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MATRICES OF SCIENCE AND TECHNOLOGY INTERACTIONS AND PATTERNS OF STRUCTURED GROWTH: IMPLICATIONS FOR DEVELOPMENT

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MATRICES OF SCIENCE AND TECHNOLOGY INTERACTIONS AND PATTERNS OF STRUCTURED GROWTH: IMPLICATIONS FOR DEVELOPMENT[(&)]

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SUMÁRIO

ABSTRACT

Scientific and other non-patent references (NPRs) in patents are important tools to analyze interactions between science and technology. This paper organizes a database with 514,894 USPTO patents granted globally in 1974, 1982, 1990, 1998 and 2006. There are 165,762 patents with at least one reference to science and engineering (S&E) literature, and there are 1,375,503 references. In 2006 there are 83 countries with USPTO patent citing S&E literature. Through a lexical analysis 71.1% of this S&E literature is classified by S&E fields. These data underscore the elaboration of global and national tri-dimensional matrices (by OST technological domains, ISI science and engineering fields and number of references). Descriptive statistics investigate how science and technology linkages differ over time across countries and across levels of development. This paper highlights how the existence (or not) of a pattern of structured growth differentiates mature and immature systems of innovation.

Key-words: science and technology linkages, stages of economic development, systems of innovation.

JEL Classification: O, O3

INTRODUCTION

Patterns of structured growth are unveiled in this paper, through inter-temporal comparisons among matrices of science and technology interactions. These patterns of structured growth differentiate developed and under-developed countries. The maturing of a country's national system of innovation might be a precondition for the formation of a structured growth pattern.

Matrices of science and technology interactions are built upon scientific and technical literature cited in USPTO patents. [1] This research tool was developed by Narin et al (1985 and 1997) and there is already a huge literature on this subject (for reviews, see Tijssen et al, 2000; and Callaert et al, 2006).

The identification of patterns of structured growth results from three original contributions of this paper: 1) a focus on less-developed countries, since this paper organizes data for the whole world, furthermore enabling a comparison between developed and non-developed countries; 2) the non-patent references analyzed involve both S&E ISI-indexed papers and scientific and technical literature that includes papers presented in congress and technical reports prepared by companies (this is important to evaluate S&E literature cited in patents from less-developed countries, as they might be less science-based vis-à-vis more developed countries); 3) this paper suggests four indicators to analyze these data, specially to grasp the main implications of these statistics for development processes and for less-developed countries: i) Matrix Fulfillment Index (MFI); ii) Matrix Height Index, iii) Matrix Rugosity Index; and iv) Inter-temporal Correlation between Matrices of science and technology interactions.

These Inter-temporal Correlations are the basis for the identification (or not) of a pattern of structured growth.

This paper is based upon a rich literature on patents citing scientific papers and other non-patent references as tools for evaluating science and technology linkages. The matrices prepared for this paper are meaningful, for the evaluation of science and technology linkages, because there is previous work investigating and supporting their significance. As a summary of a broad review, Tijssen et al (2000, p. 398) put forward: "On the whole, this new body of evidence confirms that front page NPCs (non-patent citations) represent explicit connections between scientific research and technological innovation and as a consequence can be used as reasonable valid information source of science-technology linkages". In another broad review of the literature Tijssen (2004, p. 704) stresses that the "connections reflected by citations" are "appropriate for statistics on the interactions between science and technology".

The data related to science and technology literature are used by institutions as the National Science Foundation in their statistical publications at least since 2002. These NSF publications present a topic on "Citations in US patents to scientific and technical literature" (see NSB, 2002, pp. 5.52-5.55; 2004, pp. 5.51-5.54 and 2006, pp. 5.48-5.50). The European Commission (2003) also uses these data.

[1] We use science and technology literature following the *Science and Engineering Indicators* (see NSB, 2006, p. 5-46). This expression is a synonym for NPR, NPC and S&E literature. This expression is a broader set than S&E papers and/or S&E ISI-indexed papers.

Basic statistics provided by these data and by this literature highlight an important phenomenon for modern development: there has is an increasing scientific content of technologies over time (Narin et al, 1997). This finding has deep impact on development and on public policies that would support economic growth.

The matrices of science and technology linkages presented by this paper are prepared using a database with 514,894 USPTO patents granted in selected years (1974, 1982, 1990, 1998 and 2006) and their 1,375,503 science and technical references.

This database shows that between 1974 and 2006 the number of countries with USPTO patents citing NPRs more than doubled – this leads to a question about how the development process may be affected by this increasingly scientific content of technologies. In 2006, 44% of USPTO patents had NPRs and 83% of countries with UPTO patents had NPRs. However, the concentration of these NPRs in a small set of countries has been reported by the literature: in 2003, 17 countries (USA, EU-15 and Japan) had 90.7% of USPTO patents citing ISI-indexed papers (NSF, 2006, p. 5-53).

This (uneven) international diffusion of this pattern of science and technology linkages provides the key motivation of this paper. The objective is to evaluate a broader set of countries, as an attempt to identify similarities and differences between developed and underdeveloped countries. These data and the indicators suggested in this paper introduce an evaluation about how and why levels of development matter for science and technology linkages (and vice-versa).

A first look at selected matrices of science and technology interactions would indicate how useful they may be for development issues.[2] These matrices are tri-dimensional: 1) in axis X there are 30 OST technological domains; 2) in axis Y there are 27 ISI S&E fields; and 3) in axis Z there is the number of S&E literature citations in patents in each matrix cell (section III details how these matrices are built).[3]

As an example, Figure 1 shows the 2006 matrices for United States, Brazil and Indonesia (at large, each country represents a different level of development). These three countries are selected because in a previous work (Ribeiro et al, 2006) they were in three different "regimes of interaction between science and technology".

[2] Previous utilization of compacted version of these matrices are Narin et al, p. 321; Tijssen et al (2000, p. 406), Verbeek et al (2002b, pp. 30-37), and Callert et al (2006, p. 17).

[3] For the list of corresponding numbers of OST technological domains and ISI S&E fields, see Appendix.

FIGURE 1

Matrices for countries at different stages of development
USA, Brazil and Indonesia, 2006

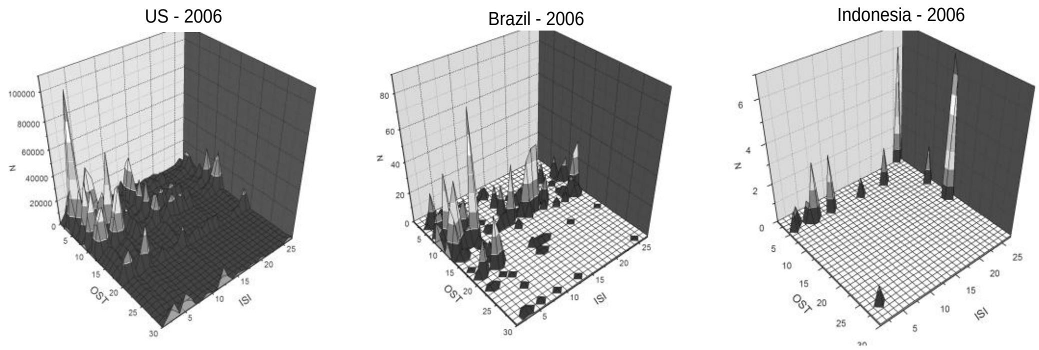


Figure 1 shows how these three matrices are different regarding the fulfillment of its floor (see cells in the x y axis), and regarding the height of the columns (the z axis). The spread and strength of the interactions between science and engineering fields and technological domains shown by these matrices provide qualitative information that complements and enriches the quantitative information provided by patent statistics. Figure 1 informs that the differences among USA, Brazil and Indonesia are not limited by the quantity of their patents, but refer also to the quality of their patents.

Figure 1, on the one hand, indicates how these matrices may be powerful indicators of different levels of development. On the other hand, Figure 1 hints how different levels of development are correlated with the nature, quantity and quality of their interactions between science and technology.

Therefore, Figure 1 suggests that these matrices can shed new light to understand a contemporary agenda for development. This is the broader goal of this paper.

The specific contributions of matrices of science and technology interactions are explored in section I through a comparison with other available tools for investigations on this subject. Section II shows the data, explains the preparation of the database and presents a preliminary statistical description. Section III presents the matrices, investigates how they evolve over time and suggests indicators to evaluate them, therefore preparing the ground for inter-country and inter-temporal comparisons. Section IV presents data and these indicators for 13 countries, selected to represent qualitative differences such as size, economic development and technological trajectories. From the analysis of these data and indicators, section V discusses the key finding of this paper – patterns of structured growth. Finally, section VI concludes this paper exploring public policies implications and an agenda for further research.

I. THE SPECIFIC CONTRIBUTIONS OF MATRICES OF SCIENCE AND TECHNOLOGY LINKAGES

The theoretical foundations of this paper come from the National Systems of Innovation approach (Freeman, 1995; Nelson, 1993; Lundvall, 1992) and specially from the role of universities and research institutions within this system (Mowery and Sampat, 2005).

Previous papers (Bernardes and Albuquerque, 2003; Ribeiro et al, 2006) put forward the importance of interactions between science and technology for development. Ribeiro et al (2006), for instance, suggest that as one country develops, the number and the channels of interactions between scientific infrastructure, technological production and economic growth also change. As the country evolves, more connections are turned on and more interactions operate. From this standpoint, a developed country is in a regime where all connections and interactions between science and technology are working. As long as the development takes place, the role of other aspects, e.g. natural resources, decreases in the causation of economic growth. As a country upgrades its economic position, its economic growth is increasingly caused by its scientific and technological resources. The feedbacks between them contribute to explain why the modern economic growth is fuelled by strong scientific and technological capabilities.

Mazzoleni and Nelson (2007) show how throughout a catching up process the interactions between universities and research institutions with industry are key for success. This paper is a very good summary of a literature that discusses the role of interactions between science and technology for development.

This literature, therefore, suggests that investigations on interactions between science and technology are important. What are the available tools to evaluate these interactions? In a brief summary, there are at least seven different approaches and tools.

First, there are lessons from history (Rosenberg, 1974 and 1982).

Second, there are case studies of technologies, inventions, technological transfer from universities and research institutes to firms (Freeman and Soete, 1997; Colyvas et al, 2002).

Third, there are investigations on patents from research institutes and papers from firms (Schmoch, 1997).

Fourth, there are surveys that investigate how firms use and value knowledge flows from universities and research institutes (Klevorick et al, 1995; Cohen et al, 2002).

Fifth, there are statistics and surveys on research groups located in universities and public institutes that investigate how these groups interact with firms (Rapini, 2007).

Sixth, there are studies based on geographical co-localization of patents and papers (Zitt et al, 2003), line of inquiry that previous work from our research group may be located (Ribeiro et al, 2006).

And finally, there are the investigations related to non-patent references in patents (Narin and Noma, 1985; Narin et al, 1997; NSF, 2002, 2004 and 2006; Verbeek et al, 2002b; Callaert et al, 2006).

As there are these seven different approaches to interactions between science and technology available, one important research subject is to know the strengths and weaknesses they have, to use them adequately.

What are the contributions of the analysis of non-patent for the investigation of science and technology linkages? The main goal here is not a survey in itself (there are excellent surveys available to the reader, as Tijssen, 2004 and Callaert et al, 2006), but to stress the points of this huge literature that underlie this paper's arguments.

The pioneering works are Narin and Noma (1985) and Narin et al (1997), since they suggest how citations in patents to scientific literature could be used to investigate science and technology links and present the first investigation about connections between selected S&E fields and selected technological sectors.

This literature classifies non-patent references into several categories and in different ways. The National Science Foundation divides them in two broad categories: S&E literature and S&E articles. "Citations to S&E papers are references to S&E articles in journals indexed and tracked by the ISI's Citation Index. Citations to S&E literature are references to S&E articles within and outside ISI's coverage and non-article material such as reports, technical notes, conference proceedings etc" (NSB, 2004, p. 5.51). Tijssen et al (2006, p. 10-15) take a "closer look at the nature of non-patent references" and show that, within USPTO patents, 55% of NPRs are journal references, and that non-journal references are divided between conference proceedings (17%), industry-related documents (25%), books (13%), reference books/databases (10%), patent-related documents (15%), research/technical reports (6%), newspapers (5%) and unclear/other references (7%). Tijssen et al (p. 15) concludes this detailed document analysis stressing that "at 42% of USPTO non-journal references refer to scientific knowledge. In addition…., a further 40% of non-journal references relates to technical information". Therefore, there are other important sources of scientific and engineering/technical knowledge beyond the set of ISI-indexed S&E articles. One of the original contributions of this paper is to use information beyond the S&E articles indexed by ISI, which is the usual way in this literature.

Researchers in this field have investigated to what extend these citations of science and engineering literature could really express linkages and interactions between science and technology. Schmoch (1997) is a cautious evaluation on potential and limitations of these data. Tijssen et al (2000, p. 396) investigate the "rationale underlying the choice of these citations by applicants and examiners". For them, one of the "key questions involved is to what extent these NPCs actually measure the 'science-intensity' of patented innovations. Their answer is "[a]t the aggregate level the answer appears to be yes".

Papers more focused in specific countries (Guan and He, 2007, for China; Tijssen et al, 2000, for Netherlands),ion industrial sectors (Bhattacharya and Meyer, 2003, for thin films), and in geographical flows of knowledge (Verbeek et al, 2003) indicate the potential application of this research tool for a broad range of subjects.

This literature highlights a very important point for this paper: the key role of domestic scientific capabilities to technological capabilities. Narin et al (1997, pp. 321-322), summarizing the "overall linkage characteristics", presents data supporting the "strong national component" of this science and technology linkage. As Narin et al stress, the analysis shows "the strong domestic component that exists in science linkage, showing that each country's inventors are preferentially building upon their own domestic science" (1997, p. 322). Tijssen (2004, p. 704) refers to Narin et al (1997) to comment on the "existence of domestic self-citation propensities in all major countries – i.e., a relatively large share of citations, in the range of two to four times more than statistically expected, refer to research papers originating from the same country. This so-called 'domestic bias' in patent citations relations of this magnitude clearly indicates localized knowledge flows, suggesting relatively strong interactions between scientific and technological progress as well as cumulative effects in knowledge creation and dissemination in regional or national R&D systems and innovation systems". This trend is also discussed in the prestigious *Science and Engineering Indicators*: "[e]xamining the share of cited literature in the United States, Western Europe, and Asia adjusted for their respective shares of scientific literature reveals that inventors favor their own country or region" (NSB, 2002, p. 5-54). These findings are very important for a discussion about the implications for development processes.

Finally, Callaert et al (2006, p. 16) in a broad overview of this literature, indicate the usefulness of this research tool: "[i]t goes without saying that, once non-patent references have been identified, science intensity can be disentangled in a substantive manner. Scientific disciplines, as well as affiliations of the authors and institutions involved, can be introduced in subsequent analysis. Linking the technology domain of citing patent to the science field of the cited publication, for instance, results in matrices that represent the presence of specific scientific disciplines and that relate them to different technological domains" (p. 16).

This brief review of the literature supports the use of matrices of science and technology linkages as a tool for the subject of this paper. This paper, as already mentioned, is based upon this literature.

Furthermore, there is a major advantage of these matrices vis-à-vis the other tools for investigation of science and technology interactions: they offer a broad inter-country and inter-temporal comparability. No other research tool is available for international comparisons as the matrices of science and technology linkages. Therefore, this is the research tool that fits to this paper's goals.

II. DATA , DATABASE, METHOD, AND A STATISTICAL DESCRIPTION

The database prepared for this paper consists of 514,894 USPTO patents granted in selected years: 59,669 were granted in 1974, 55,610 in 1982, 87,805 in 1990, 142,478 in 1998 and 169,332 in 2006 (see Table 1).

The first step for the preparation of this database was the elaboration of software-program to search and download all USPTO patents from 1974, 1982, 1990, 1998 and 2006 (www.uspto.gov).

This software collected the following fields for each patent: 1) USPTO patent number; 2) First inventor's country (if from the USA, the first inventor's state); 3) Assignee's name; 4) Assignee's country (if from the USA, the assignee's state); 5) Application date; 6) Issue date; 7) USPTO patent number of each US patent cited; 8) Other references cited by the patent (these are the non-patent references); 9) US classification code (class and subclass).

The data collection took place between December 2006 and March 2007.

The second step was the preparation of the database, with all necessary adaptations to correct and organize countries' names, adjust state codes and country codes, and the necessary checks for errors and problems. At this stage preliminary statistics could be generated.

The third step was the preparation of the matrices, one per country and per year.

To define the technological domains, the starting point was the US classification code (class and subclass). An algorithm converting the US classification into the 30 technological domains adopted by the *Observatoire des Sciences et des Techniques* (OST), available at www.obs-ost.fr (OST, 2006, p. 426). [4]

To define the science and engineering fields a more complex process was necessary. The method for conversion of non-patent references into the 27 S&E fields defined by the *Institute for Scientific Information* (ISI) involved a lexical analysis (Bassecoulard, 2004). For this analysis, a dictionary was built, connecting chosen key words and/or expressions to each of those 27 S&E fields.[5] Later a software-program that reads each word in the patent cited references to S&E literature was prepared. Basically this software-program reads each non-patent reference and search for registered key words and/or expressions filed in the dictionary. When it finds in the reference a word registered in the dictionary it imputes this reference to the corresponding S&E field. This software-program enables us to identify the S&E field of all references. This algorithm was reasonably efficient, since it identified the S&E field of 79% of the 1974 references, 75% of 1982, 75% of 1990, 72% of 1998 and 70% of 2006 (in other words, these references had at least one of their words registered in the dictionary).

The fourth step was the matrices graphic preparation.

Table 1 presents the descriptive statistics of the resulting database.

[4] See Appendix for the list of 30 technological domains, according to OST.

[5] As an example of this referencing scheme, for the ISI-discipline Biotechnology (number 16), the key words were Biotechnology, Biochemistry, Molecular Biology, Biomedical, Genetic, Heredity, Biophy, Bioch.

TABLE 1

Descriptive statistics

	1974	1982	1990	1998	2006
Patents Granted	59.669	55.610	87.805	142.478	169.332
USA share (%)	70.18	60.50	53.48	54.52	50.78
S&E citing patents	4.572	10.899	23.134	52.574	74.583
USA share (%)	72.14	64.82	58.68	60.68	57.71
S&E citations	7.115	27.013	87.117	431.525	822.733
USA share (%)	72.56	68.81	69.35	75.85	74.34
Citation per patent	0.12	0.49	0.99	3.03	4.86
Countries with patents	64	63	78	96	100
Countries with S&E citing patents	37	42	60	69	83
Leading technological domain	Electrical components	Electrical components	Electrical components	Electrical components	Information technology
Most S&E intensive technological domain (intensity)	Semi-conductors (0.25)	Biotechnology (1.63)	Biotechnology (3.36)	Biotechnology (10.15)	Biotechnology (16.44)
Leading S&E field	Electronic Engineering	Inorganic Chemistry and Engineering	Inorganic Chemistry and Engineering	Inorganic Chemistry and Engineering	Electronic Engineering

SOURCE: USTPO, authors' elaboration

As the literature has shown, Table 1 highlights at least three interrelated phenomena.

First, Table 1 shows the stead growth of USPTO patents. The decrease in patents granted for 1982 is due to bureaucratic factors and has been widely described by the literature (Griliches, 1990).

Second, Table 1 shows the steady growth of patents citing S&E literature, a proxy for the increasing linkage between science and technology over time. Patents citing S&E literature were 7.6% in 1974 and climbed to 44.0% in 2006. This is a stead trend. Furthermore, there is a persistent growth in the number of citations per patent (from 0.11 in 1974 to 4.85 in 2006), another way to show the increasing importance of science and technical information for technology.

Third, in the global scenario, there is a relative decrease of the US share over time, and the growth in the number of countries with USPTO patents (64 in 1974 and 100 in 2006) and with patents citing S&E literature (from 37 in 1974 to 83 in 2006).

These comments based on Table 1 may introduce an overall view of the global data help, according to a global science-technology linkages matrix. Figure 2 presents these global matrices, for 1974, 1982, 1990, 1998 and 2006.

FIGURE 2
Global matrices (1974, 1982, 1990, 1998 and 2006)

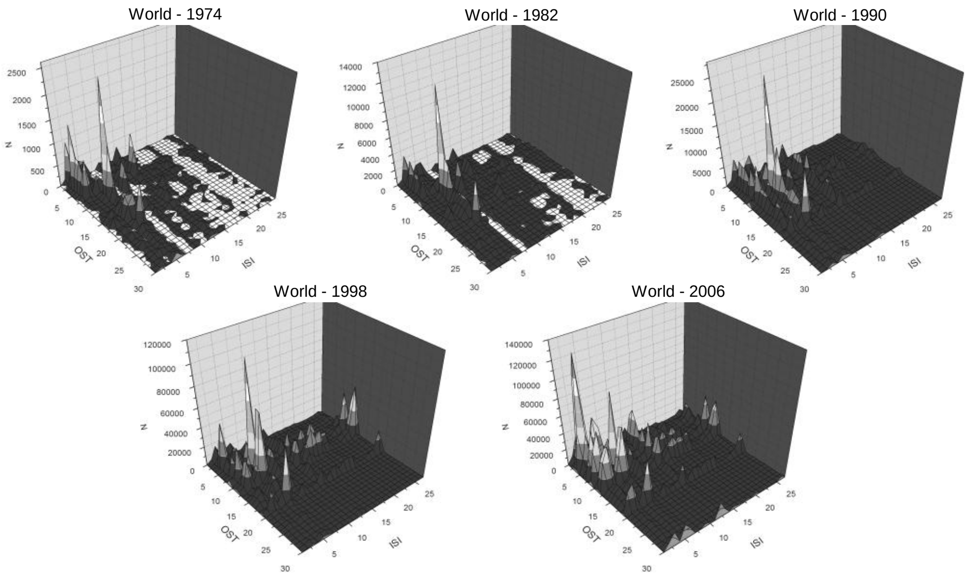


Figure 2 shows three inter-temporal movements.

First: the steady fulfillment of the floor of the matrices (compare 1974 and 2006), a process that indicates the growing importance of all S&E fields to diverse technological domains.

Second: the increase in the height of the columns over time, a change that shows how technological domains use more widely knowledge provided by different S&E fields.

Third: the number of peaks per matrix, which were few and small in 1974 and became diverse and higher in 2006.

These differences in matrices cells and cells heights express changes in science and technology fields and domains and their relative importance in each year rankings.

These "global matrices" presented by Figure 2 are useful to introduce features of this process as a whole. As the leading position of Information Technology domain in 2006, according to Table 1, hints, from 1974 to 2006 there is a growing importance of technologies related to the new information and communication technological (TICs) paradigm. In 1974 Information Technology ranked in 23rd position, Telecommunications in 13th, Semiconductors in 25th, and Audiovisual in 21st. In 2006 these technological domains jumped to 1st, 2nd, 5th and 8th positions, respectively. The steady rise of health-related technological domains between 1974 and 2006 is also noteworthy: biotechnology moved upward from the last position (30th) to the 23rd, pharmaceutical from the 29th to 20th and medical engineering from the 22nd to the 17th.

As Table 1 informs, the weight of USA patents has been declining over time. Therefore, the world data are less influenced by the USA data as time goes by. This may be exemplified by the coincidence in 1974 and 1982 between the three leading technological domains in the global data and in the USA data, and by the later coincidence only between two technological domains.

Regarding the cited S&E fields, the three leading fields and their ranking are the same in 1974 and 2006: “electronic engineering”, “inorganic chemistry and engineering”, and “mechanical and civil engineering”. In between there was a change, with inorganic chemistry and engineering in the first rank from 1982 to 1998. The weight of USA S&E literature, according to Table 1, is strong (around 70%), therefore there is a coincidence between the three leading global and USA fields from 1974 to 1998. Only in 2006 the three leading S&E fields do not coincide: for the USA, “other physics” ranks 3rd, instead of “mechanical and civil engineering”. Probably the most interesting trend is the rising of health-related S&E fields: “research medicine” ranked 18th in 1974 and jumped to the 6th position in 2006, “immunology” jumped from 22nd to 11th and “biotechnology” from 17th to 9th, and “general biology” from 14th to 10th.

This rise in health-related S&E fields certainly is inter-related with the rise of health-related technological domains, commented above. Over time changes in the leading technological domain are correlated with changes in the leading S&E fields. This is a way to capture dynamically the interactions between science and technology.[6]

At large, therefore, these global data indicate the movements related to two technological revolutions, first a more consolidated ITC paradigm, and second an emerging health-related new paradigm (Freeman & Louçã, 2001).

Can these changes hint any suggestions for less-developed countries? This is a subject to be investigated in the next sections.

III. MATRICES AND INDICATORS

The starting point is Narin et al (1997), whose pioneer work, focusing a selected technology area (drug and medicine patents), built a small matrix with the “field of the cited paper” (p. 321). Later, this kind of matrix was extended to selected technological domains and S&E fields by Tijssen et al (2000, p. 406), Verbeek et al (2002b, pp. 30-37) and Callert (2006, p. 17).

In this paper, the matrices involve all 30 technological domains proposed by the *Observatoire des Sciences et Techniques* (OST, 2006) and all 27 S&E fields defined by the ISI (Braun et al, 1996), therefore they are matrices with 810 cells. One original contribution of this paper is the presentation of these 27 X 30 matrices, since they enable a further comparative analysis between different countries, both qualitatively and quantitatively. As this section shows, empty matrix cells are very important information for these cross-country comparisons.

These matrices are the base for the indictors suggested in this section.

[6] A note of caution: over time there is an increase in the relation between intra-sectoral proportion between citing and non-citing patents. However, following the most science-based technological domains, there could be a combination of two factors in these increase: first an effective increase in the science and technological linkages, second, legal and behavioral changes within the US Patent Office (see NSB, 2002, p, 5.53, box “the growth of referencing in patents”)

III.1. Matrices for Selected Countries

This section selects three countries for a closer look: United States (the leading country in this phase of capitalism), Brazil (as a representative immature system of innovation) and South Korea (as a successful catching up country). This section presents matrices for five different years (1974, 1982, 1990, 1998 and 2006), hence they show the dynamics involved in the interactions between science and technology over time.

Figure 3 shows the United States' matrices.

FIGURE 3
USA's matrices (1974, 1982, 1990, 1998 and 2006)

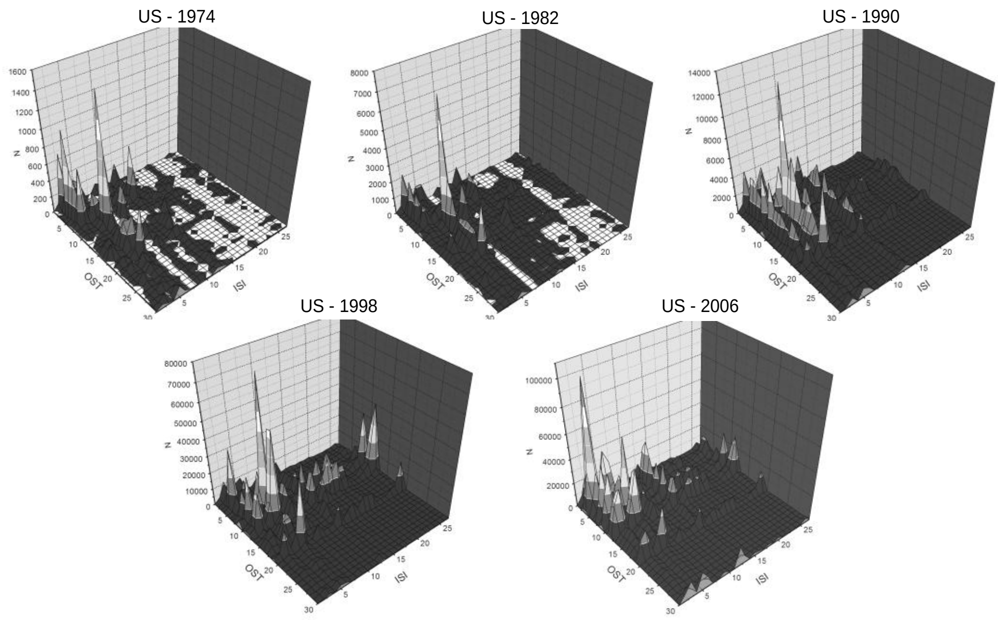


Figure 3 displays at least four interesting phenomena.

First, there is a matrix fulfillment over time. In 1974 the leading country in this process had an incomplete matrix, with areas with empty cells. One area of empty cells is the ISI-discipline Physical Chemistry (code 8), another set of empty cells are in health-related disciplines (ISI-disciplines with codes greater than 15). Over time the points of interaction spread, thus the empty cells decrease and in 2006 the USA's matrix is almost completely fulfilled.

Second, the leading ISI-disciplines in the process of this matrix fulfillment are the health-related disciplines. The role of health-related disciplines is pinpointed by the *Science and Engineering Indicators* (NSB, 2006, p. 5-49).

Third, over time there is a steady growth in the number of S&E literature citations. This can be seen in the figures relative to the Z-axis (the height of the matrices columns): in 1974 the peak was around 1,200 citations while in 2006 the peak reached almost 100,000 citations.

Fourth, there are changes in the overall matrices landscape (matrices surface), as they become more fulfilled and also as the peaks may differ and change position.

For example: in 1974 the four highest peaks were OST-Organic Chemicals /ISI- Inorganic Chemistry and Engineering, OST-Telecommunications/ISI-Electronic Engineering, OST-Macromolecular chemistry/ISI- Inorganic Chemistry and Engineering and OST-Analysis, Measurement and Control/ISI- Electronic Engineering.

In 2006 the leading peak and the ranking of the four leading peaks had changed: the new leading peak was at the cell OST-Information Technology/ISI-Electronic Engineering; the second position remained unchanged (OST-Telecommunications/ISI- Electronic Engineering); the former leading peak was now in the second position (OST-Organic Chemicals/ISI-Inorganic Chemistry and Engineering) and there is a newcomer, a health-related technological domain in the fourth position (OST- Biotechnology/ISI- Inorganic Chemistry and Engineering).

Furthermore, it is important to note that the cell OST-Biotechnology/ISI-Research Medicine was the 105th higher peak in 1974 and the 16th peak in 2006.

Figure 4 shows the Brazil's matrices.

FIGURE 4
Brazil's matrices (1974, 1982, 1990, 1998 and 2006)

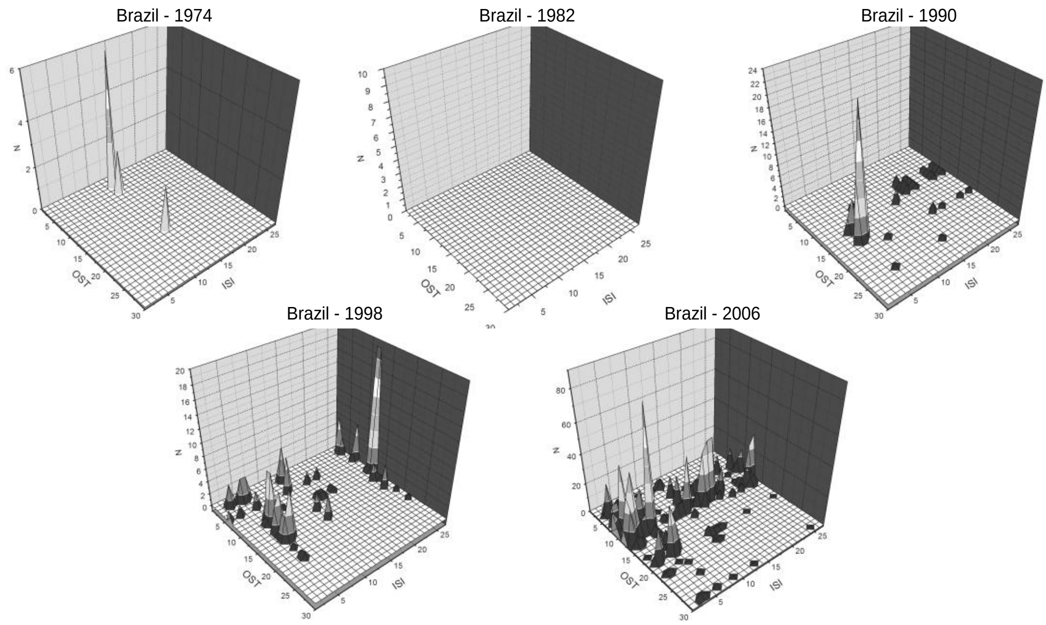


Figure 4 displays at least two phenomena.

First, there is a process of increasing matrix fulfillment, but it is an unstable (no patent with S&E literature citation in 1982) and incomplete process (it is worthwhile to note the level of non-fulfillment of the 2006 matrix: there are a lot of empty cells).

Second, there are important inter-temporal differences between the cells that express points of interaction between science and technology. The cells fulfilled in 1974 are not repeated in 1990. The peaks present in 1990 are not peaks in 1998. The inter-temporal consistency is not very high in regard to the identified points of interaction, since there is an inter-temporal wavering of points of interaction.

Figure 5 shows South Korea's matrices.

FIGURE 5

South Korea's matrices (1974, 1982, 1990, 1998 and 2006)

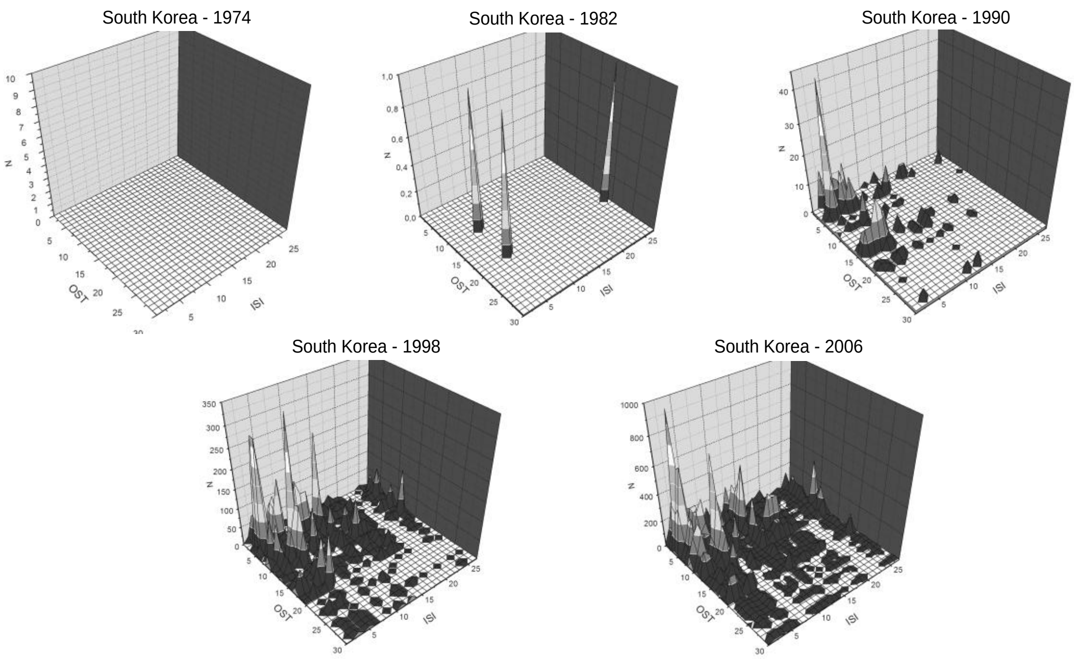


Figure 5 displays two features of Korean development.

First, there is a steady increase in matrix fulfillment, a broader fulfillment than the Brazilian.

Second, it is a two-phases process. In the first phase (between 1974 and 1990) the process of matrix fulfillment, regarding the points of interaction, is inter-temporally wavering, as in Brazil. Later (between 1990 and 2006) there is a more inter-temporally correlated pattern of matrix fulfillment, where there is a combination of less empty cells with the strengthening of previous points of interaction.

These three examples highlight how useful these matrices may be for the analysis of the development of one specific country and for the comparisons between different countries. The issue now is what could be the adequate indicators for these inter-temporal and cross-countries comparisons?

III.2. Indicators

These three cases illustrate the explanatory potentiality of these matrices, but it is necessary to suggest adequate indicators to interpret these data. This sub-section proposes four new indicators.

First, there is an indicator to grasp the overall level of interactions between science and technology in a country. As empty cell represents the lack of linkage between an OST-technological domain and an ISI-discipline, the identification of the level of matrix fulfillment is very important. Therefore it is proposed a Matrix Fulfillment Index.

The Matrix Fulfillment Index F of science-technology linkages matrix M is:

$$F(M) = \sum_{i=1}^{27} \sum_{j=1}^{30} \frac{\delta_{ij}}{27 * 30}$$

where $\delta_{ij} = 0$ if $M_{ij} = 0$ or $\delta_{ij} = 1$ if $M_{ij} > 0$, and M_{ij} is the height of i-st row (which represents the ISI classes) and j-st column (which represents the OST sub-domains) of science-technology linkages matrix.

Second, there is an indicator to differentiate non-empty cells, as these cells could be have only one citation or more than one citation. This indicator must combine both the level of matrix fulfillment (projection in the xy plane) and the number of citations by cell (the z-axis). This indicator measures the average height of the matrix surface.

Matrix Height Index $\bar{M}$ is defined as:

$$\bar{M} = \sum_{i=1}^{27} \sum_{j=1}^{30} \frac{M_{ij}}{27 * 30}$$

Third, a measure of the thickness under the matrix's surface

Matrix Rugosity Index w of a science-technology linkages matrix M is:

$$w^2(M) = \sum_{i=1}^{27} \sum_{j=1}^{30} \frac{(M_{ij} - \bar{M})^2}{27 * 30}$$

Finally, there is an indicator for inter-temporal and/or cross-country comparisons. This indicator must grasp both changes related to the level of matrices fulfillment, changes in the height of the cells and changes in the ranking of peaks. In sum, this indicator must compare different matrices' surfaces.

Inter-temporal Correlation between Matrices is a correlation coefficient $R_{M,M'}$ between the science-technology linkages matrices M and M' :

$$R_{M,M'} = \sum_{i=1}^{27} \sum_{j=1}^{30} \frac{(M_{ij} - \bar{M})(M'_{ij} - \bar{M}')}{w(M) * w(M')}$$

These four indicators may grasp both the matrices structure and their dynamics over time.

IV. HOW THESE INDICATORS DIFFERENTIATE COUNTRIES

This section uses data and indicators for 13 selected countries. This comparison would stress the similarities and differences among these countries. This comparison is a contribution to understand features of interactions between science and technology within and between countries.

The 13 selected countries involve representative countries from different stages of development and other important countries' characteristics. The United States are the leading economic during this period. Other important developed economies selected are Japan and Germany (huge economies with very broad economic and technological capabilities and diversification) and Sweden and Netherlands (wealthy countries with small and dynamic economies, with a more specialized and less diversified economy). South Korea and Taiwan are successful catching up economies and they allow an assessment of how the structural transformation that they have underwent is reflected in the data related to science and technology linkages. Brazil, Mexico, South Africa, China and India are countries that are in an intermediary level of development (they are in the Regime II, according to a previous work, see Ribeiro et al, 2006). And Indonesia represents countries classified in the less-developed regime (Regime I), with weak science and technology institutions and interactions.

Tables 2, 3 and 4 present general data related to science and technology linkages.

Table 2 shows data related to USPTO patents granted to these 13 countries.

TABLE 2

	USPTO PATENTS GRANTED				
	1974	1982	1990	1998	2006
UNITED STATES	41879	33645	46961	77671	85990
JAPAN	4572	8151	19406	30097	35727
GERMANY	4853	5585	7816	9471	10550
SOUTH KOREA	0	14	222	3180	5730
SWEDEN	803	684	763	1180	1180
NETHERLANDS	604	620	945	1161	1217
TAIWAN	0	90	728	3001	6180
INDIA	19	11	35	120	651
CHINA	4	0	46	81	717
BRAZIL	16	26	40	72	116
SOUTH AFRICA	78	73	108	111	104
MEXICO	37	33	31	55	61
INDONESIA	0	2	3	10	7

Table 2 shows the persistent leadership of the United States, the important relative growth of Japan (which had catch up with, and forged ahead from Germany in the 1970s), the stability in the rankings of Sweden and Netherlands and the Korean and Taiwanese catch up processes. Between the Regime II countries, the rates of growth in patenting are more limited vis-à-vis South Korea and Taiwan. The exceptions are China and India in the last period (between 1998 and 2006). Indonesia's patents have shown no expressive change.

Table 3 presents the growth in the share of patents with S&E literature citations.

TABLE 3

	USPTO PATENTS CITING S&E LITERATURE				
	1974	1982	1990	1998	2006
UNITED STATES	7.9%	21.0%	28.9%	41.1%	50.1%
JAPAN	8.6%	17.0%	22.8%	30.2%	35.6%
GERMANY	6.4%	18.6%	25.4%	37.0%	41.8%
SOUTH KOREA	0.0%	7.1%	12.6%	15.7%	31.0%
SWEDEN	4.6%	10.5%	15.6%	33.7%	44.1%
NETHERLAND	9.1%	20.2%	26.5%	41.2%	45.7%
TAIWAN	0.0%	4.4%	4.0%	10.9%	10.3%
INDIA	10.5%	18.2%	54.3%	55.0%	56.8%
CHINA	0.0%	0.0%	23.9%	34.6%	31.9%
BRAZIL	18.8%	0.0%	7.5%	22.2%	39.7%
SOUTH AFRICA	3.8%	19.2%	18.5%	26.1%	33.7%
MEXICO	5.4%	12.1%	22.6%	29.1%	24.6%
INDONESIA	0.0%	0.0%	0.0%	50.0%	71.4%

The main phenomenon shown in Table 3 is the pervasiveness of the growth of in patents with S&E literature citations. As Table 1 hinted, it is clearly a global phenomenon.

Table 4 displays the evolution of S&E literature citations over time.

TABLE 4

	CITATIONS OF S&E LITERATURE PER PATENT				
	1974	1982	1990	1998	2006
UNITED STATES	0.12	0.55	1.29	4.21	7.11
JAPAN	0.13	0.36	0.57	1.02	1.44
GERMANY	0.09	0.40	0.70	1.67	2.53
SOUTH KOREA	0.00	0.07	0.45	0.47	1.09
SWEDEN	0.07	0.24	0.41	2.10	4.17
NETHERLAND	0.14	0.42	0.81	1.95	3.26
TAIWAN	0.00	0.16	0.08	0.38	0.50
INDIA	0.11	1.00	2.69	5.64	5.65
CHINA	0.00	0.00	0.78	3.02	2.81
BRAZIL	0.25	0.00	0.18	1.39	3.12
SOUTH AFRICA	0.05	0.37	0.63	2.11	1.41
MEXICO	0.11	0.33	0.74	3.07	0.80
INDONESIA	0.00	0.00	0.00	2.80	2.57

Again, this is a global phenomenon, since every country increased the number of citation between 1974 and 2006. But, Table 4 also shows the difference between countries in this regard. Even between developed countries, it is noteworthy the greater propensity of US patents to cite S&E literature.

Tables 5, 6 and 7 calculate the first three indicators suggested in the previous section for these 13 countries.

Table 5 presents the Matrix Fulfillment Index.

TABLE 5

	MATRIX FULFILLMENT INDEX (OST DOMAINS X ISI DISCIPLINES)				
	1974	1982	1990	1998	2006
UNITED STATES	61.9%	78.1%	97.0%	98.1%	99.6%
JAPAN	26.2%	50.1%	81.7%	86.3%	93.5%
GERMANY	24.6%	46.5%	73.2%	81.5%	88.5%
SOUTH KOREA	0.0%	0.4%	11.2%	45.4%	70.2%
SWEDEN	7.7%	16.2%	27.0%	54.7%	62.1%
NETHERLAND	7.2%	20.9%	39.6%	51.1%	61.9%
TAIWAN	0.0%	2.5%	8.9%	35.1%	55.3%
INDIA	0.1%	1.7%	5.8%	21.2%	48.5%
CHINA	0.0%	0.0%	3.6%	14.2%	45.9%
BRAZIL	0.4%	0.0%	4.1%	6.3%	14.7%
SOUTH AFRICA	0.2%	3.8%	7.2%	13.3%	12.1%
MEXICO	0.1%	0.9%	2.1%	9.3%	3.2%
INDONESIA	0.0%	0.0%	0.0%	1.6%	1.6%

United States, the leading country, has the greater MFI (99.6%). Brazil has a MFI = 14.7%. A comparison with other research tools: comparison between the Matrix for the USA in 2006 and a Matrix built upon Cohen et al (2002, p.11): the Matrix from Cohen et al would have a MFI equal to 94,9%. A comparison: between the Matrix for Brazil 2006 and a Matrix built upon Rapini (2007): if Rapini had produced a Matrix, its MFI would be 17.7%. These observations show how these matrices of science and technology interactions are coherent with other research tools and get impressive similar results. This coherence strengthens the usefulness of this research tool, especially because these matrices allow an inter-country comparability that no other research tool has obtained, so far at least.

Table 5 describes a persistent increase in this indicator. This is a global and systematic phenomenon, with rare exceptions (Brazil between 1974 and 1982; Mexico between 1998 and 2006).

Table 5 differentiates countries in this regard. There are countries with a MFI greater than 80% (only three countries, big and rich countries: USA, Japan and Germany), countries between 50 and 80% (small and rich countries: South Korea, Sweden, Netherlands and Taiwan - probably size matters for the complete fulfillment of these matrices), and countries below 50% (countries in Regime II and I). Countries in Regime II are differentiate here, as China and India (big countries with dynamic economies) have in 2006 MFI greater than 40%, while Brazil, Mexico and South Africa are oscillating between 3% and 15% in 1998 and 2006.

Table 6 presents the Matrix Height.

TABLE 6

	MATRIX HEIGHT (AVERAGE CITATION PER MATRIX DOTS)				
	1974	1982	1990	1998	2006
UNITED STATES	28.64	122.10	464.03	2419.85	3935.61
JAPAN	3.53	17.64	77.03	178.78	278.42
GERMANY	2.41	14.83	45.34	108.78	176.97
SOUTH KOREA	0.00	0.00	0.53	9.83	35.20
SWEDEN	0.25	1.00	2.61	17.15	30.56
NETHERLAND	0.40	2.11	5.25	16.43	22.10
TAIWAN	0.00	0.11	0.39	8.07	19.04
INDIA	0.01	0.06	0.25	4.04	29.16
CHINA	0.00	0.00	0.11	2.39	13.30
BRAZIL	0.01	0.00	0.10	0.22	1.44
SOUTH AFRICA	0.00	0.15	0.40	1.96	1.29
MEXICO	0.03	0.06	0.12	0.87	0.18
INDONESIA	0.00	0.00	0.00	0.10	0.04

Table 6 shows an increase in the matrices height over time and across all countries. The exceptions are South Africa, Mexico and Indonesia, between 1998 and 2006. In other words, over time the average citation per matrix cell is increasing systematically. The literature recommends caution to analyze this data. But, as Callert et al (2006, p. 6) comment, "it is plausible to state that more scientific references signal greater relevance or relatedness between the technology at hand and scientific activity". Therefore, Table 6 shows that over time a greater "relevance" or "relatedness" between technological domains and ISI-disciplines.

Table 6 also shows an important difference between the United States and the other developed countries: in 2006 the Matrix Height Indicator for the United States is 14 times the figure for Japan. This difference may be explained, according to Narin et al (1997, p. 321), because traditionally the United States cite more paper per patent than other countries.[7] Therefore, the cross-country quantitative differences must be analyzed with care.

Table 7 presents the Matrix Thickness (Matrix Rugosity).

[7] Narin et al (1997) mention that the United Kingdom also has this propensity, but in our data her Matrix Height is 209.13 (not so different from the other developed countries listed in Table 6).

TABLE 7

	MATRIX THICKNESS (RUGOSITY)				
	1974	1982	1990	1998	2006
UNITED STATES	3.45	13.54	34.80	213.28	297.00
JAPAN	0.53	2.27	7.59	16.23	21.37
GERMANY	0.38	2.93	6.06	13.35	14.91
SOUTH KOREA	0.00	0.00	0.08	1.05	2.91
SWEDEN	0.04	0.12	0.34	2.12	2.82
NETHERLAND	0.07	0.27	0.46	1.72	1.95
TAIWAN	0.00	0.03	0.06	1.08	1.95
INDIA	0.01	0.02	0.05	0.51	3.16
CHINA	0.00	0.00	0.03	0.47	1.86
BRAZIL	0.01	0.00	0.04	0.04	0.20
SOUTH AFRICA	0.00	0.05	0.08	0.40	0.22
MEXICO	0.03	0.02	0.04	0.15	0.07
INDONESIA	0.00	0.00	0.00	0.03	0.02

Table 7 shows that the rankings for Matrix Rugosity are the same rankings for Matrix Height. This behavioral similarity between Matrices Height and Matrices Rugosity is very important for our analysis. It demonstrates that over time the growth process of matrices surfaces is not wholly random. Over time the Matrices Height grows but this growth is not random – if this process were random, while the Matrices Height would keep growing, the Matrices Rugosity would stabilize. Therefore, this behavioral similarity shown by Tables 6 and 7 suggests that the process is "preferential", as the probability of increasing the height of a matrix cell is proportional to the matrix cell height in the previous time. In other words, the inter-temporal growth of "relevance or relatedness between the technology at hand and scientific activity" (shown in Table 6) is not random.

This section puts forward that these data and indicators provide information that helps the understanding of the nature of interactions between science and technology over time and across countries. Furthermore, it helps to differentiate countries in this regard. In our research agenda, these findings complement the more strictly quantitative landscape presented in Ribeiro et al (2006): only with patent and paper statistics that paper differentiate countries in three different "regimes of interaction".

V. MATRICES SURFACES AND PATTERNS OF STRUCTURED GROWTH

The previous section analyzed the matrices' structure and dynamics. The synthesis of the indicators presented there is the matrices' surface, calculated through the Matrix Rugosity Index. The matrices' surfaces condense the diverse features discussed in the previous section (level of fulfillment, height of matrices cells and location of matrices peaks).

Then, the next step is to compare these matrices' surfaces. For this comparison, the indicator is the Inter-temporal Correlation between Matrices.

Table 8 shows the figures of Inter-temporal Correlation between Matrices for the selected 13 countries.

TABLE 8

	MATRIXES INTER-TEMPORAL CORRELATION				
	1974-1982	1982-1990	1990-1998	1998-2006	1974-2006
UNITED STATES	0.91	0.88	0.85	0.79	0.61
JAPAN	0.90	0.88	0.88	0.87	0.69
GERMANY	0.80	0.93	0.94	0.83	0.57
SOUTH KOREA	0.00	0.00	0.59	0.82	0.00
SWEDEN	0.40	0.34	0.56	0.73	0.36
NETHERLAND	0.44	0.57	0.59	0.66	0.30
TAIWAN	0.00	0.25	0.29	0.81	0.00
INDIA	0.00	0.06	0.45	0.51	0.01
CHINA	0.00	0.00	0.10	0.09	0.00
BRAZIL	0.00	0.00	0.27	0.27	0.03
SOUTH AFRICA	-0.01	0.02	0.12	0.16	-0.01
MEXICO	0.00	-0.01	0.18	-0.02	0.00
INDONESIA	0.00	0.00	0.00	-0.01	0.00

First, taking into account the whole period (the correlation between the matrices' surfaces in 1974 and in 2006), Table 8 divides these 13 countries in two broad groups: one with the correlation greater than 0.30 (United States, Japan, Germany, Sweden and Netherlands) and the other with the correlation less than 0.30 (the rest).

The first group could be divided into two sub-groups. The first sub-group involves United States, Japan and Germany, given their high inter-temporal correlations (greater than 0.79) and with a high correlation between 1974 and 2006 (greater than 0.57). These three countries combine size (expressed in the comparatively higher MFIs throughout the whole period), persistence and innovative capacity. The other sub-group involves Sweden and Netherlands, that are also have relatively high correlations (always greater than 0.34). Although their levels of MFI were between 7.2% and 20.9% during 1974 and 1982, their Inter-temporal correlations were in the neighborhood of 0.40. In other words, their technological consistence was very high, even when their MFIs were still relatively low.

The second group is more diversified and may be divided into several sub-groups.

South Korea and Taiwan have a similar pattern, because they reached a high inter-temporal correlation after 1990 (when they have reached MFIs greater than 8.9%). As the description of the South Korean matrices (in section III) has already mentioned, in a second phase of her process, the persistence of existing points of interaction had been identified. This phenomenon is grasped by the inter-temporal correlations equal to 0.59 and 0.82.

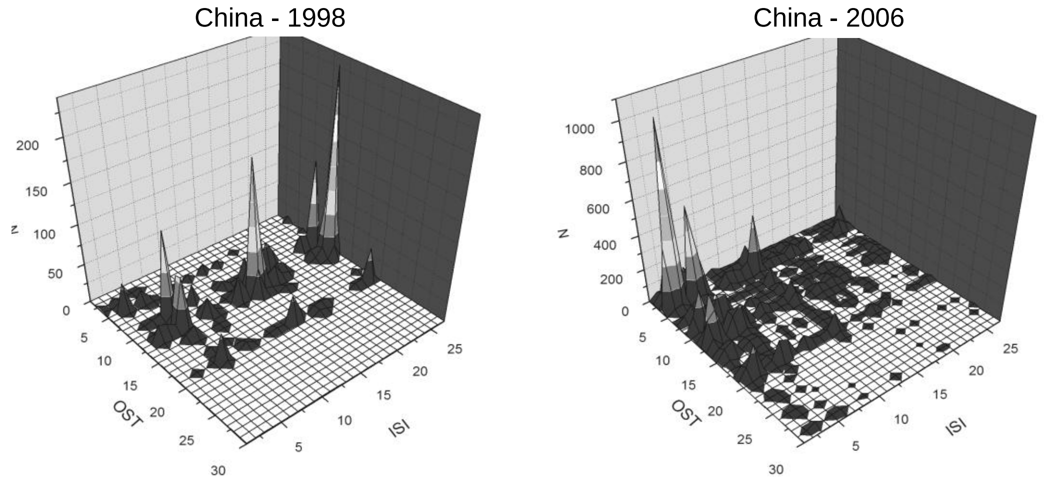
Brazil and South Africa show similar behavior, as their correlations have grown over time, but are still less than 0.30 (between 1998 and 2006, 0.27 for Brazil and 0.16 for South Africa).

Mexico (that in Ribeiro et al, 2006, clusters with Brazil and South Africa within Regime II) only between 1990 and 1998 had an expressive correlation (0.18). In all other periods the correlations were zero or less. In this regard, Mexico becomes closer to Indonesia that is in a different Regime I, according to Ribeiro et al (2006).

India and China are closer in regard to the MFI (around 45% in 2006) but have different inter-temporal correlations between 1998 and 2006: India 0.51 and China only 0.09. India, it is noteworthy, had an inter-temporal correlation equal to 0.45 between 1990 and 1998, suggesting persistence in their points of interaction.

China deserves a closer look. Figure 6 presents the Chinese matrices for 1998 and 2006.

FIGURE 6
China's matrices (1998 and 2006)



On the other hand, the low correlation for China suggests that a combination of increasing matrix's fulfillment with the occupation of new points of interaction: the surfaces are very different.

An interesting comparison could be with South Korea (see Figure 5, years 1990 and 1998): the correlation between 1990 and 1998 for South Korea, then with similar levels of MFIs (11.2% in 1990 and 45.4% in 1998), was 0.59, while China between 1998 and 2006 (MFIs equal to 14.2% and 45.9%) has a correlation of only 0.09.[8]

Probably, here size and speed of changes matter. Size, because although Chinese patents showed a nine times increase between 1998 and 2006, China still has low patent per inhabitant figures (this ratio places China in the Regime II, with Brazil, Mexico, South Africa and India). Speed of changes, since there are almost three decades of persistent high rates of Chinese economic growth. In sum, China is a huge country with diversified resources that are now under intense mobilization. This

[8] This seems to be a new phenomenon, since no other country has shown such transition from a MFI around 10-15% to a MFI around 40% with such low levels of inter-temporal correlation.

process may be summarized as a still unstable process that have not yet reached a structured pattern of growth – China presents a wavering process still searching for the right path. A conjecture: the matrix's surface for 2006 might be the staring point for a more structured pattern of growth henceforth.[9]

Preliminary conclusions about matrices surfaces inter-temporal correlations: 1) this indicator differentiates mature and immature systems of innovation; 2) a look at catching up countries: a pattern of structured growth emerges throughout the development process; 3) temporary decreases in the inter-temporal correlation may be positive, for developed countries, since it may indicate an ongoing technological revolution (new technological sectors with a new science base), and for less-developed countries, since it may signal the search for a new developmental path, a new basis for a sustained growth; 4) certainly, a pattern of uncorrelated growth (typical of countries within Regimes II and I) could be a factor that blocks the start of a positive feedback trajectory between science and technology.

VI. CONCLUSIONS

The investigation of S&E literature citations in patents is an useful tool to investigate the nature of science and technology linkages both in developed and under-developed countries, *inter alia* for it allows dialogues with other tools available both for developed (Cohen et al, 2002) and under-developed countries (Rapini, 2007);

The scientific content of technology, as measured by S&E literature citations in patents, is increasing steadily both in developed and under-developed countries, but the nature of these increases differs across countries and levels of development;

The elaboration of three dimensional matrices (OST-technological domain, ISI-disciplines, and number of references per matrix cell) for each country and each year is a powerful tool for evaluation of the stage and the dynamics of interactions between science and technology;

The indicators about Matrix Fulfillment, Matrix Height and Matrix Rugosity provide important qualitative insights about these interactions. Once these qualitative insights are available, the implications for development are not difficult to draw. The problem is not only the scarcity of patents, but also the quality of those important but few patents from developing countries, the countries within regimes I and II, in our previous work (Ribeiro et al, 2006).

The inter-temporal correlations between matrices' surfaces underlie the identification of patterns of structured growth, a key difference between countries within regime III (mature NSIs) and the rest (immature NSIs);

Given these conclusions, there are important implications for development, in an era where science, technology and their linkages matter:

[9] In this case, the correlation between the matrices from China and the United States for 2006 is relevant: in 2006 this correlation is high: 0.75.

1) The interconnections between science and technology may indicate which S&E fields should be supported for specific industrial policies, and provide policy makers a tool for designing industrial policies that take into account the interactions between science and technology as a key factor for development.

2) The role of persistence over time, which involves long-term planning by firms and public agencies (probably interacting with policies to mitigate the high mortality rates of new firms, firms so necessary to change the technological landscape of underdeveloped countries).

3) More evidence in favor of a very simple argument: a broad science and technology infrastructure is necessary for development, and this necessity grows over time. The argument is very simple: to catch up a country needs to improve its innovation capabilities. Over time, the scientific content of technology is increasing. Therefore, *inter alia*, it is necessary a greater and deeper scientific infrastructure to support these innovative activities. This process seems to be unavoidable and demands larger investments in science in LDCs than have been done so far.

4) New arguments for the necessary combination between industrial policies and science and technology policies. The evidence presented in this paper suggests that for a *quantitative* increase in patent figures a precondition is a correspondent growth in science and engineering publications. No quantitative increase in patent figures is possible without a *qualitative* improvement in the patents generated, in other words, in their science and engineering content. Therefore, this paper suggests that dynamically, over time, there is a deep relationship between the quantity of patents and the quality of these patents.

REFERENCES

BASSECOULARD, E.; ZITT, M. (2004) Patents and publications: the lexical connection. In: MOED, H.; GLÄNZEL, W.; SCHMOCH, U. (eds). *Handbook of quantitative science and technology research*: the use of publication and patent statistics in studies of S&T systems. Dordrecht: Kluwer Academic Publishers, pp. 665-694.

BHATTACHARYA, S.; MEYER, M. (2003) Large firms and the science-technology interface: patent, patent citations, and scientific output of multinational corporations in thin films. *Scientometrics*, v. 58, n. 2, pp. 265-279.

BERNARDES, A.T. & ALBUQUERQUE, E.M. (2003) Cross-over, thresholds, and interactions between science and technology: lessons for less-developed countries. *Research Policy*, v. 32, n. 5, pp. 865–885.

BRAUN, T.; GLANZEL, W.; GRUPP., H. (1996) The Weight of 50 Nations in 27 Science Areas, 1989-1993 (Part I). *Scientometrics*, v. 33, n. 3, pp. 263-293.

CALLAERT, J.; van LOOY, B.; VERBEEK, A.; DEBACKERE, K.; THUS, B. (2006) Traces of prior art: an analysis of non-patent references found in patent documents. *Scientometrics*, v. 69, n. 1, pp. 3-20.

COHEN, W.; NELSON, R.; WALSH, J. (2002) Links and impacts: the influence of public R&D on industrial research. *Management Science*, v. 48, n. 1, pp. 1-23.

COLYVAS, J.; CROW, M.; GELIJNS, A.; MAZZOLENI, R.; NELSON, R. ROSENBERG, N.; SAMPAT, B. (2002) How do university inventions get into pratice? *Management Science*, v. 48, n. 1, pp. 61-72.

EUROPEAN COMMISSION (2003) *Third European Report on Science & Engineering Indicators*: towards a knowledge-based economy. Brussels: EC-DGR.

FREEMAN, C. (1994). The economics of technical change: critical survey. *Cambridge Journal of Economics*, v. 18, pp. 463-514.

GUAN, J.; HE, Y. (2007) Patent-bibliometric analysis on the Chinese science-technology linkages. *Scientometrics*, v. 72, n. 3, pp. 403-425.

KLEVORICK, A.; LEVIN, R.; NELSON, R.; WINTER, S (1995). On the sources and significance of inter-industry differences in technological opportunities. *Research Policy*, v. 24, p. 185-205.

MAZZOLENI, R.; NELSON, R. (2007) The Roles of Research at Universities and Public Labs in Economic Catch-up. *Research Policy*, v. 36, n. 10, pp. 1512-1528.

MEYER, M. (2000) Does science push technology? Patents citing scientific literature. *Research Policy*, v. 29, pp. 409-434.

MOED, H.; GLÄNZEL, W.; SCHMOCH, U. (eds) (2004). *Handbook of quantitative science and technology research*: the use of publication and patent statistics in studies of S&T systems. Dordrecht: Kluwer Academic Publishers.

MOWERY, D.; SAMPAT, B. (2005) Universities in National Innovation Systems. In: FAGERBERG, J.; MOWERY, D.; NELSON, R. (2005) *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

NARIN, F.; HAMILTON, K. S.; OLIVASTRO, D. (1997) The increasing linkage between U.S. technology and public science. *Research Policy*, v. 26, n. 3, pp. 317-330.

NARIN, F.; NOMA, E. (1985) Is technology becoming science? *Scientometrics*, v. 7, n. 3-6, pp. 369-381.

NATIONAL SCIENCE BOARD (2002) *Science and Engineering Indicators 2002* (http://www.nsf.gov/statistics/seind02/)

NATIONAL SCIENCE BOARD (2004) *Science and Engineering Indicators 2004* (http://www.nsf.gov/statistics/seind04/)

NATIONAL SCIENCE BOARD (2006) *Science and Engineering Indicators 2006* (http://www.nsf.gov/statistics/seind06/)

NELSON, R. (1988). Institutions supporting technical change in the United States. In: DOSI, G.; FREEMAN, C.; NELSON, R.; SILVERBERG, G.; SOETE, L. (eds). *Technical change and economic theory*. London: Pinter, pp. 312-329.

OBSERVATOIRE DES SCIENCES ET DES TECHNIQUES (2006). *Science & Technologie*: indicateurs 2006. Paris: Economica (http://www.obs-ost.fr/le-savoir-faire/etudes-en-ligne/etudes-2006/rapport-2006.html).

RAPINI, M. (2007) Interação Universidade-Empresa no Brasil: Evidências do Diretório dos Grupos de Pesquisa do CNPq. *Estudos Econômicos*, v. 37, n. 2, pp. 212-233.

RAPINI, M.; ALBUQUERQUE, E.; SILVA, L.; SOUZA, S.; RIGHI, H.; CRUZ, W. (2006) *Spots of interaction*. Belo Horizonte: Cedeplar-UFMG (*Texto para Discussão* 286, http://www.cedeplar.ufmg.br/pesquisas/td/TD 286.pdf).

RIBEIRO, L. C.; RUIZ, R. M.; ALBUQUERQUE, E. M.; BERNARDES, A. T. (2006a). National systems of innovation and technological differentiation: a multi-country model. *International Journal of Modern Physics C*, v. 17, n. 2, pp. 247-257.

RIBEIRO, L. C.; RUIZ, R. M.; BERNARDES, A. T.; ALBUQUERQUE, E. M. (2006b). Science in the developing world: running twice as fast? *Computing in Science and Engineering*, v. 8, pp. 81-87, July.

ROSENBERG, N.; GELIJNS, A.; DAWKINS, H. (1995) *Sources of medical technology*: universities and industry (Medical innovation at the crossroads, v. 5). Washington: National Academy.

SCHMOCH, U. (1993) Tracing the knowledge transfer from science to technology as reflected in patent indicators. *Scientometrics*, v. 26, n. 1, pp. 193-211.

SCHMOCH, U. (1997) Indicators and the relations between science and technology. *Scientometrics*, v. 38, n. 1, pp. 103-116.

TIJSEN, R. (2004) Measuring and evaluating science-technology connections and interactions. In: MOED, H.; GLÄNZEL, W.; SCHMOCH, U. (eds). *Handbook of quantitative science and technology research*: the use of publication and patent statistics in studies of S&T systems. Dordrecht: Kluwer Academic Publishers, pp. 695-715.

TIJSSEN, R. J.; BUTER, R. K.; van LEEUWEN, N. (2000) Technological relevance of science: an assessment of citation linkages between patents and research papers. *Scientometrics*, v. 47, n. 2, pp. 389-412.

USPTO (2008). Site: http://www.uspto.gov.

VERBEEK, A.; DEBACKERE, K.; LUWEL,M.; ANDRIES, P.; ZIMMERMANN, E.; DELEUS, F. (2002a) Linking science to technology: using bibliographic references in patents to build linkages schemes. *Scientometrics*, v. 54, n. 3, pp. 399-420.

VERBEEK, A.; CALLAERT, J.; ANDRIES, P.; DEBACKERE, K.; LUWEL, M.; VEUGELERS, R. (2002b) *Science and technology interplay – a modelling approach on a regional level*. Final Report to the EC DG Research, Brussels.

VERBEEK, A.; DEBACKERE, K.; LUWEL, M. (2003) Science cited in patents: a geographic “flow” analysis of bibliographic citation patterns in patents. *Scientometrics*, v. 58, n. 2, pp. 241-263.

ZITT, M.; RAMANANA-RAHARY, S.; BASSECOULARD, E.; LAVILLE, F. (2003). Potential science-technology spillovers in regions: An insight on geographic co-location of knowledge activities in the EU. *Scientometrics*, v. 57, n. 2, pp. 295-320.