Backbones of the Knowledge Economy? Universities and the Dynamics of Technology Upgrading in a Developing Country

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ABSTRACT

The knowledge infrastructure stands for a key element of technology upgrading. Due to its ability to create and disseminate knowledge, the modern university is understood as a central agent in innovation systems, and an important part of the knowledge infrastructure. Nonetheless, scientific assessments on the mechanisms involving universities, technology upgrading and the middle-income trap could definitely use additional carefully designed empirical appraisals of the role of universities in emerging and transition economies are lacking. Hence, the goal of this research is to assess how universities in an emergent economy behave in terms of technology upgrading. Information is drawn from the case of Brazil and comprehends an evaluation of the years 1994, 2004 and 2014 for the twelve most preeminent universities in the country. Social Network Analysis is used for an in-depth comprehension of universities' interactions in patenting activity. Results indicate that the most prominent research-oriented universities in Brazil are responsible for a substantial amount of university patenting activity. Nonetheless, the levels of patenting activity for the Brazilian key universities is low. Additionally, academic co-patenting is strongly inward-oriented, involving both a lack of connections with agents abroad and with MNEs with subsidiaries in the country. A third aspect related to the dynamics of technology upgrading in this sub-sample is that the inventions are concentrated in only two broad technological domains: Human Necessities and Chemistry & Metallurgy. The evolution of technology upgrading processes in Brazil from the university perspective is recent and it has presented noticeable evolution. Due to the embryonic stage of innovation systems in emerging economies in general, it seems fair to hypothesize that the function of academic institutions in shaping the innovation environment can be significant.

Keywords: Technology upgrading; Patents; Universities; Social Network; Emerging Economy.

1. INTRODUCTION

Technology upgrading can be defined as "*a gradual shift from lower to higher value-added activities*" (Radosevic & Yoruk, 2016, p. 4). It brings a diversification in the knowledge portfolio of nations (Lee, 2013) and functions as an inherently interactive phenomenon, involving global and local actors (firms, universities, governments) (Ernst & Kim, 2002).

This approach to the dynamics of innovation in laggard economies provides a valuable critique to propositions assuming that closing the technological gap with advanced countries functions in a similar manner as advancing knowledge frontiers. The persistent lack of international-level competitiveness in many developing countries suggests that a further understanding on how to reduce inefficiencies at the technological level is a key feature that research should address in upcoming years.

Within this context, the knowledge infrastructure stands for a key element of technology upgrading. The relationship between science and technological development has long been recognized as a pillar of innovation systems and of the competitive capabilities in knowledge-based societies (Nelson & Rosenberg, 1993; Etzkowitz & Leydesdorff, 2000). If anything, this relationship has become more deeply entrenched in productive structures, and technological processes have become increasingly reliant on scientific knowledge and in multi-player settings (Caraça et al., 2009; Leydesdorff & Meyer, 2007).

Due to its ability to create and disseminate knowledge, the modern university is understood as a central agent in innovation systems (Mazzoleni & Nelson, 2007; Guerrero et al., 2016; Cooke et al., 1997; Asheim et al., 2011), and an important part of the knowledge infrastructure (Conceição & Heitor, 1999), thus playing a key role in the generation of aggregate competitiveness. Empirical evidence provides support to this proposition by showing that universities function as fundamental sources of technological opportunities for innovations in companies (Klevorick et al., 1995). Consequently, academic technology transfer has the capacity of generating pervasive effects for universities themselves and for society at large – such as improved human capital, knowledge capital and entrepreneurship (Guerrero et al. 2016). Universities have also been related to contributions to the innovation environment (Choung et al., 2014), the generation of aggregate competitive advantages (Goddard & Chatterton, 1999), and as vectors of integration with international knowledge communities (Heitor, 2015).

The recognition of this role for academia has given rise to institutional changes aiming at promoting a closer connection between universities and markets (Caraça et al., 2009). Nonetheless, there remains a need to further explore the relationship between countries' science base and its connections with technological and industrial knowledge (Radosevic & Yoruk, 2014). Such aspects are particularly critical for emerging and transition countries – those in search for technology upgrading. These nations often lack adequate knowledge infrastructures able to feed the economic system with skills and ideas necessary to attain higher levels of productivity.

The goal of this research is to ***assess how universities in an emergent economy behave in terms of technology upgrading***. Emphasis is given to the intensity and breadth of technology upgrading, as well as to interactions with domestic and foreign industries. We assess the case of Brazilian universities for three distinct years to capture evolutionary trends in the phenomenon under analysis: 1994, 2004 and 2014. Academic institutions in this country have historically played a strategic role in transferring scientific knowledge to firms and development of new technologies (Suzigan & Albuquerque, 2011; Suzigan et al., 2009). Recent assessments have also revealed the capacity of these institutions to also function as sources of knowledge-intensive entrepreneurship (Fischer et al., 2017).

The article is structured in five sections. Aside from this introduction, Section 2 reviews the literature on technology upgrading and the role of universities. Section 3 describes the analytical method. Section 4 describes preliminary results. We conclude with some discussion in Section 5.

2. TECHNOLOGY UPGRADING: THE ROLE OF UNIVERSITIES

Neoclassical models in economics are known for their lack of concern with the barriers faced by developing countries in the generation of technological capabilities – which are taken as freely available (Lall, 1992). This argument rests on a mechanistic understanding of economic systems (Solow, 1957; Romer, 1986; Lucas, 1988), and systemic aspects either ignored or taken as given. This implies that innovations generated in advanced nations should be appropriated in developing economies at low costs and that some level of convergence should be attained over the long run. Nonetheless, persistent technological lags in most emergent and transition economies provides a body of evidence that contradicts these assumptions.

For instance, even in the face of signs of increased absorptive capacity in laggard nations for the past couple of decades, scientific leadership remains concentrated in developed economies (Radosevic & Yoruk, 2014). By no means this is a natural process in economic systems. Strategic policies and initiatives to develop and acquire capabilities needed for increased efficiency in productive systems have played a central role in these dynamics (Lall, 1992; Dahlman et al., 1987).

Distinct approaches have been directed towards the idea of technology upgrading processes in developing and emerging nations. Some key areas of interest include interactions with agents embedded in Global Value Chains as a transmission channel explicit and tacit knowledge (Ernst & Kim, 2002), complexity of economic structures (Hidalgo & Hausmann, 2009; Krüger, 2008), dynamic specialization towards emerging areas, locally *versus* internationally-oriented research (Radosevic & Yoruk, 2014), sequential upgrading based on leading sectors (Ozawa, 2009), among other arguments and aspects of interest. Jindra et al. (2015) have summed up these arguments in three dimensions of technology upgrading processes:

a) *Intensity of Technology Upgrading*: a vector of technology acquisition strategies conditional upon countries' current technological capabilities;
b) *Breadth of Technology Upgrading*: it comprehends structural factors connected to the dynamics of technology upgrading, such as infrastructure, structural aspects of the productive system, and firm structure in terms of size and capabilities.
c) *Interaction with the Global Economy*: this dimension makes reference to the international interconnectedness that is embedded in knowledge flows, highlighting interdependencies across different nations and technological systems.

Departing from these propositions, analytical focus on aspects related to technology upgrading processes can take diverse paths. Nonetheless, the cornerstone of catching-up dynamics is ultimately based on the availability and application of economically valuable knowledge (Esterhuizen et al., 2012). With that in mind, the next step of this literature review deals with bringing together broader economic aspects of productive systems and the role of universities as potential backbones for innovation systems to alter evolutionary trajectories and enter long term upgrading paths.

2.1 Universities as Agents of Technology Upgrading

Universities are entities that comprise complex functions, involving social, educational and scientific objectives (Bercovitz & Feldmann, 2006). This translates into multiple roles, including teaching, research and technology transfer. These activities contribute to the socioeconomic environment via spin-offs, patents, licenses, knowledge via trained graduates, publications and consulting activities (Caraça et al., 2009; Klofsten & Evans, 2000; Cohen et al., 2002). These contributions end up being sources of knowledge for firm-level innovation (Klevorick et al., 1995), justifying policymakers' approaches to universities as engines of economic development (Feller, 1990).

Science and Technology (S&T) advancements function as important learning mechanisms for firms' technological trajectories. Academic institutions can be regarded as central agents in these evolutionary processes due to their ability to create and deploy disseminate knowledge (Bercovitz & Feldmann, 2006; Conceição & Heitor, 1999). Illustratively, "*university expansion coincided with spectacular rise of innovation activity in industrialized world*" (Cowan & Zinovyeva, 2013, p. 788)[1].

A traditional pillar of this knowledge transmission comes in the form of human capital. Tertiary education has been perceived as a strategic vector of developing countries' growth trajectories, supplying economic systems with advanced skills (Hanushek, 2013; Martin, 1998). Bercovitz and Feldman (2006) have also underscored the issue of universities as generators of qualified labor for productive systems. Education, however, provides a limited view on how universities interact with innovation systems and disseminate capabilities required for aggregate technology upgrading. Higher Education Institutions (HEIs) have themselves evolved to become entrepreneurial agents (Etzkowitz, 2004; Van Looy et al., 2011) and parts of knowledge networks embedded in innovation systems (Yoruk, 2013). This is mainly a function of the view that universities operate as sources of aggregate industrial

[1] The mechanisms through which this knowledge is disseminated, however, are not necessarily simple (Lundvall et al., 2002). We acknowledge this issue, even though a precise description of technology transfer dynamics is beyond the scope of this research.

competitiveness (Rosenberg & Nelson, 1994). Similar propositions can be found for productivity (Goldstein & Drucker, 2006; Martin, 1998) and technological performance in firms (Leten et al., 2014; Goldstein & Renault, 2004). These outcomes of academic research – coupled with stronger incentives for university-level R&D - can reduce domestic dependence on foreign sources of technology and promote the development of domestic capabilities (Chang et al., 2016; Spencer, 2001).

University-Industry links stand accordingly as a matter of intense interest. Positive feedbacks between universities and firms can foster economic development and catching-up processes (Mazzoleni & Nelson, 2007; Conceição & Heitor, 1999). Jensen et al. (2007) define this situation as a "Science & Technology mode of innovation". As a result, the "*interaction between science and industry is an important aspect of the innovation ecology*" (Caraça et al., 2009, p. 866). While this often happens via formal university-industry links (Cassiman & Veugelers, 2002), informal relationships also generate knowledge spillovers for companies (Yoruk, 2013). Ultimately, these relationships between universities and businesses are associated to innovation and economic development (Galan-Muros & Davey, 2017). Additionally, these effects can also manifest in benefits for students and their academic performance (Galan-Muros & Davey, 2017; Drucker & Goldstein, 2007; Strunz et al., 2003), thus affecting the quality of human resources generated by universities that develop close links with firms.

While this discussion is obviously of interest to developed economies, we argue for their critical importance to emerging nations. Dahlman et al. (1987) have proposed that institutions dedicated to research, education and training can play the role of specialized technological agents in developing countries' evolutionary processes. Moreover, the incipient nature of innovation systems in these countries (Albuquerque, 1999) grants universities a critical role in shaping overall capabilities in firms (Suzigan et al., 2009), even though systemic connections between academia and industry may still lack critical mass (Fischer et al., 2017).

Some recent evidence (Britto et al., 2015) points out that developing countries demonstrate a weaker participation of universities in the economic structure (measured through university-industry interactions), and that this can be associated to lower levels of overall economic development and innovative activity. This implies that the presence of key agents in innovation systems is insufficient for technology upgrading to take place: interactions matter. Nonetheless, there is still an insufficient body of knowledge on how universities in emerging nations are connected to developing countries' productive systems (Suzigan et al., 2009), making it hard to assert if the dynamics are similar to what has been observed in developed economies (Suzigan et al., 2009). This provides the motivation for the present analysis.

3. METHOD

Information is drawn from the twelve most preeminent research-oriented HEIs in Brazil for years 1994, 2004 and 2014. We classify these institutions according to the SCImago ranking[2] of academic institutions. Since research quality significantly affects the university's ability to engage with non-university actors (Laursen et al., 2011; Abramovsky, 2007), dealing with the most preeminent academic institutions is considered appropriate for assessing the dynamics of universities as agents of technology upgrading. This is also supported by evidence that positive effects in terms of technological capabilities arising from universities are mainly concentrated in those institutions with higher quality research (Cowan

[2] This ranking corresponds to a classification of academic and research-related institutions according to a composite indicator based on research performance, innovation outputs and societal impact (http://www.scimagoir.com/methodology.php).

& Zinovyeva, 2013). On the contrary, one would expect universities with lower research quality to have a limited contribution to the surrounding socioeconomic environment. The selected timeframe (1994, 2004 and 2014) allows capturing potential effects of the 2004 National Innovation Law, which regulates and sets incentives for academic technology transfer.

Key utilized indicators related to patenting activity, in accordance to the analytical framework developed in Jindra et al. (2015). Patents have been proven useful indicators of university linkages to innovation systems (Cowan & Zinovyeva, 2013; Cassiman et al., 2007) and as proxies for technology diffusion (Chang et al., 2016). In addition, there has been a substantial increase in academic patenting in recent decades (Leydesdorff & Meyer, 2007). Still, recognizing that patents proxy current technological activity but not stocks of capabilities (Archibugi et al., 2009) we focus on patenting trends over time.

In order to build a consistent picture of the participation of Brazilian universities to technological upgrading intensity, breadth and interaction with the global economy, we assess: i) domestic and international patents; ii) field and technological domains; and iii) networks of assignee/applicant. Data sources include Orbit Intelligence, World Intellectual Property Organization (WIPO), the Brazilian Patent Office, the Brazilian Innovation Survey (PINTEC) and the CNPq Research Group Directory carried out by the National Statistics Office.

A total of 807 patent applications with participation of at least one of the twelve institutions of interest was analyzed for three years: 1994, 2004, and 2014[3]. Patent for universities data was retrieved from Orbit Intelligence. Searches were performed for each individual university included in our sample (12 institutions) taking into account the declared assignees of applications. Analytical periods involved applications from January 1st until December 31st for selected years (1994, 2004 and 2014). As a search criterion for patent applications, we focused on the earliest publication date of documents, minimizing potential double counting of patents. Universities' acronyms were used in order to comprehend variations in applicants' names[4] (see Table 1 for the correspondence between names and acronyms).

After the patent selection procedures, each document was analyzed individually. For each patent we collected information on the office of application, IPC (International Patent Classification) and co-assignees. Table 1 summarizes the overall quantity of patent applications for each university/year of interest.

Table1. Patent applications for each University/Year.

University	Acronym	1994	2004	2014
University of São Paulo	USP	3	39	112
University of Campinas	UNICAMP	8	73	83
Federal University of Rio de Janeiro	UFRJ	0	35	35
State University of São Paulo	UNESP	1	9	42
Federal University of Rio Grande do Sul	UFRGS	0	13	47
Federal University of Minas Gerais	UFMG	0	26	89
Federal University of São Paulo	UNIFESP	0	1	0
Federal University of Santa Catarina	UFSC	0	3	20
Federal University of Paraná	UFPR	0	6	65
Federal University of Pernambuco	UFPE	0	7	26
Federal University of São Carlos	UFSCAR	0	7	30
University of Brasília	UnB	0	1	26
	TOTAL	**12**	**220**	**575**

[3] Data for each year includes all patent applications deposited from January 1st until December 31st.
[4] Universities' names appeared in different languages, while acronyms remained constant.

Social Network Analysis (SNA) allowed in-depth understanding of interactions between universities and industry (a vector of both knowledge creation and dissemination within the productive system) as per co-patents. A co-patent is a patent applied for by two or more actors. Generally, this is a sign of innovation-based cooperation activity. Concerning the evaluation of social networks, patent data with focus on universities represent a *one-mode* perspective (Wal & Boschma, 2009). Also, besides the cross-section nature of our sample, we analyze universities over time (longitudinal analysis for years 1994, 2004 and 2014), allowing to capture structural changes in social ties related to co-patenting. Network structures were built with the Pajek Package.

4. RESULTS

Preliminary results indicate that the most preeminent research-oriented universities in Brazil are responsible for a substantial amount of patenting activity in the country. According to the Brazilian Patent Office (INPI), six among the ten most active players in terms of patent generation are universities[5], a trend that widely differs from what is observed in developed economies. Moreover, the top twelve academic institutions in the country have enhanced their share of patenting from 0.45% in 1994 to a 8.57% share in 2014[6].

Nonetheless, these institutions are still regarded by firms as marginally important for their innovative processes. In aggregate terms, the latest Brazilian Innovation Survey, carried out in 2014, identifies that only 2.3% of innovating firms in the country have recognized universities as strategic partners for innovation processes. Previous editions of this survey demonstrate a stagnant trend in this item. As a result, the chasm between academia and industry seems to hamper a faster diffusion of knowledge in the country, arguably affecting technology upgrading processes. Moreover, the main universities in Brazil still present a rather domestic-oriented focus on patenting, providing signs of the slow pace of improvement on technological activity in this country.

Another point of concern is that Brazilian Science and Technology activities are concentrated in the South-Southeast axis (Suzigan et al., 2009). This corresponds to the geographic distribution of the twelve institutions in our sample (map 1[7]). Hence, one can expect impacts exerted by these universities in terms of technology upgrading to be somewhat restricted to more developed regions, reinforcing the existing economic geography of the country.

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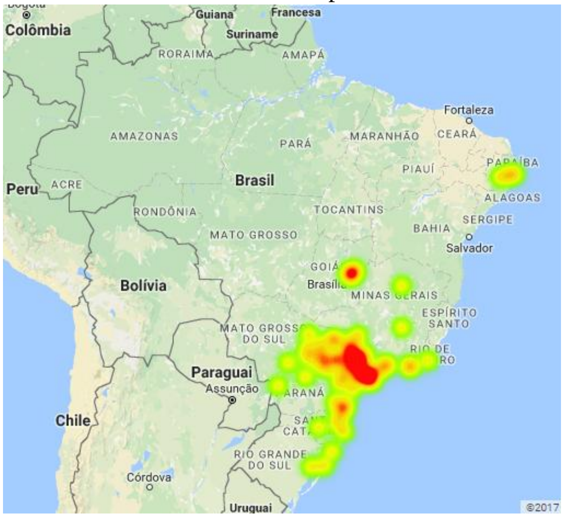
[5] http://revistapesquisa.fapesp.br/2016/11/18/protagonismo-incomum/ (in Portuguese).
[6] Patents with at least one Brazilian inventor.
[7] The map considers all of the multiple campuses of each university included in our sample.

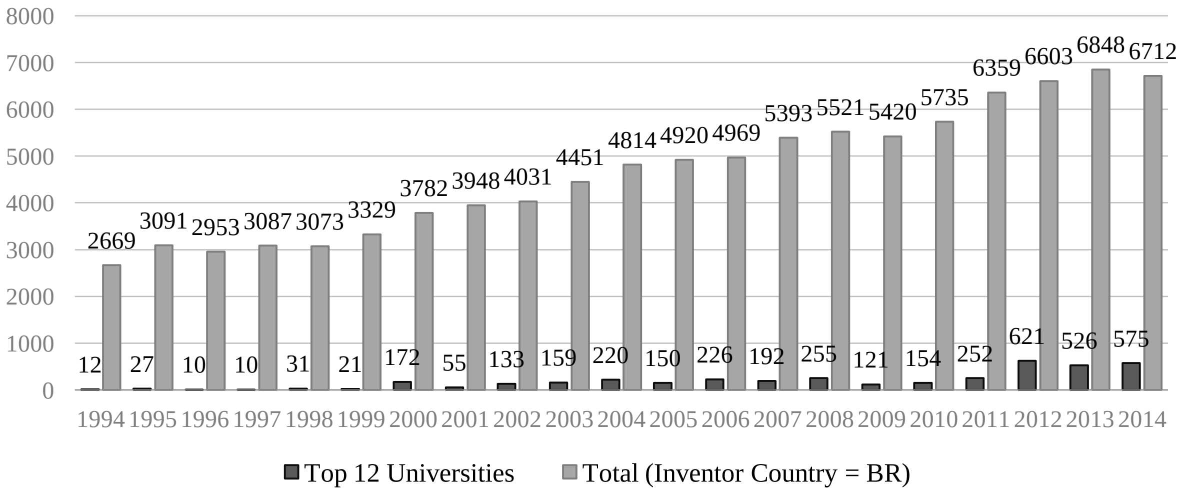
Map 1. Zones of influence of the top-12 Brazilian universities.



A second description of the sample is offered in Graph 1. There, we verify the weight of the top twelve Brazilian universities vis-à-vis the overall patenting activity (domestic and international applications) including as inventor at least Brazilian resident. We used the focal periods of analysis (1994, 2004 and 2014) as references for this introductory assessment. The complete series is presented (1994-2014). Even though it can be noticed that there has been a remarkable increase in total patenting activity in Brazil (domestic and international), absolute numbers remain extremely low when compared to the reality of developed nations. Nonetheless, the weight of the top twelve universities is remarkable.

In contrast, although developed economies present increasing levels of academic patenting in recent decades, universities are still marginally relevant in this indicator (Blind et al. 2006; Geuna & Nesta 2006). The analysis of the Brazilian sample of key institutions reveals a completely different picture in terms of academic weight in overall patenting activity. This is more striking considering we are dealing with data from a dozen units. This feature of the sample correspond to our expectation that universities in developing countries stand for strategic agents in triggering technology upgrading processes.

Graph 1. Participation of top-12 Brazilian universities in total patenting activity (1994-2014).



4.1 Brazilian Universities and the Pillars of Technology Upgrading

The next step in organizing the top twelve Brazilian universities' data on patents according to the established measures of technology upgrading that can be assessed for this sample: i) domestic and international patents; ii) field and technological domains; and iii) networks of inventors. Firstly, table 2 brings a description of the universities according to the three pillars of our analysis.

Table 2. Measures of technology upgrading.

	1994	2004	2014
Intensity of technology upgrading			
Domestic	11	200	494
International	1	20	81
Breadth of technology upgrading			
Field and technological domains (IPC-code)[a]			
Human Necessities	5	93	258
Performing Operations; Transporting	1	27	92
Chemistery; Metallurgy	5	98	214
Textiles; Paper	1	2	7
Fixed Constructions	0	6	11
Mechanical Engineering; Lighting; Heating; Weapons; Blasting	0	3	6
Physics	1	35	81
Electricity	0	19	29
Herfindahl-Hirschman Index (HHI)[ba]	.796	.181	.178
Interaction with global economy			
Co-patents	3	47	203
International co-patents[c]	1	7	21

Notes: [a]Some patents do not have information on technological domains, while other are assigned to more than one area of knowledge.

[b] HHI was calculated based on the subfield of technological domains containing the 23 subareas with patenting activity for our sample.

[c]This indicator represents only how many co-patents were deposited with international partners. However, the number of interactions may differ from this data because each application could consist in multiple interactions.

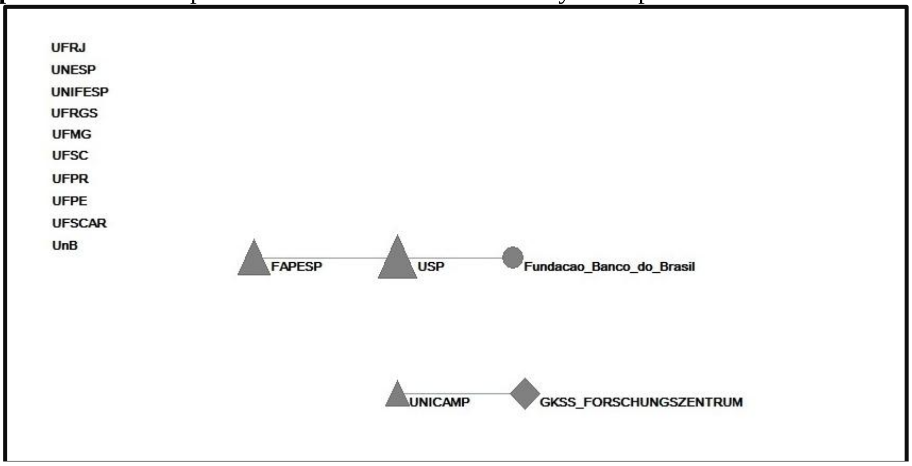
As per these outcomes, the academic system under analysis presents weaknesses related to: i) intensity of technology upgrading and; ii) interactions with the global economy. As descriptive results have highlighted, the levels of patenting activity for the Brazilian Innovation System in general are low. This trend is also present in academia, a backbone of the Brazilian patenting scenario. Additionally, academic co-patenting is strongly inward-oriented, involving both a lack of connections with agents abroad and with MNEs with subsidiaries in the country.

A third aspect related to the breadth of technology upgrading in this sub-sample of the Brazilian academic environment is related to a lack of diversification in the application of patents. Inventions are concentrated in only two broad technological domains: Human Necessities and Chemistry & Metallurgy. However, when technological sub-areas are introduced in the analysis, the Herfindahl-Hirschman Index demonstrates a relative deconcentration process in patenting activity. Illustratively, technological specialization – reaching a value of 0.796 in 1994 – was reduced to .178 in 2014. This findings can be deemed as positive, as catching-up process from idle to high-income status is permeated by the diversification of technological knowledge (Lee, 2013).

Digging deeper into the structure of co-patenting networks involving our focal group of Brazilian universities we develop a SNA. Emphasis reside in the characteristics of connections, i.e., the nature of agents (companies, other universities, research institutes and research support institutions) and their respective origin (domestic, multinational subsidiaries or foreign entities). For each of the twelve universities of interest, the portfolio of patents was addressed in detail to identify co-patenting activity. Then, each agent involved in co-patenting was categorized for each university/year (1994, 2004 and 2014). In the representation of social networks, the size of symbols reflects the degree of centrality of each agent (absolute number of collaboration in patent deposits for each agent). Distinctive symbols are also used as markers for each kind of agent included in the analysis. Triangles comprehend domestic Universities and Research Foundations & Institutions. Diamonds identify these same agents that are located abroad. Circles represent Brazilian firms. Boxes stand for multinational[8] and foreign corporations. Lastly, indicators of network density and centrality.

The dataset reveals that Brazilian universities have a low level of interaction with industry[9], as demonstrated in graphs 2, 3 and 4. A first assessment of social networks in 1994 underscores the scarcity of co-patenting involving the top twelve Brazilian universities. This can be related to small numbers in overall patents with university applicants in this particular year (twelve in total). The only institutions among the top 12 academic units in Brazil that appear in this graph are the University of São Paulo (USP) and University of Campinas (UNICAMP). The latter one was the sole agent to engage in transnational patenting activity.

Graph 2. Network of patent collaborations established by the top 12 Brazilian universities – 1994.

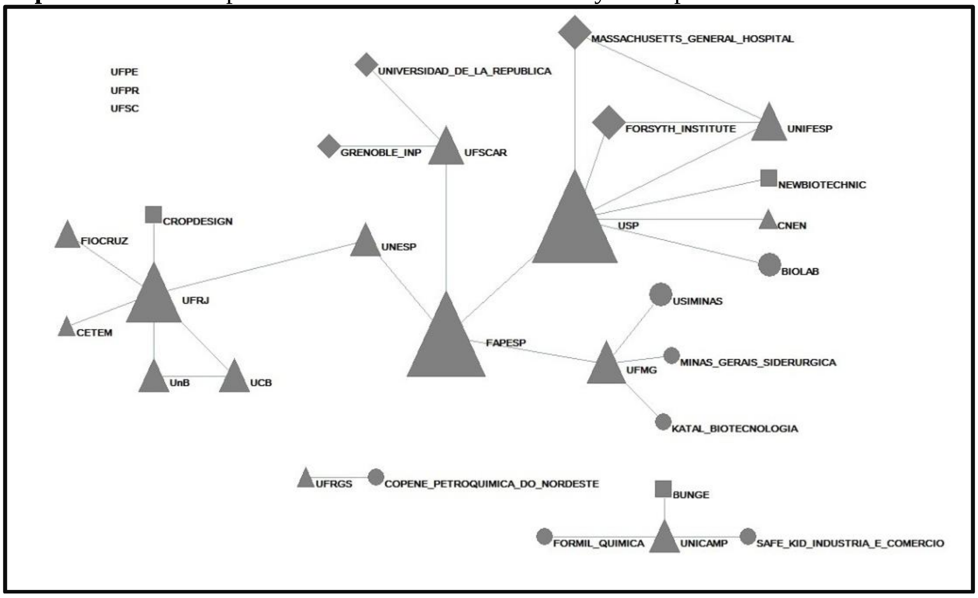


The evaluation of networks in 2004 demonstrate an evolution in the context of the Brazilian System of Innovation (graph 3). Differently from 1994 – when 10 out of 12 universities did not engage in co-patenting – in 2004 we notice that only 3 of these institutions are left out of the graph. Nonetheless, even if this network appears to be denser, interactions with multinational companies and other agents located abroad are marginal: 3 Multinationals and 4 Universities and Research Foundations & Institutions are included in graph 3. Moreover, we might highlight the central role played by the São Paulo Research Foundation (FAPESP), which interacts not only with universities from its state (São Paulo), but also with the Federal University of Minas Gerais (UFMG).

[8] With subsidiaries in Brazil.

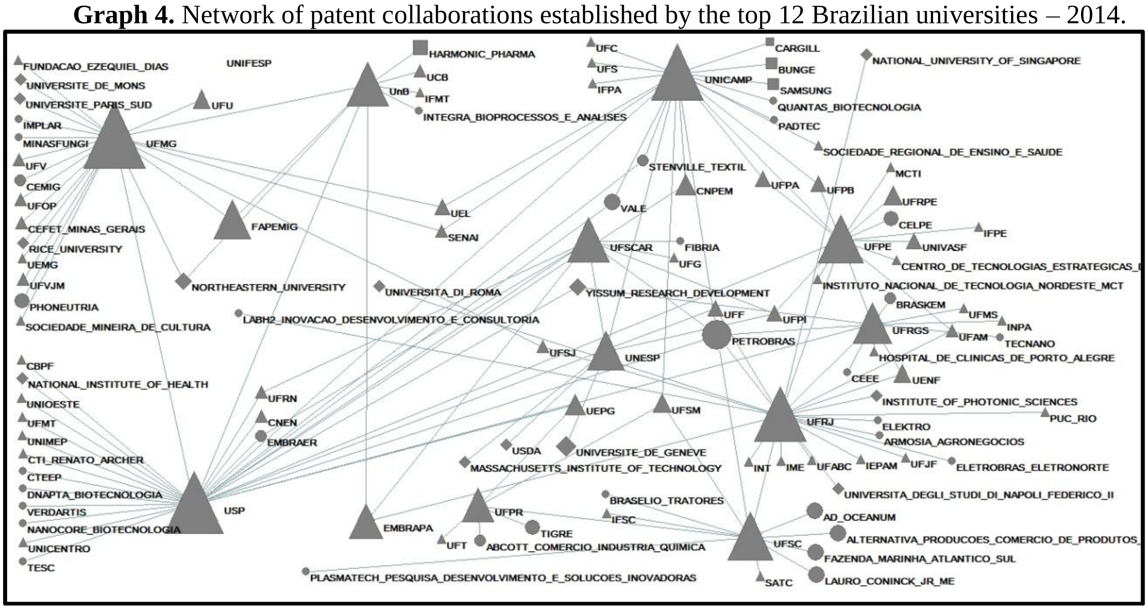
[9] Cooperation in patents is mainly oriented towards networks with other academic institutions and Research Foundations.

Graph 3. Network of patent collaborations established by the top 12 Brazilian universities – 2004.



The 2014 network is clearly denser than what was observed for previous periods. Only one university in our sample is not included in this analysis. Over the last decades, noticeable advances can be perceived as per the role of Brazilian academic institutions as central agents in processes involved in technology upgrading dynamics. The University of São Paulo (USP), University of Campinas (UNICAMP), Federal University of Rio de Janeiro (UFRJ) and Federal University of Minas Gerais (UFMG) stand out in terms of interactions in patenting activity. However, only 25 out of 268 identified collaborations are related to Multinationals or other entities located abroad. The remaining 243 interactions are based predominantly in relationships with other domestic universities or research institutes. This is as aspect that underscores the domestic orientation of Brazilian academia.

Graph 4. Network of patent collaborations established by the top 12 Brazilian universities – 2014.



Indicators presented in table 3 provide evidence supporting our interpretations of graphs. The average number of interactions per university evolved from 0.53 in 1994 to 4.58 in 2014.

Even though the growth pattern of this dimension was stronger between 1994 and 2004, in 2014 we verify that only one university among the top 12 Brazilian institutions was isolated in terms of patenting activity.

Table 3. Indicators of centrality and density - 1994 / 2004 / 2014.

		1994	2004	2014
Average Degree Centrality		.53	3.29	4.58
Density (no loops allowed)		.0381	.1097	0.0394
Closeness Centrality	Mean	.05	.17	.31
	Std. Dev.	.0708	.0865	.0525
Betweenness Centrality	Mean	.00	.04	.02
	Std. Dev.	.00	.0897	.0648

The density indicator is defined by the sum of all existing connections divided by the number of possible connections amongst agents. In 1994, only 3.84% of possible connections were effectively established. This number goes up to 10.97% in 2004, but it is reduced to 3.94% in 2014. This latter feature of the sample, however, carries with it the abovementioned increase in the total number of different interacting partners involved in networks with our focal group of universities. This aspect helps explaining this apparent involution in observed trends, since the closeness centrality indicator is based on the total distance between one vertex and all other vertices, where larger distances yield lower closeness centrality scores (Nooy et al., 2005). So, the progressive increase of outcomes respective to this indicators' mean value between 1994 (.05) and 2014 (.31) suggests a considerable reduction in terms of distances among different agents participating in the network. The betweenness centrality indicator is the proportion of all geodesics between pairs of other vertices that include this vertex. In other words, it indicates if there is a specific agent with the power to play a centralized role within the dynamics of connections established among the remaining set of participants. The low observed values in years 1994, 2004 and 2014 underscore the inexistence of such central entities.

To delve deeper into these results, some contextualization is necessary. Data from the 2003 Brazilian Innovation Survey (PINTEC) (Appendix I) show that, in Brazil, about 1.96% (551 out of 28,036 innovative companies) of the innovative sample develop interactions with universities and research institutes. More importantly, two thirds of these firms (65.3% or 360 companies) establish R&D-oriented activities (instead of technical, training and consulting forms of cooperation). In 2014, the numbers of companies establishing UIC has grown significantly. About 7.20% (3,432 out of 47,693 innovative companies) of the innovative sample interact with universities and research institutes, but only about half of these firms (54.8% or 1,882 companies) establish R&D-oriented activities. Furthermore, in the last data, more than three quarters of companies with collaborative processes (73.5% of 7,299 firms) believe UIC to be of little or no importance for innovative processes.

Data obtained from the Brazilian Census on Research Groups corroborate these propositions (Appendix II). In 2002, universities' research groups presenting interactions with industry represented 8.4% of the total sample (1,279 out of 15,158 research groups), while figures for 2014 highlight an increase in this value to 26.4%. However, despite this substantial expansion in interacting research groups, the evolution in R&D-oriented collaboration has been marginal, representing about half of relationships throughout the analyzed period.

In its turn, the low density observed for the networks developed in this research - along with the scarcity of co-patents (particularly with multinational companies) - ratify the Brazilian landscape of scant interactions between academia and industry. This is even more pronounced for the case of high-quality, R&D-oriented collaborations. These are the sorts of relationships that enable leveraging patent activity with firms, allowing universities to reach out to markets and transfer technology more effectively.

Lastly, the results also suggest that the generation of knowledge (as measured through patenting activity) may have a restricted reach to local markets. Also, networks with multinational companies is rare. As this is a potential conduit for technology upgrading, academic research efforts in Brazil might not be on their way to generate the overall economic benefits that are desirable for the evolution of the National System of Innovation. For instance, university-industry links in developed economies present a marked international orientation (Leydesdorff & Sun, 2009).

5. CONCLUDING REMARKS

Implications of this study should help guiding institutional adjustments that create incentives and promote the integration of a broader spectrum of research-oriented universities into Global and National Value Chains. By embedding academia into productive systems, emerging and transition economies may be able to boost intensity and breadth of technology upgrading and innovative activity (Caraça et al., 2009; Klofsten & Evans, 2000; Cohen et al., 2002). In its turn, universities may disseminate this knowledge via human capital and technology transfer activities.

This is not a straightforward process that happens mechanistically over time. In fact, technology upgrading takes place slowly (Radosevic & Yoruk, 2014) and depends strongly on adequate institutional settings. To include universities as central agents in this process can be a strategic step for innovation policy, but it involves systemic coordination and paradigm shifts in the way academia is perceived (by itself and by external agents) in developing economies. Even though our empirical argument supports the centrality of higher education institutions in the Brazilian S&T system, the relative participation of universities can be regarded as high because of small absolute numbers of patents, and not due to a structural strong technological activity in the academic context.

Nonetheless, the evolution of technology upgrading processes in Brazil from the university perspective is rather recent and it has presented noticeable evolution. Due to the embryonic stage of innovation systems in emerging economies in general, it seems fair to hypothesize that the function of academic institutions in shaping the innovation environment can be significant. Thus, these agents shall play the role of backbones of the knowledge economy by helping to generate and diffuse knowledge and technological capabilities. Notwithstanding, the sample is constituted entirely by public institutions. This can represent a threat for sustained contributions from these universities to the Brazilian Innovation System as economic crisis affect funding and research budgets. For instance, the Federal University of Rio de Janeiro has faced severe financial constraints in 2016, an issue that had substantial negative impacts on ongoing research projects. This was the most relevant case, but budgetary constraints are currently taking place in all of the units included in our sample.

These initial insights have some limitations that should be taken into account. For instance, do the analyzed patents capture technology upgrading *per se* or are they representations of institutional efforts to increase patenting activity in universities without thorough concerns for quality (Archibugi et al., 2009)? This is an aspect that is often raised when assessing incentives for productivity indicators. In Brazil, the 2004 Innovation Law may have had significant impacts in terms of patent indicators, but patent quality is by no means warranted. This could represent a possible explanation for why university-industry interactions are significantly marginal for firms' strategies. Deeper empirical analyses on the content of such inventions represents an important avenue for future research when evaluating the connection between academic institutions and technology upgrading processes.

Appendix I. Brazilian Innovation Survey (PINTEC): UIC trends in Brazil from the companies perspective

PINTEC	Total Companies in the Survey	Innovative Companies	Companies with Collaborative Processes	Companies with UIC	UIC Object (Only Companies with UIC)		UIC Importance (Companies with Collaborative Processes)		
					R&D activities	Others	High	Medium	Low/No relevan.
2003	84,262	28,036	1,052 (3.76%)	551 (1.96%)	360 (65.3%)	191 (34.7%)	188 (17.9%)	124 (11.8%)	740 (70.3%)
2005	91,055	30,377	2,194 (7.22%)	777 (2.56%)	341 (43.9%)	436 (56.1%)	432 (19.7%)	256 (11.7%)	1,506 (68.6%)
2008	106,822	41,223	4,248 (10.31%)	1,759 (4.27%)	1,028 (58.4%)	732 (41.6%)	829 (19.5%)	477 (11.2%)	2,942 (69.3%)
2011	128,699	45,950	7,694 (16.74%)	3,405 (7.41%)	1,850 (54.3%)	1,555 (45.7%)	1,431 (18.6%)	826 (10.7%)	5,437 (70.7%)
2014	132,529	47,693	7,299 (15.30%)	3,432 (7.20%)	1,882 (54.8%)	1,551 (45.2%)	1,098 (15.0%)	840 (11.5%)	5,361 (73.5%)

Appendix II. Brazilian Census from the CNPq Research Group Directory: UIC trends in Brazil from the universities perspective

Census	Research Groups	Interacting Research Groups	Cooperating Firms[10]	R&D-oriented Collaborations	Training and Consultancy-oriented Collaborations	Total[11]	% of R&D-oriented Collaborations
2002	15,158	1,279	1,791	2,615	3,514	6,129	42.66%
2004	19,470	2,151	2,768	4,143	5,519	9,662	42.88%
2006	21,024	2,509	3,352	4,521	5,825	10,346	43.70%
2008	22,797	2,726	3,865	4,549	5,874	10,423	43.64%
2010	27,523	3,506	4,995	5,808	7,305	13,113	44.29%
2014	35,424	9,348	7,913	14,204	14,042	28,246	50.29%

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[10] Cooperating firms are computed according to each established UIC. Hence, if a company cooperates with several groups it will be counted for each one of these links.

[11] The number of collaborations exceeds the number of companies and research groups because each company can establish up to 3 different kinds of UIC agreements with each group.

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