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THE SCIENTIFIC AND TECHNOLOGICAL TRAJECTORIES OF FOUR LATIN AMERICAN COUNTRIES: MEXICO, COSTA RICA, ARGENTINA, AND BRAZIL

Leonardo Costa Ribeiro
Isabel de Azeredo Moura
Luiza Teixeira de Melo Franco
Márcia Siqueira Rapini
Eduardo da Motta e Albuquerque

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UNIVERSIDADE FEDERAL DE MINAS GERAIS
FACULDADE DE CIÊNCIAS ECONÔMICAS
CENTRO DE DESENVOLVIMENTO E PLANEJAMENTO REGIONAL

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* This research note was presented at the Latin American Workshop on Interactions between Universities and Firms (Belo Horizonte, July 27 and 28, 2009). This manuscript is a summary of secondary data on science and technology in the four countries of our research, and it aims to contextualize the general conditions under which the interactions between universities and firms take place. This is one of the products of our research (Dutrénit et al, 2007). This research is supported by IDRC (Canadá), Fapemig, CNPq, and Fapesp.

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SUMÁRIO

ABSTRACT

This paper introduces the differences and similarities of interactions between science and technology (S&T) among four Latin American countries: Argentina, Brazil, Costa Rica and Mexico. Through the analysis of articles and patents data as well as the elaboration of global matrices and national three-dimensional matrices, it was possible to observe the recent trajectory of the scientific and technological production of countries. The results indicate that the Latin American countries have a similar pattern regarding their scientific and technological structure and they are part of a regime characterized by immature National Systems of Innovation (NSI).

RESUMO

Este artigo discute semelhanças e diferenças na forma como se processam as interações entre ciência e tecnologia em quatro países latino-americanos: Argentina, Brasil, Costa Rica e México. Para tanto são utilizados dados de artigos científicos e patentes, assim como matrizes de interação entre ciência e tecnologia. Os resultados indicam que os países analisados têm padrões muito similares em termos da sua trajetória tecnológica, na medida em que todos os quatro países encontram-se em um nível intermediário no cenário mundial, além de estarem sofrendo com o "efeito Rainha Vermelha". No geral, todos os quatro países podem ser classificados como sistemas imaturos de inovação.

Keywords: Latin American countries, science and technology interaction, national systems of innovation

JEL Classification: O, O3

I. INTRODUCTION

According to a vast literature, there is a strong correlation between science, technology and wealth. Based on this assertion, this introduction presents some indicators that provide information about the level of human, economic, scientific and technological development for Argentina, Brazil, Costa Rica and Mexico.

The Human Development Index (HDI) is a basic measure that summarizes the level of human development of countries in terms of health, education and economic indicators. The closer this index is from 1, the higher is the level of human development of a country.

As we can notice on table 1, Brazil presented in 2006, the smallest value of HDI, and it is, as a matter of fact, the only one among the selected countries with a value below Latin America and the Caribbean's mean. In fact, it is 24 positions behind Argentina in the list, occupying the 70th place in the global ranking. Argentina is the nation with the highest HDI, although its life expectancy at birth - one of the indexes that compose the HDI - is smaller than the ones from Costa Rica and Mexico. Mexico, in turn, presents the greatest Gross Domestic Product (GDP) *per capita*, followed by Argentina, Costa Rica and Brazil, respectively. On top of that, Mexico holds the second place regarding population, with approximately 105 millions of inhabitants. On the other hand, Brazil's population embraces more than a third of Latin America and the Caribbean's population and it has the most acute income inequality, represented by a 0.604 Gini coefficient. Costa Rica, on the other hand, presents the lowest income inequality, followed by Mexico and Argentina. According to the Gini index, a score of 0 indicates perfect equality and a score of 1 indicates perfect inequality.

Regarding the *per* thousand population who are first level university and master graduates, Costa Rica presents the best indicators, as we can see in table 2. The country's rate of first level university graduates is almost twice the Brazilian and Mexican ones and three times the Argentine one. This latter country is also responsible for the humblest relative number of master graduates: 0.04 per thousand people versus 0.17, 0.33 and 0.71 relative to Brazil, Mexico and Costa Rica, respectively. In the doctoral level, all four countries have a very similar participation but Brazil has a slightly higher rate. Furthermore, Costa Rica's expenditure on research and development (R&D) per researcher was, in 2004, higher than the ones relative to Brazil and Argentina in 2006. On the other hand, the country's expenditure on R&D as a percentage of GDP (0.41% in 2004) was similar to those from Mexico (0.46% in 2005) and Argentina (0.49% in 2006). While these three countries spent from 0.4% to 0.5% of the GDP in R&D, Brazil spent at least twice as much: 1.02%. Argentina presented the highest number of researchers per thousand people: 3.37 head count and 2.20 full-time equivalent. Despite being the home of over 50% of all Latin America and Caribbean's researchers, Brazil held the second position in terms of the proportion of head count and full-time equivalent researchers: 1.96 and 1.22, respectively. Considering the 2005 data relative to Costa Rica, the country comes in third place with less than half the rate of Brazil for head count researchers and less than a quarter for full-time researchers. The proportion of full-time researchers in Mexico is very similar to the Brazilian one: 1.03. However, it is very difficult to compare the participation of all head count researchers in Mexico per thousand people since only that data refers to 1995 whilst the ones from other countries refer to 2005 or 2006.

This manuscript has 5 sections, besides this introduction, that presents some overall data on human and economic development and S&T regarding Argentina, Brazil, Costa Rica and Mexico. Initially, it evaluates papers and patents data, which serves as basis for the elaboration of an analysis of a *per capita* scientific and technological production, presented in the second topic. The third and the fourth topics present an examination of the most important science and engineering fields (S&T fields) in terms of scientific and technological production of these countries, measured by the absolute and relative numbers of papers and patents, according to the Information Sciences Institute (ISI) and United States Patent and Trademark Office (USPTO), respectively. Topic III approach considers 5 years in time: 1974, 1982, 1990, 1998, 2006 (tables from 1982 and 1998 are not shown) and topic II examines 6 years in time: 1974, 1982, 1990, 1998, 2006 and 2008 (tables from 1982, 1998 and 2006 are not shown), which allows us to investigate the changes that took place in these countries throughout a considerable period of time. The fifth topic, in turn, presents national three-dimensional matrices (technological domains, S&E fields and number of references), which enables the identification of structured growth patterns. Finally, in the sixth topic we draw conclusions and highlight this mansucript's main contributions.

TABLE 1

Human and Economic Development Data. Argentina, Brazil, Costa Rica and Mexico, 2006

HDI rank	Country	Population * (millions of people)	Human development index (HDI) (Values between 0 and 1)	Life expectancy at birth ** (years)	GDP per capita ** (PPP US$)	Gini Coefficient *** (Values between 0 and 1)
46	Argentina	38.2	0.860	75.0	11,985	0.510 [1]
70	Brazil	186.8	0.807	72.0	8,949	0.604
50	Costa Rica	4.3	0.847	78.6	9,889 [2]	0.478
51	Mexico	104.9	0.842	75.8	12,176	0.506
	Latin America and the Caribbean	**551.8 [3]**	**0.810**	**73.1**	**9,051**	-

Sources: * The Network on Science and Technology Indicators - Ibero-American and Inter-American - RICYT
** The World Bank
*** Economic Commission for Latin America and the Caribbean - ECLAC
Notes: HDI: Human Development Index
GDP: Gross Domestic Product
[1] Greater Buenos Aires
[2] World Bank estimation based on regression
[3] Estimated Value

TABLE 2

Scientific and Technological Data. Argentina, Brazil, Costa Rica and Mexico, 2006

HDI rank		First level university		Master Graduates		Doctorates		Expenditure on R&D as a percentage of GDP	Number of Researchers per Thousand Labour		E Res
		Total	Per Thousand Population	Total	Per Thousand Population	Total	Per Thousand Population		Head Count	FTE	He
46	Argentina	82,294 [1]	2.15	1,697	0.04	685	0.02	0.49%	3.37	2.20	
70	Brazil	736,829	3.94	32,280	0.17	9,366	0.05	1.02%	1.96	1.22	
50	Costa Rica	26,800 [2]	6.23	3,067	0.71	111	0.03	0.41% [1]	0.76 [2]	0.28 [2]	
51	Mexico	331,807	3.16	34,393	0.33	1,910	0.02	0.46% [2]	0.73[3]	1.03 [2]	
	Latin America and the Caribbean **	**1,593,152**	**2.89**	**81,974**	**0.15**	**12,687**	**0.02**	**0.63%**	**1.58**	**0.96**	

Source: The Network on Science and Technology Indicators - Ibero-American and Inter-American - RICYT
Notes: HDI: Human Development Index
R&D: Research and Development
GDP: Gross Domestic Product
PPP: Purchasing Power Parity
FTE: Full-time Equivalent
[1] Data from 2004
[2] Data from 2005
[3] Data from 1995
* The estimation in dollars were done by applying the Purchasing Power Parity Indexes published by the World Bank (World Development Indicators 2008) according to local currency info
** Data from Latin America and the Caribeean are estimated
*** 43,922 in 2005

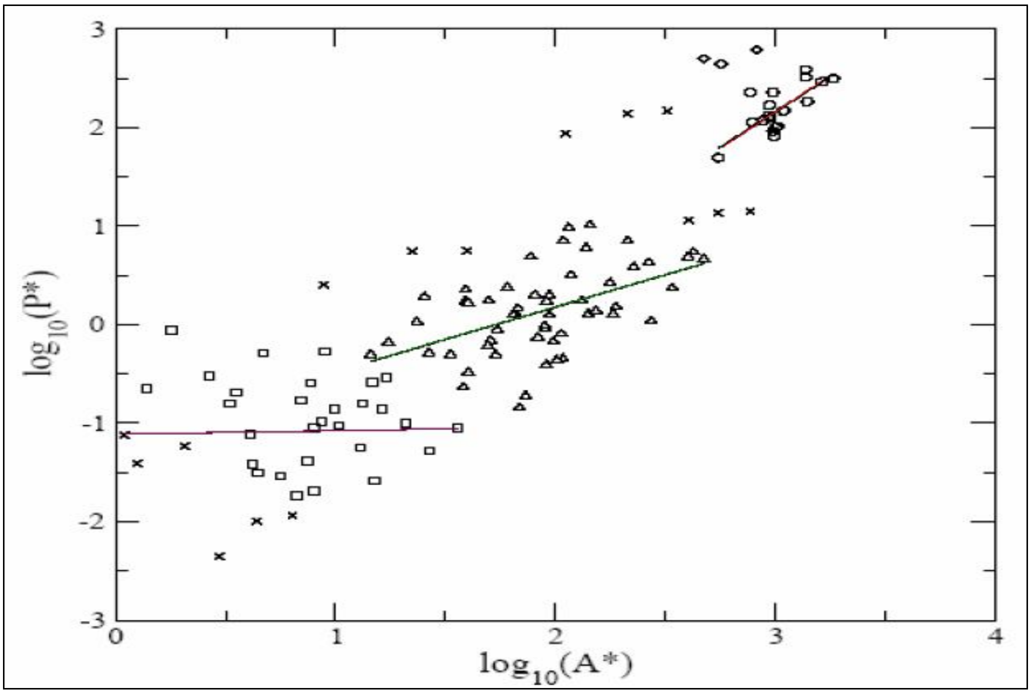
II. RED QUEEN EFFECT

In biology, the “Red Queen Effect” sets how fast the evolutionary machinery must operate for specific species in order to maintain its capabilities for competing to survive. When it is applied in a scientific and technological context, the “Red Queen Effect” means that countries may enlarge their scientific and technological production just to remain in the same position in a classification that concerns the National Systems of Innovation.

Ribeiro *et al*. (2006) applied a super-paramagnetic clustering technique based on the scientific and technological production – measured by scientific articles and patents - of 183 countries, from 1974 to 2003, and identified three Regimes in which nations were divided, distinguished by the interactions between their NSI. In Regime I, the scientific infra-structure is still too immature and incapable of fomenting a minimum technological production. Some African countries are part of this Regime. In Regime II, the scientific production is higher and capable of fomenting some technological production, but not enough to make a feedback effect viable in the scientific production. Regime III, in turn, is characterized by consistent connections and interactions between S&T, and the main determinant of economic increase is the S&T qualification. Hence, there is a strong necessity for catching-up countries to reach a critical mass of scientific production in order to achieve a higher stage of interaction between the scientific and technological dimensions (BERNARDES & ALBUQUERQUE, 2003).

The squares in figure I represent countries in Regime I, triangles belong to Regime II, and squares represent countries in Regime III. Countries represented by *x* are those that do not belong to any of these 3 Regimes.

FIGURE 1
Three Regimes according to the countries´ scientific and technological production.
All countries, 1999-2003



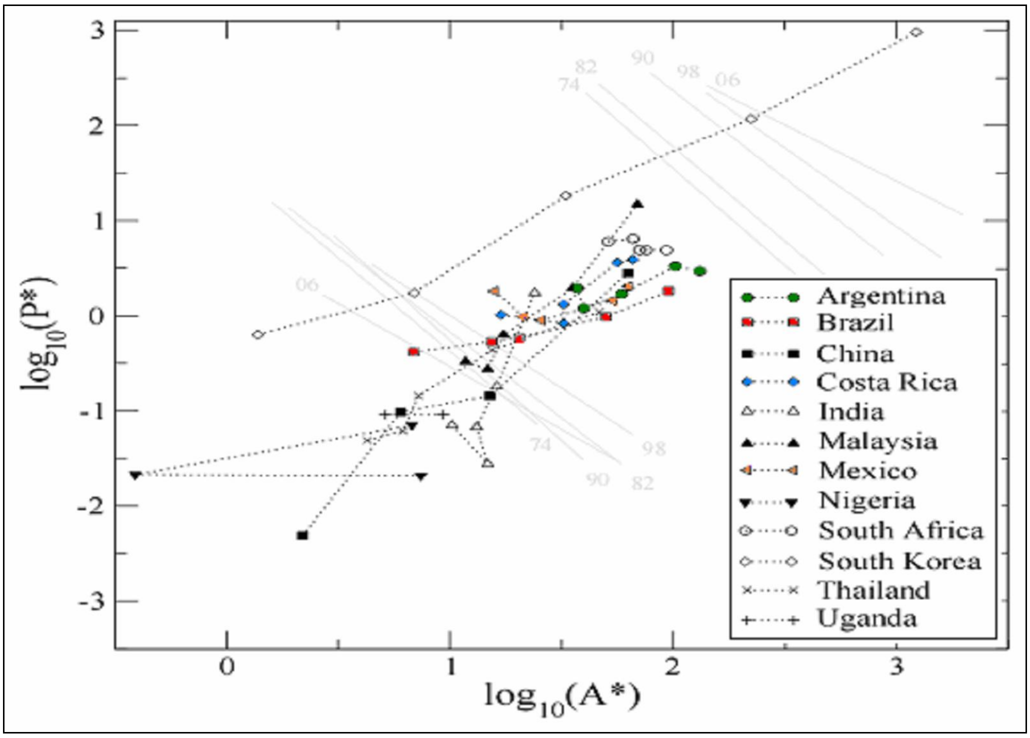
Source: Ribeiro *et al*., 2006.

In order to understand the behaviors of these Regimes, an exponential model was calculated, and the results indicated that there is a threshold in a continuous annual movement between Regimes II and III (a *per capita* increase of 6.6%) and another with a faster movement among Regimes I and II (a *per capita* increase of 4.2%), making it difficult for countries to leave their original groupings.

The same technique was applied to the countries indicated below in figure 2, displayed below, among which we can observe the four Latin American nations - Argentina, Brazil, Costa Rica and Mexico - in 5 selected years: 1974, 1982, 1990, 1998 and 2006.

FIGURE 2

Evolution of the *per capita* scientific and technological production for the selected countries. 1974, 1982, 1990, 1998 and 2006



Source: USPTO.

As we can see, South Korea as well as Taiwan (not shown in the graph) are examples of successful catching-up countries. They achieved impressive growth rates both in articles and in patens during the whole period and, therefore, their scientific and technological production rose in an articulated manner. In 1974, South Korea was in Regime I and moved upwards in the following periods, reaching Regime III in 1998. China's analysis only began in 1982, but it seems that this country has been following the Asian path, as well as Malaysia, which presented a high and regular increase in its scientific and technological production. China has reached Regime II in 2003 and, according to projections made by Ribeiro *et al*. (2006), it will join Regime III in 2050, *ceteris paribus*.

The Latin American countries, on the other hand, started, in 1974, their trajectory in Regime II (composed by immature NSIs) and they were not capable of reaching Regime III in the last period of the analysis. That means that they have followed a similar scientific and technological production path among themselves during the whole period. On top of that, they could not run faster than their moving thresholds, as the Asian countries did. Particularly in case of Brazil, as projected by Ribeiro *et al* (2006), if its trajectory continues, *ceteris paribus*, this country would join Regime III only in 2144.

III. SCIENTIFIC PRODUCTION

Tables 03, 04, 05 and 06 show the ten main specialization areas of Argentina, Brazil, Costa Rica and Mexico in terms of scientific production, respectively. Throughout the years, the number of articles raised in all these countries. This was true especially for Brazil, which experimented an enlargement of 3,449% between 1974 and 2008. Mexico had an increment of 1,440%, followed by Costa Rica, which produced 1,153% more articles in the last year of the analysis if compared to the first one. Argentina, on the other hand, was the country which had the most modest progress on its scientific production (an increase of approximately 654%) although it published, in 1974, more articles than any of the other countries.

This general increase entails a tendency of a smaller specialization within these countries along with a wider diversity of S&T fields. In fact, the first ten S&E fields reduced their percentage representation throughout the analyzed years. For instance, all articles that were published in Costa Rica in 1974 were related to at least one country´s ten first S&E field. This explains the S&E fields' participation of over 100% in the articles, once an article can be associated with more than one subject area. Regarding Argentina and Mexico, this participation was about 60% in 1974 for both countries. In the last period of analysis, Costa Rica's contribution dropped to approximately 60% and Argentina and Mexico to 40%. Nevertheless, Brazil was the least concentrated country in terms of S&E fields presenting a major dispersion in both years, bearing in mind that the top 10 specialization areas of the scientific production represented, in 1974, 55.1% of the total of papers, and 33.4% in 2008.

Regarding the scientific production specialization of these countries, we can notice that health and/or agriculture-related fields are the most important categories, especially in 1974, when the scientific production was more concentrated. This overall tendency has changed throughout the years and, in 2008, the countries presented a more wide-ranging structure. Although health and/or agriculture-related fields are still the prominent ones, subjects that are not related with these areas entered the ranking, mainly in Mexico. In 1974, this country was extremely specialized in health-related fields presenting 8 subjects related with this area. In 2008, on the other hand, only 2 S&E fields were within health-related fields, whereas 6 of the subjects were linked with fields different from health and/or agriculture-related ones. In 1974, Argentina was a very specialized country in health-related fields considering the fact that 9 out of the 10 disciplines in Argentina were associated with these fields. In 2008, 7 were the disciplines related with health and/or agriculture and three of them were not related with these S&E fields: Physical Chemistry, Multidisciplinary Physics and Astronomy & Astrophysics. Brazil differs from this pattern with 6 health and/or agriculture-related disciplines in 1974 and 4 of them with other fields. In 2008, we can notice a shift towards a concentration in health-related fields. Furthermore, there is no subject, in the top 10 ranking related with an area different from health or agriculture. Despite experiencing a change in its disciplines from 1974 to 2008, Costa Rica maintained its concentration pattern in agriculture and mainly in health-related fields.

In 1974, General & Internal Medicine was the only common area among all countries despite the fact that, from 1998 on, this discipline did not occupy any position in the rankings. On the other hand, in 2008, Plant Science field appeared in all rankings. In addition to that, important changes occurred throughout the 34 years of analysis and only a few discipline areas remained in the countries' top 10 ranking. With regards to Argentina and Costa Rica, only one common discipline was observed both in 1974 and 2008: Biochemistry & Molecular Biology and Ecology, respectively. Biochemistry & Molecular Biology and Pharmacology & Pharmacy were the disciplines that appeared in both years in the Brazilian top 10 ranking. Mexico's list, in turn, was the country that most presented stability, although seven disciplines changed during the analyzed period. Biochemistry & Molecular Biology, Physics Multidisciplinary and Astronomy & Astrophysics were the remaining ones.

TABLE 03

Top 10 ISI science disciplines. Argentina, 1974, 1990 and 2008

Argentina, 1974

	Area	N°	%
1	Medicine, Research & Experimental	131	15.2
2	Medicine, General & Internal	96	11.2
3	Biochemistry & Molecular Biology	76	8.8
4	Physiology	59	6.9
5	Chemistry, Multidisciplinary	42	4.9
6	Biophysics	37	4.3
7	Endocrinology & Metabolism	31	3.6
8	Pharmacology & Pharmacy	25	2.9
9	Multidisciplinary Sciences	21	2.4
10	Biology	20	2.3
	Subtotal	**538**	**62.6**
	Total	**860**	**100.0**

Argentina, 1990

	Area	N°	%
1	Biochemistry & Molecular Biology	136	7.3
2	Medicine, Research & Experimental	111	6.0
3	Pharmacology & Pharmacy	108	5.8
4	Chemistry, Physical	97	5.2
5	Plant Sciences	79	4.2
6	Chemistry, Multidisciplinary	77	4.1
7	Medicine, General & Internal	69	3.7
8	Physiology	69	3.7
9	Physics, Condensed Matter	68	3.7
10	Astronomy & Astrophysics	64	3.4
	Subtotal	**878**	**47.1**
	Total	**1,863**	**100.0**

Argentina, 2008

	Area	N°	%
1	Biochemistry & Molecular Biology	329	5.8
2	Chemistry, Physical	326	5.8
3	Plant Sciences	246	4.4
4	Food Science & Technology	210	3.7
5	Microbiology	202	3.6
6	Zoology	192	3.4
7	Ecology	185	3.3
8	Physics, Multidisciplinary	182	3.2
9	Environmental Sciences	178	3.2
10	Astronomy & Astrophysics	173	3.1
	Subtotal	**2,223**	**39.5**
	Total	**5,625**	**100.0**

Source: ISI.

TABLE 04

Top 10 ISI science disciplines. Brazil, 1974, 1990 and 2008

Brazil, 1974

	Area	N°	%
1	Medicine, General & Internal	83	11.8
2	Multidisciplinary Sciences	79	11.2
3	Biochemistry & Molecular Biology	43	6.1
4	Pharmacology & Pharmacy	38	5.4
5	Physics, Condensed Matter	35	5.0
6	Physics, Multidisciplinary	29	4.1
7	Mathematics	25	3.5
8	Genetics & Heredity	20	2.8
9	Public, Environmental & Occupational Health	19	2.7
10	Plant Sciences	18	2.5
	Subtotal	**389**	**55.1**
	Total	**706**	**100.0**

Brazil, 1990

	Area	N°	%
1	Agriculture, Multidisciplinary	210	7.5
2	Biology	157	5.6
3	Biochemistry & Molecular	146	5.2
4	Tropical Medicine	137	4.9
5	Physics, Multidisciplinary	134	4.8
6	Genetics & Heredity	121	4.3
7	Physics, Condensed Matter	114	4.1
8	Pharmacology & Pharmacy	98	3.5
9	Astronomy & Astrophysics	88	3.1
10	Medicine, General & Internal	81	2.9
	Subtotal	**1,286**	**45.9**
	Total	**2,804**	**100.0**

Brazil, 2008

	Area	N°	%
1	Veterinary Sciences	985	4.0
2	Biochemistry & Molecular Biology	982	4.0
3	Pharmacology & Pharmacy	923	3.8
4	Agriculture, Multidisciplinary	916	3.8
5	Dentistry, Oral Surgery & Medicine	825	3.4
6	Zoology	768	3.2
7	Plant Sciences	751	3.1
8	Neurosciences	707	2.9
9	Chemistry, Multidisciplinary	653	2.7
10	Agronomy	616	2.5
	Subtotal	**8,126**	**33.4**
	Total	**24,353**	**100.**

Source: ISI

TABLE 05

Top 10 ISI science disciplines. Costa Rica, 1974, 1990 and 2008

Costa Rica, 1974

	Area	N°	%
1	Agronomy	16	53.3
2	Medicine, General & Internal	3	10.0
3	Public, Environmental & Occupational Health	3	10.0
4	Ecology	2	6.7
5	Multidisciplinary Sciences	2	6.7
6	Tropical Medicine	2	6.7
7	Biotechnology & Applied Microbiology	1	3.3
8	Evolutionary Biology	1	3.3
9	Microbiology	1	3.3
10	Pathology	1	3.3
	Subtotal	**32**	**106.7**
	Total	**30**	**100.0**

Costa Rica, 1990

	Area	N°	%
1	Agronomy	30	27.8
2	Biology	20	18.5
3	Pharmacology & Pharmacy	7	6.5
4	Ecology	6	5.6
5	Toxicology	5	4.6
6	Agriculture, Multidisciplinary	4	3.7
7	Biochemistry & Molecular Biology	4	3.7
8	Entomology	4	3.7
9	Plant Sciences	4	3.7
10	Public, Environmental & Occupational Health	4	3.7
	Subtotal	**88**	**81.5**
	Total	**108**	**100.0**

Costa Rica, 2008

	Area	N
1	Biology	5
2	Ecology	3
3	Environmental Sciences	2
4	Entomology	1
5	Forestry	1
6	Plant Sciences	1
7	Zoology	1
8	Marine & Freshwater Biology	1
9	Genetics & Heredity	1
10	Biodiversity Conservation	1
	Subtotal	**21**
	Total	**34**

Source: ISI.

TABLE 06

Top 10 ISI science disciplines. Mexico, 1974, 1990 and 2008

Mexico, 1974			
	Area	N°	%
1	Medicine, General & Internal	104	20.2
2	Medicine, Research & Experimental	70	13.6
3	Cardiac & Cardiovascular Systems	52	10.1
4	Biochemistry & Molecular Biology	22	4.3
5	Obstetrics & Gynecology	22	4.3
6	Pathology	17	3.3
7	Endocrinology & Metabolism	14	2.7
8	Physics, Multidisciplinary	13	2.5
9	Astronomy & Astrophysics	11	2.1
10	Reproductive Biology	11	2.1
	Subtotal	**336**	**65.1**
	Total	**516**	**100.0**

Mexico, 1990			
	Area	N°	%
1	Medicine, General & Internal	86	6.7
2	Plant Sciences	68	5.3
3	Biochemistry & Molecular Biology	64	5.0
4	Medicine, Research & Experimental	61	4.8
5	Astronomy & Astrophysics	58	4.5
6	Neurosciences	52	4.1
7	Physics, Condensed Matter	45	3.5
8	Pharmacology & Pharmacy	44	3.4
9	Agronomy	43	3.4
10	Physics, Multidisciplinary	42	3.3
	Subtotal	**563**	**43.9**
	Total	**1,283**	**100.0**

Mexico, 2008			
	Area	N°	%
1	Plant Sciences	327	4.4
2	Physics, Multidisciplinary	313	4.2
3	Biochemistry & Molecular	299	4.0
4	Materials Science,	299	4.0
5	Chemistry, Physical	294	4.0
6	Astronomy & Astrophysics	287	3.9
7	Environmental Sciences	269	3.6
8	Ecology	260	3.5
9	Physics, Applied	254	3.4
10	Marine & Freshwater Biology	223	3.0
	Subtotal	**2,825**	**38.0**
	Total	**7,434**	**100.0**

Source: ISI.

IV. TECNOLOGICAL PRODUCTION

The technological specialization areas of Argentina, Brazil, Costa Rica and Mexico are displayed in tables 7, 8, 9 and 10, respectively. They allow us to conclude that the trajectory of patents production is not similar among the countries. In fact, Brazil was the only country exhibiting a linear trajectory, with a gradual increase in the number of granted patents throughout the years: an average raise of 171% among the selected years, and an increase of approximately 727% in the whole period. Argentina, on the other hand, experienced, from 1974 to 1982, a decline in the number of patents granted - as we have already mentioned in the second topic of this paper - dropping from 60, in 1974, to 51, in 1982. Mexico, in turn, presented a drop of 16.8% in 1990 in comparison to 1982, but, in 1998 and in 2006, it recovered its trajectory of ascension. Costa Rica was the country that presented the most unstable trajectory: in 1974, the total number of granted patents was 17, but, in 1982, it declined to 7 (the same value of the year 1990). In 1998, Costa Rica's situation deteriorated and did not present any patent granted in USPTO. Nevertheless, eight years later, in 2006, this country had a boost and presented the greatest number of patents of all selected years. This pattern, in fact, was the same for all countries, considering that all of them presented, in 2006, more granted patents in comparison to the first year of the analysis, evidencing a technological progress throughout the years.

A comparison with the scientific production analysis, made in topic III of this paper, allows us to conclude that there is no articulation within the national systems of innovation of the selected countries, once most technological sub-domains are not associated with health and/or agriculture, as we have noticed in the scientific fields. The lack of scientific and technological connection has not changed during the analyzed period, as well as the sub-domains did not suffer greater shifts in terms of ranking along the years in all of these countries, except Costa Rica. Sub-domains tend to occupy different positions according to the year of the analysis, but the majority of them do not leave the ranking. For instance, Costa Rica presented, in all the selected years, 6 sub-domains in the ranking, and only 1 of them, relative to the 1974 list, repeated itself in 2006. However, in Mexico, 7 out of the 10 first specialization areas of technological production, in 1974, could also be found in the 2006 list. In Argentina, 8 out of these top 10 areas relative to 1974 were also in the 2006 list. On the other hand, the sub-domains were all the same for both years in the Brazilian case.

TABLE 7

USPTO granted patents per technological sub-domain. Argentina, 1974, 1990 and 2006

Argentina - 1974			
	Technological Sub-domain	N°	%
1	Handling and printing	14	23,3
2	Medical engineering	6	10,0
3	Consumer goods and equipment	6	10,0
4	Audiovisual	5	8,3
5	Engines, pumps and turbines	5	8,3
6	Electrical components	4	6,7
7	Analysis, measurement and control	3	5,0
8	Material processing	3	5,0
9	Agricultural and food machinery	3	5,0
10	Civil engineering and building	3	5,0
11	Agricultural and food products	2	3,3
12	Mechanical components	2	3,3
13	Space technology and weapons	2	3,3
14	Surface technology and coating	1	1,7
15	Environment and pollution	1	1,7
16	Telecommunications	0	0,0
17	Information technology	0	0,0
18	Semiconductors	0	0,0
19	Optics	0	0,0
20	Organic fine chemicals	0	0,0
21	Macromolecular chemistry	0	0,0
22	Pharmaceuticals and cosmetics	0	0,0
	Total	60	100,0

Argentina - 1990			
	Technological Sub-domain	N°	%
1	Handling and printing	18	21,4
2	Consumer goods and equipment	12	14,3
3	Agricultural and food products	9	10,7
4	Civil engineering and building	8	9,5
5	Technical procedures	7	8,3
6	Thermal techniques	5	6,0
7	Materials and metallurgy	4	4,8
8	Audiovisual	3	3,6
9	Organic fine chemicals	3	3,6
10	Electrical components	2	2,4
11	Macromolecular chemistry	2	2,4
12	Pharmaceuticals and cosmetics	2	2,4
13	Environment and pollution	2	2,4
14	Analysis, measurement and control	1	1,2
15	Biotechnology	1	1,2
16	Material processing	1	1,2
17	Machine tools	1	1,2
18	Mechanical components	1	1,2
19	Agricultural and food machinery	1	1,2
20	Transport	1	1,2
21	Telecommunications	0	0,0
22	Information technology	0	0,0
	Total	84	100,0

Argentina - 2006			
	Technological Sub-domain	N°	%
1	Pharmaceuticals and cosmetics	50	21,6
2	Basic chemical processing	33	14,2
3	Consumer goods and equipment	28	12,1
4	Organic fine chemicals	19	8,2
5	Engines, pumps and turbines	18	7,8
6	Agricultural and food products	16	6,9
7	Telecommunications	13	5,6
8	Analysis, measurement and control	8	3,4
9	Agricultural and food machinery	7	3,0
10	Medical engineering	5	2,2
11	Macromolecular chemistry	5	2,2
12	Mechanical components	5	2,2
13	Biotechnology	4	1,7
14	Technical procedures	4	1,7
15	Transport	4	1,7
16	Audiovisual	3	1,3
17	Information technology	3	1,3
18	Electrical components	2	0,9
19	Optics	2	0,9
20	Machine tools	1	0,4
21	Handling and printing	1	0,4
22	Nuclear engineering	1	0,4
	Total	232	100,0

Source: USPTO

TABLE 8

USPTO granted patents per technological sub-domain. Brazil, 1974, 1990 and 2006

Brazil - 1974			
	Technological Sub-domain	N°	%
1	Consumer goods and equipment	12	20,3
2	Agricultural and food products	11	18,6
3	Mechanical components	8	13,6
4	Transport	7	11,9
5	Information technology	4	6,8
6	Analysis, measurement and control	3	5,1
7	Medical engineering	3	5,1
8	Technical procedures	3	5,1
9	Electrical components	2	3,4
10	Basic chemical processing	2	3,4
11	Optics	1	1,7
12	Thermal techniques	1	1,7
13	Machine tools	1	1,7
14	Handling and printing	1	1,7
15	Audiovisual	0	0,0
16	Telecommunications	0	0,0
17	Semiconductors	0	0,0
18	Organic fine chemicals	0	0,0
19	Macromolecular chemistry	0	0,0
20	Pharmaceuticals and cosmetics	0	0,0
21	Biotechnology	0	0,0
22	Surface technology and coating	0	0,0
23	Material processing	0	0,0
24	Materials and metallurgy	0	0,0
25	Environment and pollution	0	0,0
26	Engines, pumps and turbines	0	0,0
27	Agricultural and food machinery	0	0,0
28	Nuclear engineering	0	0,0
29	Space technology and weapons	0	0,0
30	Civil engineering and building	0	0,0
	Total	59	100,0

Brazil - 1990			
	Technological Sub-domain	N°	%
1	Engines, pumps and turbines	18	11,0
2	Materials and metallurgy	17	10,4
3	Consumer goods and equipment	17	10,4
4	Electrical components	13	8,0
5	Mechanical components	13	8,0
6	Macromolecular chemistry	10	6,1
7	Agricultural and food products	10	6,1
8	Machine tools	10	6,1
9	Handling and printing	10	6,1
10	Civil engineering and building	8	4,9
11	Medical engineering	7	4,3
12	Surface technology and coating	5	3,1
13	Basic chemical processing	5	3,1
14	Agricultural and food machinery	5	3,1
15	Technical procedures	4	2,5
16	Thermal techniques	3	1,8
17	Space technology and weapons	2	1,2
18	Audiovisual	1	0,6
19	Analysis, measurement and control	1	0,6
20	Organic fine chemicals	1	0,6
21	Pharmaceuticals and cosmetics	1	0,6
22	Biotechnology	1	0,6
23	Transport	1	0,6
24	Telecommunications	0	0,0
25	Information technology	0	0,0
26	Semiconductors	0	0,0
27	Optics	0	0,0
28	Material processing	0	0,0
29	Environment and pollution	0	0,0
30	Nuclear engineering	0	0,0
	Total	163	100,0

Brazil - 2006			
	Technological Sub-domain	N°	%
1	Consumer goods and equipment	38	8,9
2	Material processing	35	8,2
3	Basic chemical processing	33	7,7
4	Biotechnology	27	6,3
5	Engines, pumps and turbines	27	6,3
6	Mechanical components	26	6,1
7	Analysis, measurement and control	22	5,1
8	Pharmaceuticals and cosmetics	22	5,1
9	Machine tools	19	4,4
10	Information technology	17	4,0
11	Civil engineering and building	17	4,0
12	Agricultural and food products	15	3,5
13	Technical procedures	15	3,5
14	Organic fine chemicals	14	3,3
15	Thermal techniques	14	3,3
16	Medical engineering	11	2,6
17	Transport	11	2,6
18	Agricultural and food machinery	10	2,3
19	Electrical components	9	2,1
20	Materials and metallurgy	8	1,9
21	Handling and printing	8	1,9
22	Telecommunications	7	1,6
23	Macromolecular chemistry	6	1,4
24	Surface technology and coating	5	1,2
25	Environment and pollution	5	1,2
26	Audiovisual	4	0,9
27	Optics	3	0,7
28	Space technology and weapons	1	0,2
29	Semiconductors	0	0,0
30	Nuclear engineering	0	0,0
	Total	429	100,0

Source: USPTO

TABLE 9

USPTO granted patents per technological sub-domain. Costa Rica, 1974, 1990 and 2006

Costa Rica - 1974			
	Technological Sub-domain	N°	%
1	Agricultural and food products	8	47,1
2	Technical procedures	6	35,3
3	Agricultural and food machinery	2	11,8
4	Environment and pollution	1	5,9
5	Electrical components	0	0,0
6	Audiovisual	0	0,0
	Total	17	100,0

Costa Rica - 1990			
	Technological Sub-domain	N°	%
1	Consumer goods and equipment	6	85,7
2	Analysis, measurement and contr	1	14,3
3	Electrical components	0	0,0
4	Audiovisual	0	0,0
5	Telecommunications	0	0,0
6	Information technology	0	0,0
	Total	7	100,0

Costa Rica - 2006			
	Technological Sub-domain	N°	%
1	Handling and printing	16	55,2
2	Basic chemical processing	5	17,2
3	Pharmaceuticals and cosmetics	3	10,3
4	Technical procedures	2	6,9
5	Consumer goods and equipment	2	6,9
6	Analysis, measurement and cont	1	3,4
	Total	29	100,0

Source: USPTO

TABLE 10

USPTO granted patents per technological sub-domain. Mexico, 1974, 1990 and 2006

	Mexico - 1974		
	Technological Sub-domain	**Nº**	**%**
1	Organic fine chemicals	29	23,0
2	Materials and metallurgy	18	14,3
3	Mechanical components	9	7,1
4	Technical procedures	8	6,3
5	Handling and printing	8	6,3
6	Electrical components	7	5,6
7	Medical engineering	7	5,6
8	Civil engineering and building	7	5,6
9	Environment and pollution	6	4,8
10	Machine tools	4	3,2
11	Consumer goods and equipment	4	3,2
12	Optics	3	2,4
13	Analysis, measurement and control	3	2,4
14	Material processing	3	2,4
15	Engines, pumps and turbines	3	2,4
16	Transport	3	2,4
17	Thermal techniques	2	1,6
18	Agricultural and food machinery	2	1,6
19	Audiovisual	0	0,0
20	Telecommunications	0	0,0
21	Information technology	0	0,0
22	Semiconductors	0	0,0
23	Macromolecular chemistry	0	0,0
24	Pharmaceuticals and cosmetics	0	0,0
	Total	**126**	**100,0**

	Mexico - 1990		
	Technological Sub-domain	**Nº**	**%**
1	Material processing	17	13,2
2	Handling and printing	17	13,2
3	Consumer goods and equipment	15	11,6
4	Civil engineering and building	13	10,1
5	Surface technology and coating	11	8,5
6	Transport	7	5,4
7	Organic fine chemicals	6	4,7
8	Pharmaceuticals and cosmetics	6	4,7
9	Materials and metallurgy	6	4,7
10	Basic chemical processing	6	4,7
11	Electrical components	5	3,9
12	Medical engineering	5	3,9
13	Biotechnology	4	3,1
14	Agricultural and food products	4	3,1
15	Mechanical components	3	2,3
16	Analysis, measurement and control	1	0,8
17	Technical procedures	1	0,8
18	Thermal techniques	1	0,8
19	Agricultural and food machinery	1	0,8
20	Audiovisual	0	0,0
21	Telecommunications	0	0,0
22	Information technology	0	0,0
23	Semiconductors	0	0,0
24	Optics	0	0,0
	Total	**129**	**100,0**

	Mexico - 2006		
	Technological Sub-domain	**Nº**	**%**
1	Material processing	43	17,2
2	Electrical components	33	13,2
3	Analysis, measurement and control	22	8,8
4	Consumer goods and equipment	20	8,0
5	Telecommunications	17	6,8
6	Thermal techniques	17	6,8
7	Machine tools	15	6,0
8	Information technology	11	4,4
9	Materials and metallurgy	10	4,0
10	Transport	10	4,0
11	Technical procedures	8	3,2
12	Surface technology and coating	8	3,2
13	Audiovisual	7	2,8
14	Handling and printing	7	2,8
15	Semiconductors	3	1,2
16	Pharmaceuticals and cosmetics	3	1,2
17	Basic chemical processing	3	1,2
18	Agricultural and food machinery	3	1,2
19	Optics	2	0,8
20	Medical engineering	2	0,8
21	Agricultural and food products	2	0,8
22	Engines, pumps and turbines	2	0,8
23	Mechanical components	1	0,4
24	Civil engineering and building	1	0,4
	Total	**250**	**100,0**

Source: USPTO

V. MATRICES

The theoretical and empirical support for the matrices and its tri-dimensional graphic representation presented in this paper comes from Ribeiro *et al*. (2009), an article based in a rich literature on patents citing scientific papers and other non-patent references as tools for evaluating science and technology linkages. In this work, we introduce matrices with USPTO patents data for 5 years (1974, 1982, 1990, 1998 and 2006), collected and processed for 15 selected countries, summarized in table 11, 12 and 13. Moreover, we present the graphical representation of matrices for 4 Latin American countries: Argentina, Brazil, Costa Rica and Mexico. This procedure enables us to perform an inter-temporal comparison among these countries.

As it was explained by Ribeiro e*t al*. (2009), the construction of a matrix consists of an algorithm which prepares the matrices of S&T interactions in three stages. Initially, the patents' classes are processed to organize these patents according to technological sub-domains prepared by the *Observatoire des Sciences et Techniques*. After that, the algorithm identifies all citations made by these USPTO patents to S&E literature, records them and then, the algorithm processes the cited S&E literature and organizes it according to a classification prepared by the Institute for Scientific Information. As result, each line of the three dimensional *x*-axis graphic corresponds to one OST technological sub-domain; each column of the *y*-axis corresponds to one ISI S&E field; and the *z*-axis, N, corresponds to the number of citations that patents in a specific OST technological sub-domain assigns to a specific S&E field. Each matrix cell informs how many citations were made in patents classified in a specific technological area, relative to S&E literature classified in a specific scientific area (RIBEIRO *et al*., 2009).

An analysis of figures 3, 4, 5 and 6 presented further on, shows the dynamics involved in the interactions between S&T over time and allows us to evidence the differences and similarities among the 4 Latin American countries selected, characterized by different levels of development. The main similarity of these countries is that they are in an intermediary level of development and, as presented in topic II, they are all part of Regime II. Besides, with some exception of specific years - e.g. Brazil in 1982 and Mexico in 2006 - there is a matrix fulfillment over time, although it is still an incomplete process, considering the great number of empty cells in the last period. There is also a general growth in the number of S&E literature citations, noticed by the increase in the number of citations reached by the peaks in the figures, relative to the Z-axis.

Table 11 presents the matrix fulfillment index (MFI), a tool which allows us to comprehend better the inter-country comparability regarding the interaction between science and technology. As we can notice along this analysis, table 11 describes a global and persistent increase in this indicator although it has some exceptions, e.g. Brazil between 1974 and 1982 and South Africa and Mexico between 1998 and 2006. On the other hand, table 11 differentiates countries according to their MFI percentages. In 2006, there were big and rich countries with MFIs greater than 80% (USA, Japan and Germany); small and rich countries that presented MFIs between 50% and 80% (South Korea, Sweden, Netherlands, Taiwan); and countries with MFIs below 50%, among which there were big countries with dynamic economies, such as China and India, characterized by MFIs greater than 40%, and the 4 Latin American countries, whose MFIs vary from 0,5% (Costa Rica) to 14,9% (Argentina).

TABLE 11

Matrix fulfillment index to 15 selected countries.
1974, 1982, 1990, 1998 and 2006

	MATRIX FULFILLMENT INDEX (OST DOMAINS X ISI DISCIPLINES)				
	1974	1982	1990	1998	2006
WORLD	65,8%	80,0%	97,8%	98,9%	99,8%
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%
SOUTH AFRICA	0,2%	3,8%	7,2%	13,3%	12,1%
INDONESIA	0,0%	0,0%	0,0%	1,6%	1,6%
ARGENTINA	0,4%	0,4%	1,6%	11,1%	14,9%
BRAZIL	0,4%	0,0%	4,1%	6,3%	14,7%
COSTA RICA	0,0%	0,0%	0,0%	0,0%	0,5%
MEXICO	0,1%	0,9%	2,1%	9,3%	3,2%

Source: USPTO

Table 12 presents the matrix height and the matrix rugosity. The first one demonstrates a general increase in the matrices height over time, which means that the average citation per matrix cell is increasing systematically. Some exceptions were noticed: South Africa, Mexico and Indonesia, between 1998 and 2006, and Brazil between 1974 and 1982. The matrix thickness or rugosity, in turn, evidences that the growth process of matrices surfaces is not wholly random otherwise, while the matrix height kept on growing, the matrix rugosity would be stable. Therefore, the similar behavior among the two matrices suggests that the relation between science and technology is also not random.

TABLE 12

Matrix height and matrix thickness to 15 selected countries.
1974, 1982, 1990, 1998 and 2006

	MATRIX HEIGHT (AVERAGE CITATION PER MATRIX CELLS)				
	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
NETHERLANDS	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
SOUTH AFRICA	0,00	0,15	0,40	1,96	1,29
INDONESIA	0,00	0,00	0,00	0,10	0,04
ARGENTINA	0,00	0,01	0,03	1,62	2,60
BRAZIL	0,01	0,00	0,10	0,22	1,44
COSTA RICA	0,00	0,00	0,00	0,00	0,01
MEXICO	0,03	0,06	0,12	0,87	0,18

	MATRIX THICKNESS (RUGOSITY)				
	1974	1982	1990	1998	2006
WORLD	5,16	22,18	56,81	283,56	399,96
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
NETHERLANDS	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
SOUTH AFRICA	0,00	0,05	0,08	0,40	0,22
INDONESIA	0,00	0,00	0,00	0,03	0,02
ARGENTINA	0,00	0,00	0,01	0,28	0,48
BRAZIL	0,01	0,00	0,04	0,04	0,20
COSTA RICA	0,00	0,00	0,00	0,00	0,00
MEXICO	0,03	0,02	0,04	0,15	0,07

Source: USPTO

Table 13 presents the inter-temporal correlation between matrices of the selected countries, which allows us to compare the surfaces of the matrices and to differentiate mature and immature systems of innovation.

Considering the whole period, it is possible to divide the countries into two large groups: one with correlation greater or equal to 0.3, composed by countries characterized by persistence and innovative capacity and by higher MFIs throughout the whole period (USA, Japan, Germany, Sweden and Netherlands), and another one with correlation smaller than 0.3 (the remaining ones, including the selected Latin American countries). This last group is more diversified. South Korea and Taiwan have a similar pattern, once they have reached a high inter-temporal correlation after 1998, whereas Brazil and South Africa presented a much smaller increase over time. Argentina was the only Latin American country to present a correlation higher than 0.3 and Mexico the only one with a negative correlation in this period. Costa Rica, in turn, did not make any progress throughout the years, presenting a constant null correlation. Although it is not Mexico’s situation, temporary decreases in inter-temporal correlation for less-developed countries may be positive, since it is a pursuit for a new development pattern and, in case of developed countries, it may indicate an ongoing technological revolution.

TABLE 13

Matrices of inter-temporal correlation to 15 selected countries.
1974, 1982, 1990, 1998 and 2006

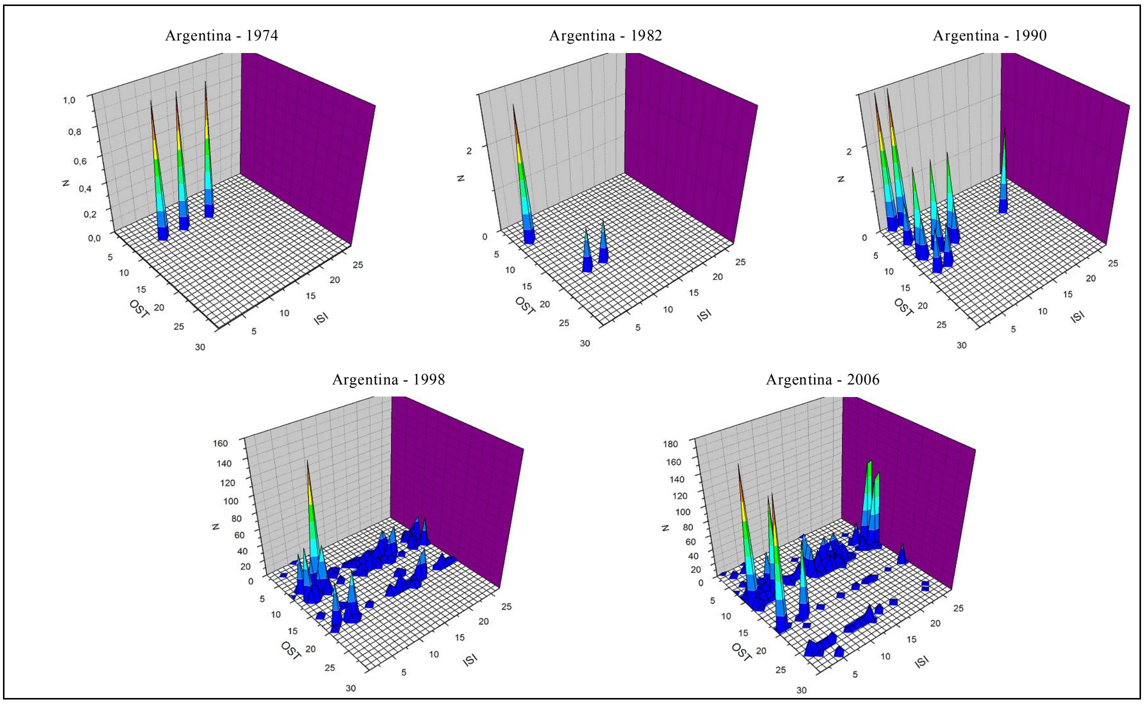
	MATRICES INTER-TEMPORAL CORRELATION				
	1974-1982	1982-1990	1990-1998	1998-2006	1974-2006
WORLD	0,93	0,91	0,87	0,83	0,60
UNITED STATES	0,91	0,88	0,85	0,79	0,61
JAPAN	0,90	0,88	0,88	0,87	0,69
GERMANY	0,80	0,93	0,94	0,83	0,57
SOUTH KOREA	0,00	0,00	0,59	0,82	0,00
SWEDEN	0,40	0,34	0,56	0,73	0,36
NETHERLANDS	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
SOUTH AFRICA	-0,01	0,02	0,12	0,16	-0,01
INDONESIA	0,00	0,00	0,00	-0,01	0,00
ARGENTINA	0,00	0,14	0,25	0,36	-0,01
BRAZIL	0,00	0,00	0,27	0,27	0,03
COSTA RICA	0,00	0,00	0,00	0,00	0,00
MEXICO	0,00	-0,01	0,18	-0,02	0,00

Source: USPTO

Even though the points of interaction advance over time, decreasing the number of empty cells mainly in the Brazilian and Argentine matrices, all of the selected countries still present incomplete matrices, characterized by areas with empty matrix cells, as it is possible to notice in figures 3, 4, 5 and 6. Brazil, specifically, presented an unstable process of increasing matrix filling, once there were no patents with S&E literature citation in 1982. Moreover, there are important inter-temporal differences between the cells that express points of interaction between science and technology: the countries' peaks presented in a specific year change position when compared with another one, representing the variation of scientific and technological linkages throughout the years, and the cells filled in a specific year are not necessarily are the same in another year, which means that there is not a stable correlation among two specific scientific and technological domains. Mexico presents this same pattern until 1998, but this country has suffered a retrocession in the scientific and technological production in 2006, as it presented emptier matrix cells comparing to 1998. Costa Rica, in turn, did not present granted patents in the first 4 selected years of the analysis, which means it will be necessary an analysis from 2006 on to comprehend the leading pattern.

FIGURE 3

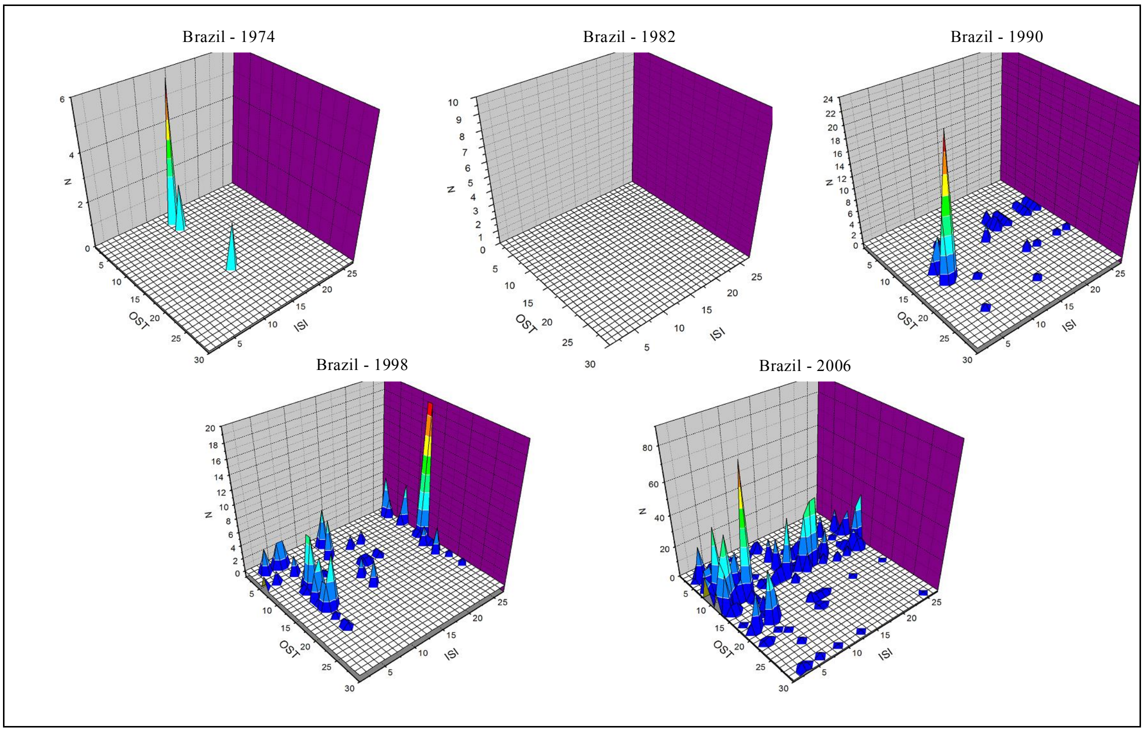
Matrices of science and technology interactions. Argentina, 1974, 1982, 1990, 1998 and 2006



Source: USPTO.

FIGURE 4

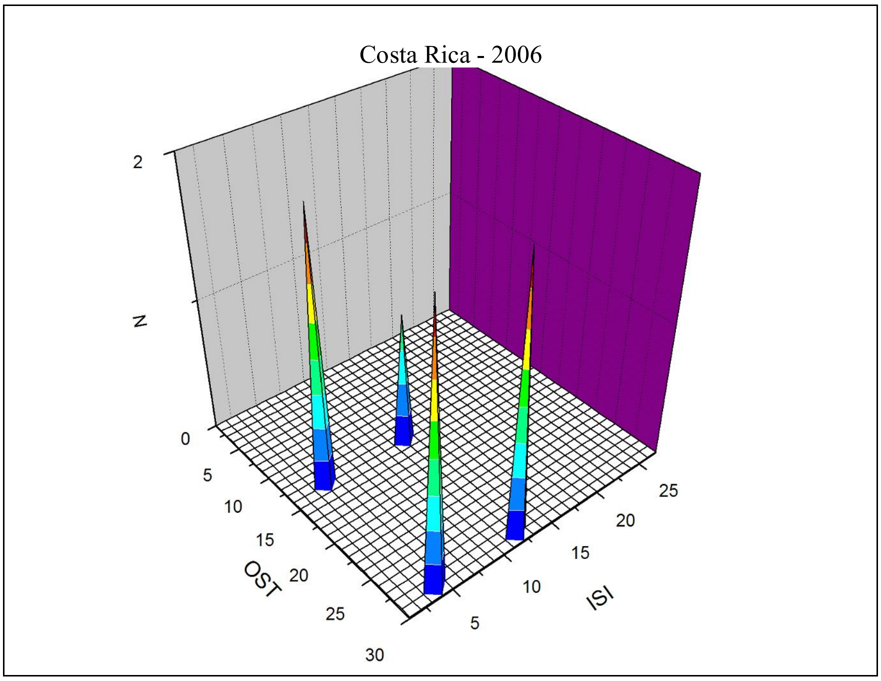
Matrices of science and technology interactions. Brazil, 1974, 1982, 1990, 1998 and 2006



Source: USPTO.

FIGURE 5

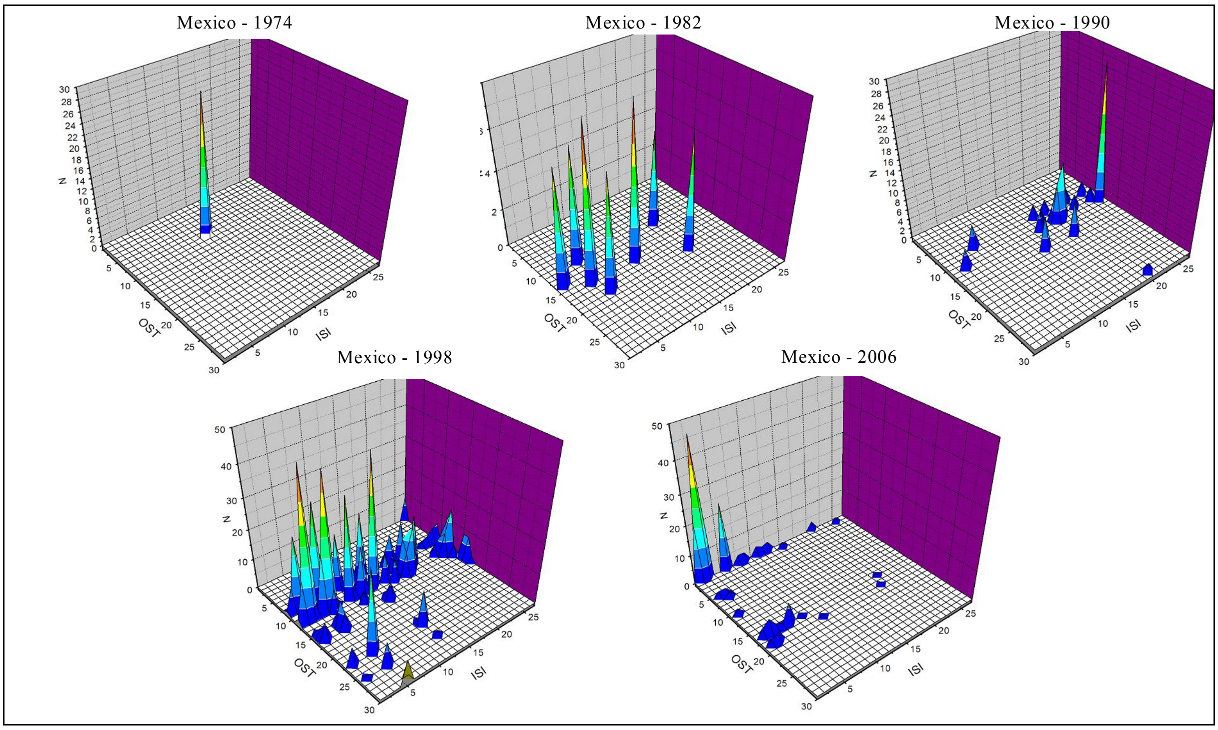
Matrices of science and technology interactions. Costa Rica, 2006



Source: USPTO.
Note: Costa Rica did not present any patent granted in USPTO in the other years of the analysis.

FIGURE 6

Matrices of science and technology interactions. Mexico, 1974, 1982, 1990, 1998 and 2006



Source: USPTO.

VI. CONCLUSIONS

The analysis of four Latin American countries - Argentina, Brazil, Costa Rica and Mexico - was useful for identifying the similarities and differences regarding the scientific and technological trajectory of each country.

We could notice that, despite presenting the worst human and economic development indexes, Brazil had, in 2006, the highest GDP participation on R&D. Nonetheless, the expenditure on R&D per researcher as well as other human and economic development indexes *per capita* was weakened by the vast population of Brazil. Costa Rica stood out in terms of the proportion of its population with first level university and master degrees as well as its expenditure on R&D *per* researcher.

The evolution of the *per capita* scientific and technological production of all four countries evidenced how much of an effort must be done in order for these countries to move from Regime II, where they are now located, to Regime III. As an example of the Red Queen Effect, if Brazil, Costa Rica, Argentina and Mexico just continue with the same pace of articles and patents production, that will still not be enough for them to reach countries in Regime III. This is due to the fact that countries like South Korea increased their scientific and technological production with a superior rate to that of Regime II threshold. Asian countries tend to follow a pattern towards Regime III that is similar to the South Korean one. For instance, Malaysia experienced a steep rise in its scientific and technological production in the analysed period and China has been going on the same direction. In order for countries with immature NSIs to have a chance to reach Regime III as soon as possible, an immediate effort of heavy investment in the production of articles and patents as well as in their articulation is necessary. Therefore, public policies in these Latin American countries are essential to foment and swell scientific and technological production once there is a strong connection between science, technology and the welfare of nations, as it has already been proved by S&T literature.

It was observed that the scientific production of the four analyzed countries boosted between 1974 and 2006. Along with this scientific expansion, it was possible to observe a rise in the number of S&T fields and, consequently, a smaller specialization of all four countries.

Although Argentina, Brazil and Costa Rica broaden their number of S&T fields in their scientific structure, health and/or agriculture-related fields remained the leading ones throughout the years. Mexico, on the other hand, presented the highest number of non-health and/or agriculture-related fields in the ranking as well as a stability in terms of maintaining most fields in the ranking throughout the years.

By analyzing the technological production of all four countries, it was clear that they did not follow a similar path. Brazil was the only country displaying a linear trajectory whereas Costa Rica was the most unstable one in terms of patent production.

Despite varying in rank, patents' sub-domains did not suffer great shifts greater shifts in terms of leaving and entering these countries' rankings - except Costa Rica.

Throughout the analyzed years, it was possible to observe the lack of articulation between scientific fields and technological sub-domains, once most patents were not associated with health and/or agriculture, as they were in articles.

We could also observe, in the analyzed matrices, a general matrix fulfillment throughout time - with some exceptions in specific years such as Brazil, in 1982, and Mexico, in 2006. Despite this tendency, this is still an incomplete process, considering the great number of empty cells in the last period. There is also a general growth in the number of S&E literature citations, noticed by the increase in the number of citations reached by the peaks in the figures, relative to the Z-axis.

The analysis of countries' interactions between S&T, through the matrix fulfillment index (MFI), allowed us to identify the tendency of a worldwide increase of this interaction. Mexico was an exception in 2006 when its MFI index dropped significantly from the previous selected year. It was also possible to observe the different groups that countries belong to according to their scientific and technological interaction: the richer the country is the strongest the interaction. The four Latin American countries were part of the group with the humblest interaction between S&T. Furthermore, by analyzing the matrix height, we could also observe the rise of the countries' average citation per matrix cell.

In addition to that, Argentina, Brazil, Costa Rica and Mexico presented incomplete matrices of S&T interactions during the analyzed years. We could also observe that there was no stable correlation among two specific scientific and technological domains due to the fact that the countries' peaks, as well as the filled cells, changed over time.

Lastly, the four Latin American countries were identified within the group of immature systems of innovation according to the inter-temporal correlation between matrices. It was suggested that temporary decreases in the inter-temporal correlation for less-developed countries may be positive once, in case of developed countries, it may indicate an ongoing technological revolution through the pursuit for a new developmental pattern.

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