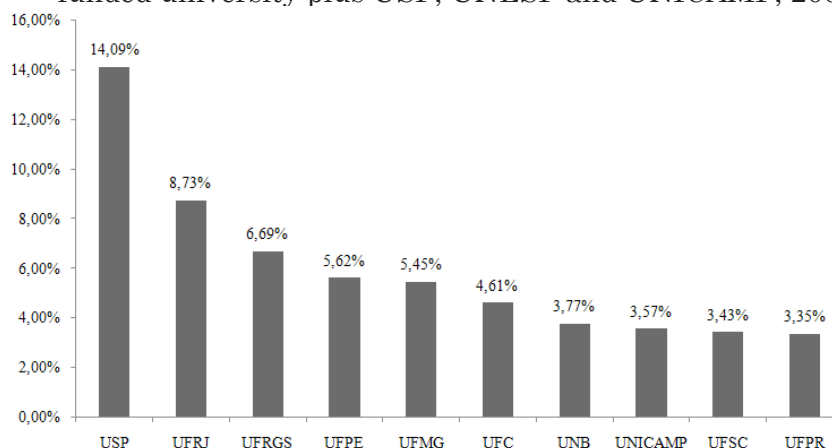

Source: Authors' own. Data sourced from the National Council for Scientific and Technological Development (CNPq).

These three agencies (Capes, FAPESP and CNPq) are very important in supporting Brazilian HEIs research and knowledge production. However, here we take into account only the investment of CNPq to support research projects. There are two reasons that justified this choice. The first is institutional: the choice of analyzing only this research supporter agency is because of its aim to promote and stimulate the scientific and technological development of the country and to contribute to the formulation of national science and technology policy and it is linked to the Ministry of Science and Technology. It is also recognized as the main source of non-recoverable fund for research as was identified in Table 6. The second reason is determined by our research in this paper: it is very difficult to find investment data on other institutions in research by HEIs, and this is true for all the other data investigated in this paper. Therefore we based our research on data sourced from CNPq.

In 2008, of the US$ 635.7 million, CNPq invested US$ 195 million only in research projects (of which 64% were placed in the federally funded universities plus USP, UNESP and UNICAMP.) Of this 64%, 14.09% was allocated to USP (figure 6).

Figure 6 - Percentage of CNPq investment in research project, selected federally funded university plus USP, UNESP and UNICAMP, 2008

Source: Authors' own. Data sourced from the the National Council for Scientific and Technological Development (CNPq), Statistics on Science and Technology.

As opposed to what happens to the large amount of human resources allocated within humanities, applied social sciences and linguistics, arts and letters (together accounting for almost 37% of researchers, as was shown previously in section 3.2), Brazil seems to allocate financial resources more in Biological Science (21.7%) and Engineering (15.2%) which seems to align with the country's Industrial and Technological Policy (Table 7). Thus, if Brazil has a lag in innovation it may well cbe aused due to the lack of human resources in areas like engineering rather than from financing of research.

Table 7 - Distribution of Financing to Research per field of knowledge, 2008.

	US$	%
Biological Science	42,428,019	21.7
Engineering	29,775,138	15.2
Exact and Earth Science	29,284,522	15.0
Agricultural Science	29,261,384	15.0
Health Science	28,622,003	14.7
Humanities	9,682,300	5.0
Applied Social Science	6,594,161	3.4
Linguistics. Arts and Literature	1,382,026	0.7
Not available/not applicable/others	18,262,863	9.4
Total	195.292.416	100

Source: Authors' own. Data sourced from the National Council for Scientific and Technological Development (CNPq), Statistics on Science and Technology.

5 Conclusion: policy consideration

The hypothesis of this paper was that Brazil was not appropriately allocating resources to produce new techno-scientific knowledge to compete in the world's technologically advanced markets in order to act on 'windows of opportunities' and that the country was not ready to act in an internationally

competitive environment. Brazil seems to allocate financial resources more to biological sciences and engineering research which aligns with the country's Industrial and Technological Policy, however, it was demonstrated that not every type of research conducted by Brazilian HEIs was destined for strategic sectors. This was also true for the allocation of human resources in research.

In Brazil there is a large allocation of human resources within humanities, applied social sciences and linguistics, arts and letters (together accounting for almost 37% of researchers) whereas only 13% of researchers are allocated to engineering. Brazil may not be producing the quantity of relevant human resources required to compete in the world's hi-tech markets. This is very worrisome since the country needs qualified human capital in technological areas if it is to realize its goal of playing 'catch-up' with developed economies. Furthermore, training people in areas like health and education is also crucial in the Brazilian context, in order to meet needs that are both social and economical bottlenecks in the country.

The focus of the analysis was on federally funded universities and the three state funded universities of São Paulo because they are the main agents in producing knowledge in the Brazilian Innovation System. We demonstrated how the researchers are distributed in these institutions and also how productive each one of them is in terms of articles and technological production. From this, we could classify those institutions in three classes: 'leader universities' (formed only by USP), 'threshold universities' (which is constituted by UNESP, UNICAMP, UFRJ, UFRGS and UFMG) and the 'unveiling universities' which are clearly divided into two different subclasses: 'catching-up universities' (UFPE, UFSC, UFBA, UFF, UFPR and UNB) and 'embryonic universities' (the others).

The empirical findings presented suggest some normative actions: science and technology policies should make it possible for the country to enter a new pattern of industrial growth relying heavily on basic and applied research in the Brazilian universities. Thus, there should be a better coordination inducing scientific research to sectoral areas such as software, biotechnology, nanotechnology, biomass, capital goods, semiconductors and pharmaceuticals. This means that "research and development activities should be selective and clearly associated with broader processes of innovation based on the transfer, diffusion and absorption of technological competence" (Schwartzman, S., *et al.*, 1995, p. 33). The state's role in providing highly qualified human capital is crucial in Brazil. The public HEIs are the main supporter of the public system of research, especially thanks to the pos-graduation programs sustained by those institutions.

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Appendix 1 - List of the federally funded Universities of Brazil and the State funded Universities of São Paulo State,the Region where they are located, their abbreviation and their establishment year

Region	Abbreviation	Universities	Establishment year
Center-West	UFG	Universidade Federal de Goiás	1960
	UFGD	Universidade Federal da Grande Dourados	2005
	UFMS	Universidade Federal do Mato Grosso do Sul	1979
	UFMT	Universidade Federal do Mato Grosso	1970
	UNB	Universidade de Brasília	1962
North	UFAC	Universidade Federal do Acre	1974
	UFAM	Universidade Federal do Amazonas	1962
	UFPA	Universidade Federal do Pará	1957
	UFRA	Universidade Federal Rural da Amazônia	2002
	UFRR	Universidade Federal de Roraima	1985
	UFT	Universidade Federal de Tocantins	2000
	UNIFAP	Universidade Federal do Amapá	1987
	UNIR	Fundação Universidade Federal de Rondônia	1982
Northeast	UFAL	Universidade Federal do Alagoas	1961
	UFBA	Universidade Federal da Bahia	1950
	UFC	Universidade Federal do Ceará	1954
	UFCG	Universidade Federal de Campina Grande	2002
	UFERSA	Universidade Federal Rural do Semi-Árido	2005
	UFMA	Universidade Federal do Maranhão	1966
	UFPB	Universidade Federal da Paraíba	1960
	UFPE	Universidade Federal do Pernambuco	1965
	UFPI	Universidade Federal do Piauí	1968
	UFRB	Universidade Federal do Recôncavo Bahiano	2006
	UFRN	Universidade Federal do Rio Grande do Norte	1960
	UFRPE	Universidade Federal Rural do Pernambuco	1955
	UFS	Universidade Federal de Sergipe	1967
	UNILAB	Universidade da Integr. Inter. da Lusofonia Afro-Brasileira	2010
	UNIVASF	Universidade Federal do Vale do São Francisco	2002
South	FURG	Universidade Federal do Rio Grande	1971
	UFCSPA	Universidade Federal de Ciências da Saúde de Porto Alegre	1980
	UFFS	Universidade Federal da Fronteira Sul	2009
	UFPEL	Universidade Federal de Pelotas	1969
	UFPR	Universidade Federal do Paraná	1950
	UFRGS	Universidade Federal do Rio Grande do Sul	1950
	UFSC	Universidade Federal de Santa Catarina	1959
	UFSM	Universidade Federal de Santa Maria	1961
	UNILA	Universidade Federal da Integração Latino-Americana	2010
	UNIPAMPA	Universidade Federal dos Pampas	2008
	UTFPR	Universidade Tecnológica Federal do Paraná	2005
Southeast	UFABC	Universidade Federal do ABC	2005
	UFES	Universidade Federal do Espírito Santo	1961
	UFF	Universidade Federal Fluminense	1960
	UFJF	Universidade Federal de Juiz de Fora	1960
	UFLA	Universidade Federal de Lavras	1994
	UFMG	Universidade Federal de Minas Gerais	1949
	UFOP	Universidade Federal de Ouro Preto	1969
	UFRJ	Universidade Federal do Rio de Janeiro	1920
	UFRRJ	Universidade Federal Rural do Rio de Janeiro	1943
	UFSCAR	Universidade Federal de São Carlos	1968
	UFSJ	Universidade Federal de São João del Rei	2002
	UFTM	Universidade Federal do Triângulo Mineiro	2005
	UFU	Universidade Federal de Uberlândia	1978
	UFV	Universidade Federal de Viçosa	1969
	UFVJM	Universidade Federal do Vale do Jequitinhonha e Mucurí	2005
	UNIFAL/MG	Universidade Federal de Alfenas	2002
	UNIFEI	Universidade Federal de Itajubá	2002
	UNIFESP	Universidade Federal de São Paulo	1994
	UNIRIO	Universidade Federal do Estado do Rio de Janeiro	1979
	UNESP	Universidade Estadual Paulista*	1976
	UNICAMP	Universidade Estadual de Campinas*	1966
	USP	Universidade de São Paulo*	1934

Source: Brazilian Ministry of Education. (*)State funded universities of São Paulo State.

Appendix 2 - Research groups, researchers, bibliographic production and technical production of the federally funded Universities of Brazil and the State funded Universities of São Paulo State, %, 2008

	Research Groups	Researchers	Bibliographic Production*	Tecnical Prodution**
FURG	0.87	0.79	0.70	0.83
UFABC	0.09	0.07	0.10	0.25
UFAC	0.26	0.33	0.15	0.06
UFAL	1.58	1.35	0.38	0.52
UFAM	1.34	1.62	0.54	0.80
UFBA	3.06	3.43	1.65	1.69
UFC	1.93	2.01	2.08	1.66
UFCG	0.96	1.05	1.61	0.46
UFCSPA	0.21	0.20	0.40	0.03
UFERSA	0.20	0.21	0.46	0.06
UFES	1.71	1.34	0.63	0.74
UFF	2.89	2.78	1.62	1.05
UFG	1.71	1.99	1.94	1.60
UFGD	0.41	0.42	0.94	0.28
UFJF	1.20	1.12	0.54	0.74
UFLA	0.52	0.70	1.40	1.54
UFMA	0.84	0.87	0.61	0.03
UFMG	4.74	4.81	2.71	9.23
UFMS	1.48	1.26	3.11	0.46
UFMT	1.54	1.44	0.85	0.52
UFOP	0.50	0.47	0.41	0.40
UFPA	1.72	1.72	0.68	0.83
UFPB	1.83	1.87	1.49	1.38
UFPE	3.49	3.29	2.10	2.28
UFPEL	1.12	1.17	2.19	0.89
UFPI	0.96	0.88	0.86	0.34
UFPR	2.80	3.09	1.93	3.60
UFRA	0.16	0.21	1.52	0.00
UFRB	0.24	0.31	0.22	0.37
UFRGS	4.71	4.77	3.02	4.00
UFRJ	6.19	5.67	5.65	7.66
UFRN	1.18	1.47	1.19	1.14
UFRPE	0.58	0.79	0.96	0.28
UFRR	0.39	0.34	0.42	0.06
UFRRJ	0.96	0.95	0.64	0.46
UFS	0.91	0.97	0.77	0.37
UFSC	3.18	3.31	2.09	4.31
UFSCAR	2.24	1.84	2.41	1.91
UFSJ	0.41	0.37	1.39	0.25
UFSM	1.88	1.62	1.47	0.98
UFT	0.69	0.64	1.05	0.03
UFTM	0.26	0.24	0.21	0.00
UFU	1.43	1.37	0.95	2.00
UFV	1.75	1.71	2.72	5.84
UFVJM	0.40	0.28	1.15	0.18
UNB	2.36	2.84	2.28	3.17
UNIFAL/MG	0.19	0.21	0.15	0.22
UNIFAP	0.02	0.15	0.05	0.06
UNIFEI	0.32	0.30	0.14	0.52
UNIFESP	2.03	1.74	3.13	1.81
UNIPAMPA	0.12	0.14	0.11	0.06
UNIR	0.32	0.42	0.12	0.15
UNIRIO	0.62	0.63	0.39	0.09
UNIVASF	0.26	0.22	0.15	0.12
UTFPR	1.07	1.04	0.47	0.92
UNESP	6.02	6.08	8.45	4.71
UNICAMP	5.32	5.36	6.60	9.44
USP	13.84	13.78	18.02	16.61
Total (%)	100.00	100.00	100.00	100.00
Total (absolute value)	13,282	71,074	477,806	3,251

Source: Authors' own. Data sourced from the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq). (*) Articles published in nationally and internationally indexed journals; (**) Technical Production here refers to the sum of the production of software and technology products which had patent registration.