# Innovation systems and changes in the core-periphery divide: notes on a methodology to determine countries' trajectories using science and technology statistics[1]

Catari Vilela Chaves, Leonardo Costa Ribeiro, Ulisses Pereira dos Santos and Eduardo da Motta e Albuquerque

## Abstract

This paper presents a methodology to evaluate the international position of national innovation systems. Data on patents, scientific articles, population and gross domestic product (GDP) for all countries for 1974, 1982, 1990, 1998, 2006, 2012 and 2014 form the basis for the application of this country clustering methodology. In addition to establishing a threshold between clusters (the core-periphery divide interpreted on the basis of science and technology data), it is possible to capture movement in thresholds, driven by technological revolutions in core countries. The result is a dynamic framework, which makes it increasingly difficult to implement convergence processes.

## Keywords

Science and technology, innovations, peripheral capitalism, science and technology policy, economic development, developed countries, developing countries, least developed countries, case studies, science and technology statistics, Brazil

## JEL classification

O30, O33, O57

## Authors

Catari Vilela Chaves is a professor and research coordinator in the Department of Economics at the Pontifical Catholic University of Minas Gerais, Brazil. Email: catari@pucminas.br.

Leonardo Costa Ribeiro is an associate professor in the Department of Economics at the Federal University of Minas Gerais, Brazil. Email: leonardocostaribeiro@gmail.com.

Ulisses Pereira dos Santos is an associate professor in the Department of Economics at the Federal University of Minas Gerais, Brazil. Email: ulisses@cedeplar.ufmg.br.

Eduardo da Motta e Albuquerque is a professor in the Department of Economics at the Federal University of Minas Gerais, Brazil. Email: albuquer@cedeplar.ufmg.br.

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[1] The authors thank the National Council for Scientific and Technological Development (CNPq) (Processes 302857/2015-0 and 401054/2016-0) for its support and an anonymous referee for the critique of a previous version of this article and the suggestions made. Errors are the sole responsibility of the authors.

# I. Introduction

This paper presents a methodology based on science and technology statistics to evaluate the international position of national innovation systems. In addition to determining the position of specific national innovation systems, this methodology enables intertemporal tracking of the trajectories of selected countries. This procedure allows countries to be placed in clusters according to the quantitative characteristics of their innovation systems, helping to determine whether there is a core-periphery divide and assess its movement, based on science and technology data.

The concept of a national innovation system appeared in literature in the late 1980s (see Freeman, 1987; and the section on national systems of innovation in the book edited by Dosi and others, 1988). Over the last 30 years, innovation systems have been the subject of enormous body of theoretical study. Teixeira (2014) presents the results of this work in a bibliometric analysis that systematizes the diffusion and refinement of the concept. The consolidation of this concept in literature on economics, particularly economics of technology, is further evidenced by its inclusion in economics handbooks (see Fagerberg, Mowery and Nelson, 2005, chapter 7; Hall and Rosenberg, 2010, chapter 27).

The body of studies on innovation systems posed new challenges, including the applicability of the concept to countries on the capitalist periphery. A group of researchers in the so-called "Global South" dealt with this issue (Coutinho and Suzigan, 1991; Villaschi, 1992; Cassiolato, Lastres and Maciel, 2003; Viotti, 2002; Silva, 2003). The emergence of initiatives such as Globelics in 2003 (led by Lundvall) and the Catch-Up Project in 2005 (led by Nelson) enabled significant progress to be made in defining new questions for researchers working on the topic. The works of Lundvall and others (2009) and Nelson (2004) are two important outcomes.

The starting point of this article is the possibility of evaluating innovation systems using selected statistics, as pioneered by Patel and Pavitt (1994). Since then, a tradition has formed of empirical studies —directly or indirectly related to innovation systems— based on statistics for patents and scientific articles (for a comprehensive account see Moed, Glänzel and Schmoch, 2004). The main hypothesis of this article is that statistics on patents and scientific articles synthesize and summarize assessment of the key components of innovation systems: technology produced by enterprises; scientific knowledge produced by universities and research institutions; and the interactions between the two.

The article is divided into six sections including this introduction. Section II reviews the literature on the construction stages of innovation systems and the regimes of interaction between science and technology. The databases on scientific and technological output and the economic development indicator are described in section III, together with the methodology. Section IV explains the intertemporal trajectories of the science and technology output thresholds of the countries that make up each regime of interaction. The case of Brazil is presented in section V, linking the position and trajectory of the country with a preliminary assessment of its industrial structure. Lastly, section VI details the main conclusions of the study.

# II. National innovation systems: differentiation, measurement and typology

Before the concept of the innovation system had been defined, neo-Schumpeterian literature had already systematized an interpretation of the role of technological revolutions in the long-term dynamics of the capitalist system (see the special issue of the magazine *Futures*, edited by Freeman in 1981, later published as a book (Freeman, 1983)). The theoretical development regarding the role of technological revolutions is summarized in Freeman and Louçã (2001) and Pérez (2010).

Technological revolutions are at the root of the metamorphoses of capitalism (Furtado, 2002) that periodically reconfigure the entire system. The emergence of the concept of the innovation system is related to the dynamics of technological revolutions in two ways. Firstly, technological revolutions are the result of the innovation systems' component institutions: by systematizing the body of institutions that drive technological progress, analysis of innovation systems helps to understand the roots of technological revolutions. Secondly, systematization of the relationship between technological revolutions and metamorphoses of capitalism suggests that innovation systems must transform periodically, in keeping with such changes.

The dynamic framework resulting from linking these two elements of neo-Schumpeterian theory has important implications for efforts to quantify innovation systems. These systems cannot be evaluated statically; changes must be captured over time.

The theoretical framework offered by the combination of technological revolutions and innovation systems poses two challenges. On one hand, differentiation between innovation systems —which has been evident since the first comparative studies (Nelson, 1993)— resulted in construction of innovation system typologies. On the other hand, such typologies should allow for the possibility of changes over time, both within innovation systems and in the resulting international context.

Freeman (1995) was a pioneer in proposing a typology, suggesting a differentiation between four types: advanced country systems (exemplified by Japan); East Asian countries; Latin American countries; and the former Union of Soviet Socialist Republics. Freeman opened a discussion on the particularity and differentiation between peripheral countries, illustrated by the contrast between Latin America (which remains on the periphery) and the Republic of Korea and Taiwan Province of China, which have proved able to undergo convergence processes and move out of the periphery. The structure of the book by Nelson (1993) suggests another means of organizing the differentiation among innovation systems.

An important theoretical issue is the link between the analysis of innovation systems and the literature on varieties of capitalism. The important and significant structural differences among the different types of innovation systems can be linked to the nature of the institutions built by the various varieties of capitalism. The literature on varieties of capitalism has concentrated on the analysis of core countries (for example Coates, 2000). The study of the different varieties of capitalism in the periphery in general, and in Latin America in particular, is a challenge. Ribeiro and others (2015, pp. 11-12) suggest five different types of capitalism involving countries on the periphery and countries where convergence processes have been found to have taken place: (i) India; (ii) Republic of Korea and Taiwan Province of China; (iii) China; (iv) countries that are rich in natural resources, such as South Africa, and countries in the Middle East and North Africa; and (v) Latin America. There is possibly another variety of peripheral capitalism, represented by the Russian Federation post-1991 (Ribeiro and others, 2015, p. 16). This linkage is key to a more widespread understanding that the literature on innovation systems describes much more comprehensive institutional arrangements than science and technology institutions.

Since 1995 there has been a profusion of studies on innovation systems and specific cases —the systematization of which is not addressed in this article— that can be re-examined in works such as Teixeira's (2014). The frame of reference for innovation systems resulted in papers that systematized, in some cases in detail, the characteristics of innovation systems in Africa (Kruss, Adeoti and Nabudere, 2012), Latin America (Dutrénit and Arza, 2010) and Asia (see the special issue of the *Seoul Journal of Economics*, edited by Keun Lee, in 2009).

A challenge arises from this wide and detailed body of literature regarding the formulation of a typology based on statistical data, helping to systematize somehow the differentiations identified in the literature, while also capturing any intertemporal movement in innovation systems.

# III. Quantitative elements for a typology of innovation systems

Although the statistical analysis proposed herein is mainly based on a measure of wealth, as a proxy variable for economic development, this study adopts a broader perspective of this phenomenon. Development is interpreted here as a process of structural change based on greater income distribution and improvement in living conditions (Furtado, 2002; Fajnzylber, 2016). In other words, development is a comprehensive process, based on economic growth and the distribution of benefits from the creation or internalization and adaptation of new technologies. Authors who have investigated underdevelopment or comparative development have noted significant relationships between changes in the production structure, the process of income distribution and the expansion of national scientific and technological capabilities.

According to Furtado (1987), technological deficiencies resulting from importation of technologies that are not suited to local specificities is one of the main imbalances in the later industrialization process. Fajnzylber (2016) also states that this may be one of the main causes of greater income concentration in less developed economies. He considers that the lack of an "endogenous nucleus of technological dynamization" —a concept similar to the national innovation system— may limit internal capacity to open the "black box" of technical progress, leading countries of the periphery to prioritize imitation rather than creating their own technologies adapted to local shortcomings and potentialities. In this regard, Fajnzylber (2016) details how the contradictions of industrialization in the periphery, the main one being social inequality, appear to be related to limited scientific and technological activity in those countries.

When comparing late industrialization and the convergence process in the countries of East Asia and Latin America, Freeman (1995) notes that some factors related to improvements in living conditions —such as the universalization of education— may explain differences in the development trajectories of the countries of these regions from the 1980s onward. In this connection, Amsden (2009) affirms that, in addition to strengthening the national business class, income distribution and internal technological capacity-building appear to be associated with the convergence process in the East Asian economies, but this has not occurred in Latin America.

According to these studies, development of internal scientific and technological capabilities is fundamental to the process of economic development in its broadest sense. In other words, strengthening actors in a national innovation system appears to contribute to income growth, wealth distribution and improvements in living conditions. In this regard, industrialization of the periphery can only take into account national specificities by structuring a comprehensive national innovation system, in order to exploit potentialities and correct current imbalances. Thus, the convergence process is conceived not only as a process of growth in income and in local scientific and technological output, but also as a broader process of social transformation of which these variables are a part. This makes clear the limitations of the proposed statistical exercise. Nonetheless, improvement in the science and technology variables, in particular, may indicate the creation of internal conditions that favour improvements in living conditions, as indicated in the literature.

The hypothesis underlying the methodology proposed herein is the capacity of science and technology statistics to synthesize the relative position of countries in the global context. Statistics for science (scientific articles) and technology (patents) are the "tip of the iceberg" of countries' scientific and technological capabilities.

The scientific capacity of a country is linked to the existence of scientific institutions and universities and financial support for scientific activities, reflecting the presence of significant non-commercial elements. In turn, scientific institutions depend on the presence of an educational system that, from the most basic levels upward, seeks to prepare students for a university education. A good quality educational system, in turn, presupposes essential food and income conditions that enable families to send their children to school in a position to learn and develop creativity. These elements are linked to the more general condition of social welfare systems.

A country's technological output is linked to the presence of stable companies that are able to acquire knowledge, invest in research and development and recruit qualified professionals from the educational system, and that have the financial resources to make innovative investments. These factors are linked to the educational and scientific dimension and to the financial and macroeconomic dimension and are also related to the historical context in which companies and other institutions developed.

Thus, the statistical approach of this paper presupposes this vision of scientific and technological dynamics that is implicit in the development of innovation systems (Freeman, 1995), which undoubtedly interacts with the evolution of social capabilities described by Abramovitz (1986).

Based on this interpretation of the meaning of the data (the "tip of the iceberg" of scientific and technological capabilities), this article aims to evaluate the specific contribution that the data can make, as a synthesis of the information, to studies of changes in the core-periphery divide in the longer term.

A reading of Patel and Pavitt (1994), Freeman (1995) and Nelson (1993), focusing on interpretation of the data presented therein, suggests that there is correlation between measures of nations' wealth (per capita GDP) and indicators of scientific and technological output.

These studies describe the consolidation of scientific and technological infrastructure, the functioning of feedback loops between these two dimensions and the existence of interactions between science and technology and the economic sphere in developed countries (Germany, Japan, the United States of America). In the case of developing countries, such as Brazil, while there is evidence of systematic science and technology activities, and the related publication of articles and patents, there is also evidence that the interactions between science and technology are not yet fully consolidated. In even less developed countries, such as the poorest countries of Africa and Latin America, these data indicate an absence of systematic science and technology activities, meaning that articles are published and patents are registered infrequently. For these countries, this also indicates a lack of interconnection between the scientific and technological spheres.

Examination of this basic statistical information raises doubts as to the existence of divides between these groups of countries and questions as to how the core-periphery divide addressed by structuralist literature (Furtado, 2002) could be determined by using these statistics.

The literature on innovation systems therefore calls for the identification of statistics to measure and a methodology to analyse them.

## 1. Database: scientific and technological output and economic development

The database prepared for this analysis includes statistics on scientific articles (as a proxy for scientific output), patents (as a proxy for technological output) and per capita GDP (as a proxy for economic development) for the years 1974, 1982, 1990, 1998, 2006, 2012 and 2014. The aim is to collect data for all the countries in the world. In order to create the database on scientific and technological output and economic development, it was necessary to address the geopolitical changes that have taken place since 1974. Some adjustments were therefore made to make the series compatible over time.[2]

## (a) Scientific output

Data on scientific articles were obtained from the Institute for Scientific Information (ISI) database[3] and are used as proxies for scientific output.

To analyse scientific infrastructure in each country, the articles used are from all science and engineering disciplines that have a direct relationship with the process of economic development and are in the Science Citation Index Expanded prepared by ISI.

The use of articles as indicators of scientific infrastructure has both advantages and disadvantages. The discussion on the meaning of the statistics published by ISI can be summarized as follows.

Firstly, not all scientific output is indexed by ISI. The requirements for a journal to be indexed are very strict. In the field of economics, for example, it is much easier for an academic journal to be included in the prestigious EconLit database than in the Science Citation Index Expanded.

Secondly, simply counting the number of articles certainly does not capture the different scientific contributions they make. Thus, an article that represents a major scientific breakthrough is counted in the same way as one that only makes an incremental contribution. To overcome this bias, citation statistics are commonly used. However, such statistics also pose problems, in particular they reduce to a certain extent the global share of the least developed countries. This article therefore uses the number of articles as a basis for the statistics.

Thirdly, the marked linguistic bias of ISI statistics favours the scientific output of English-speaking countries to the detriment of others (Sandelin and Sarafoglou, 2004).

Fourthly, scientific output is not expressed solely through the production of articles. Events such as conferences, congresses and debates are also important and are key sources of information on technological flows in interaction with the production sector (Cohen, Nelson and Walsh, 2002).

However, the ISI database is a valuable contribution, owing to its long statistical series, international comparability, disaggregation by disciplines, identification of authors and institutions (enabling geographical location of the activity), and easy access.

## (b) Technological output

A patent is a document, issued by an authorized governmental agency, granting the right to exclude anyone else from the production or use of a specific new invention for a stated number of years. The patent is issued to the inventor of the device or process after an examination that focuses on both the novelty of the item and its potential utility. The right embedded in the patent can be assigned by the inventor to somebody else, usually to his or her employer (which may be a corporation), and/or sold to or licensed for use by somebody else (Griliches, 1990).

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[2] Given that Germany reunified in 1990, a decision was made to aggregate the scientific publication and patent data of the Federal Republic of Germany and the German Democratic Republic from that year onward. In 1993, Czechoslovakia separated into the Czech Republic and Slovakia. Therefore, the resulting countries were inserted in 1998, 2006, 2012 and 2014. The former Union of Soviet Socialist Republics was included in 1974, 1982 and 1990. Armenia, Azerbaijan, Belarus, Estonia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, the Russian Federation, Ukraine and Uzbekistan were included in 1998, 2006, 2012 and 2014. Yugoslavia was also divided, but data on articles and patents were included for 1974, 1982, 1990 and 1998. Bosnia and Herzegovina, Croatia, Slovenia and North Macedonia (previously known as "the former Yugoslav Republic of Macedonia") were added in 1998, 2006, 2012 and 2014.

[3] See [online] www.webofknowledge.com.

The patent documents (requested and granted) available from the website of the United States Patent and Trademark Office (USPTO)[4] contain the information used to develop the databases. The research that gave rise to this article focused on granted patents, by the country of the inventor.

In short, with respect to science and technology indicators, the use of published articles and patents in this study (instead of indicators that are derived from articles and patents) is justified, because the parallel observation of these variables is important for analysing relationships between science and technology and for formulating models on innovative processes (Schmoch, 1997).

### (c) Per capita GDP and economic development

In this paper, it is assumed that income is one of the variables that determine scientific and technological output in both developed and developing countries. The indicator that will be used to express the wealth of nations is per capita GDP, measured at purchasing power parity (PPP) in constant 2011 international dollars, taken from the World Development Indicators Databank of the World Bank.[5] This particular income level indicator is used because the analysis covers a number of countries at different stages of development.[6]

## 2. Methodology: superparamagnetic data clustering

Based on the science and technology statistics on scientific articles and patent data, a methodology is needed to form clusters of innovation systems. Ribeiro and others (2006) list the key references with regard to the development of the technique of superparamagnetic data clustering, based on tools used in the field of physics and in theoretical research into the economics of technology.

This article applies a methodology based on a series of generalizations of Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998), which was originally used to simulate magnetic systems in the field of physics. Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998) consists of $N$ points arranged in a lattice. Each point is characterized by its state, which can be either +1 or -1. Points interact with their nearest neighbours (the four points closest to them, in the case of a lattice) so that if two neighbouring points are in the same state an amount of energy is subtracted from the system, while if two neighbouring points are in different states the same amount of energy is added. Thus, in order to minimize system energy, neighbouring points tend to remain in the same state.

One of the generalizations made is to allow points to be continually distributed spatially, rather than fixed in a regular lattice. Therefore, the means of determining the neighbours of each point must be defined, which is a simple operation in a regular lattice. The concept used here is that of mutual neighbourhood. Point $i$ is a neighbour of $j$ if $j$ is among $K$ points closest to $i$ and $i$ is among $K$ points closest to $j$. Accordingly, the maximum number of neighbours of a point is $K$.

The second generalization is that interaction $J$ between neighbouring points is no longer a constant but a function of the distance between the points. The behaviour required for this function is that, for distances less than the mean distance $a$ between all points, there is strong interaction and, for greater distances, the interaction is weak. This defines a local scale of interaction: neighbouring points (at a distance less than $a$) interact strongly and distant points (at a distance greater than $a$) interact weakly.

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[4] See [online] www.uspto.gov.

[5] See [online] https://databank.worldbank.org/source/world-development-indicators.

[6] The concept of purchasing power parity relies on the law of one price, according to which goods or baskets of goods have the same price in an integrated market, measured in a common currency (Dornbusch, 1987). In algebraic terms:

$$e = P/P^*$$

where: $e$ = exchange rate; $P$ = price level at home; $P^*$ = price level abroad. However, the assumptions underlying PPP are very strong.

In a non-homogeneous distribution, with high- and low-density regions of points, this means that there is strong interaction within high-density regions and weak interaction within low-density regions. With a given distribution of points, it is possible to study this model using the same techniques as those described for Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998). In the case of low temperatures, the system shows unitary magnetization, since all the points are in the same state. In the case of high temperatures, magnetization is null, and the states are distributed equally among the points. However, a new phase arises between those of low and high temperatures, called the superparamagnetic phase, in which the spins of points belonging to the same cluster are strongly correlated, while the spins of points in different clusters are weakly correlated. This causes a plateau in the susceptibility graph owing to the fluctuations caused by the change in the state of the clusters.

In this analysis, these clusters translate into sets of countries with similar quantitative characteristics in terms of their innovation systems, as measured by statistics on patents and scientific articles. The differences between the groups of innovation systems may suggest a quantification of the core-periphery divide.

# IV. Analysis of the results

Having constructed the database and described the clustering methodology, the science and technology statistics were then analysed to understand how they can contribute to improving differentiation between innovation systems at various stages of development.

To this end, this section is structured in such a manner to examine the existence of correlations between science, technology and the wealth of nations, to test the clustering of countries at different quantitative and qualitative levels of interaction between science and technology, and to evaluate how this analysis and methodology can be used to systematize the dynamic elements of the core-periphery divide.

## 1. Correlation between science, technology and the wealth of nations

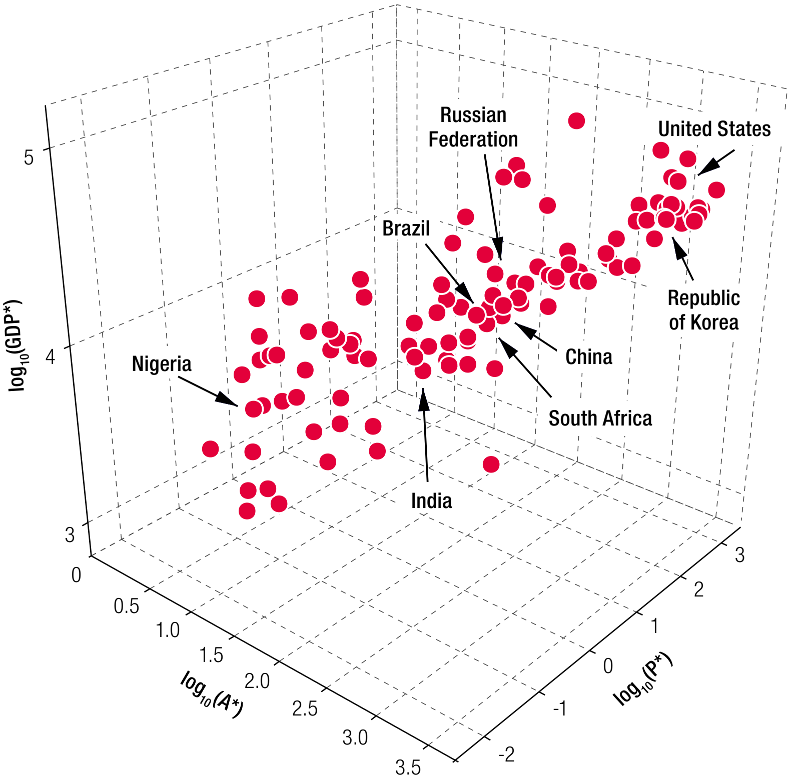
Figure 1 shows, in three-dimensional plot, the data on articles, patents and GDP (measured at PPP) in a logarithmic scale, per million inhabitants, for 111 countries in 2014. All these countries and territories have at least one patent granted by USPTO and one published scientific article included in the Science Citation Index Expanded, organized by ISI.

It can be seen that the more developed a country is, the more articles it publishes and patents it registers and vice versa, indicating a positive correlation between these three variables.

In general, countries that have greater technological capabilities and have endogenized their own technologies generate more wealth and are the richest in the world. Admittedly, there are exceptions to the correlation between wealth and scientific and technological development. While some countries with large oil reserves have high per capita GDP, their capacity to generate science and technology is far from proportionate to the wealth provided by the extraction and sale of this commodity.

As shown in figure 1, the United States and the newly included Republic of Korea are examples of countries located at the core of the capitalist system. The periphery can be divided into at least two groups: countries such as Nigeria, which are in a less developed position, and countries such as Brazil, India, China, South Africa and the Russian Federation, which are in more advanced positions, with an intermediate level of economic, scientific and technological development.

**Figure 1**
Selected countries and territories:[a] articles, patents and per capita GDP, 2014
*(Per million inhabitants and in 2011 constant international dollars at purchasing power parity)*



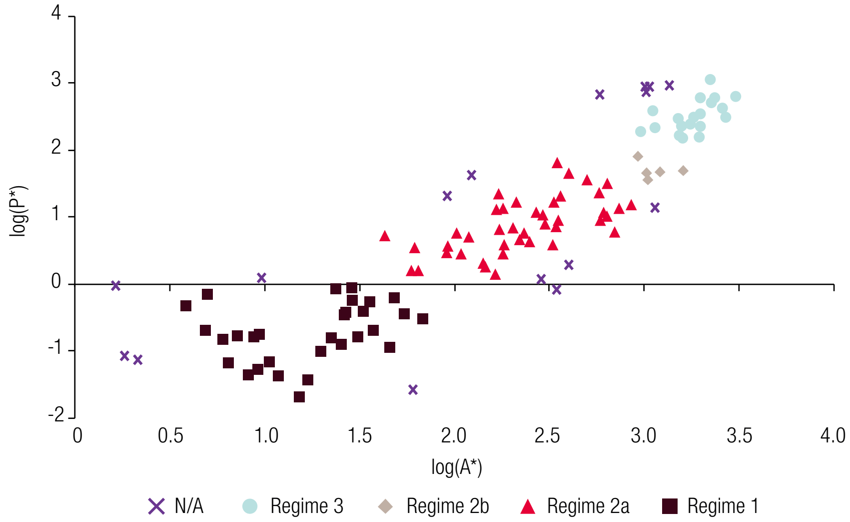
**Source:** Prepared by the authors, on the basis of data from World Bank, Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).

[a] The countries and territories analysed are: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belgium, Bermuda, the Bolivarian Republic of Venezuela, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chad, Chile, China, Colombia, Costa Rica, Croatia, Czechia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Eswatini, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Hungary, Iceland, India, Indonesia, Iraq, Ireland, the Islamic Republic of Iran, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Liberia, Lithuania, Luxembourg, North Macedonia, Madagascar, Malaysia, Malta, Mexico, Monaco, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, the Plurinational State of Bolivia, Poland, Portugal, Qatar, the Republic of Korea, the Republic of Moldova, Romania, the Russian Federation, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan Province of China, Thailand, Tunisia, Turkey, Turkmenistan, Ukraine, the United Arab Emirates, the United Kingdom of Great Britain and Northern Ireland, the United Republic of Tanzania, the United States of America, Uruguay, Uzbekistan, Viet Nam and the West Bank and Gaza.

## 2. The clustering technique and three regimes of interaction in 2014

The data presented in dimension $xy$ of figure 1 (scientific output x technological output) constitute the input for application of the clustering methodology presented in section III.2. The result is shown in figure 2.

**Figure 2**
Selected countries and territories:[a] articles and patents per capita, 2014
*(Per million inhabitants)*



**Source:** Prepared by the authors, on the basis of data from Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).

[a] The countries and territories analysed are: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belgium, Bermuda, the Bolivarian Republic of Venezuela, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chad, Chile, China, Colombia, Costa Rica, Croatia, Czechia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Eswatini, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Hungary, Iceland, India, Indonesia, Iraq, Ireland, the Islamic Republic of Iran, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Liberia, Lithuania, Luxembourg, North Macedonia, Madagascar, Malaysia, Malta, Mexico, Monaco, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, the Plurinational State of Bolivia, Poland, Portugal, Qatar, the Republic of Korea, the Republic of Moldova, Romania, the Russian Federation, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan Province of China, Thailand, Tunisia, Turkey, Turkmenistan, Ukraine, the United Arab Emirates, the United Kingdom of Great Britain and Northern Ireland, the United Republic of Tanzania, the United States of America, Uruguay, Uzbekistan, Viet Nam, and the West Bank and Gaza.

Using the clustering technique, the body of countries with recorded scientific and technological output —in the form of articles and patents— were divided into three large groups. The analysis suggests that each of these groups can be considered representative of a different "regime of interaction". The reasoning behind this suggestion assumes that, in line with the literature, not only is there a quantitative difference between advanced and less developed countries—greater scientific and technological output— but also an important qualitative difference: the interaction between the scientific and technological dimensions is assumed to be more consolidated in advanced countries, allowing for a positive feedback loop between them. This group is "regime 3" in figure 2. Countries in an intermediate position are in "regime 2", characterized by less output, which is less sophisticated. In this regime, there is a feedback loop between the two dimensions but it is weaker. Lastly, the poorest and least scientifically and technologically advanced countries are in "regime 1".

Regime 3 includes 19 countries that are among the most advanced in the world, i.e. the richest in economic, scientific and technological terms: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Singapore, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland. It is important to contrast this situation with the case of the five countries that are close to regime 3 but are considered outliers of the model: Israel, Japan, the Republic of Korea, Taiwan Province of China and the United States. They are indicative of a differentiation between the most advanced countries, reflecting a subset of countries that transform their scientific output into technological output with greater efficiency.[7]

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[7] The position of the European countries, compared to the United States in particular, illustrates the so-called European paradox (Dosi, 2006). For the purposes of this article, the discussion presented by Dosi (2006) is part of an initiative to subdivide the group of developed countries.

Regime 2 comprises 50 countries, including Brazil. During application of the technique outlined in section III.2, a subgroup was seen to decouple, without being characterized as a new separate group. Consequently, it is considered that, in 2014, regime 2 has a special feature, as it divided into two subgroups.

The first subgroup (referred to as "regime 2B" in figure 2) consists of five countries that were in regime 1 in 2012, but lost their places in 2014, shifting away from their peers. They are Czechia, Estonia, Italy, Slovenia and Spain. The second subgroup ("regime 2A") comprises 45 countries (there are six outliers close to this regime) at an intermediate stage of development: Argentina, Armenia, Bahrain, Barbados, Bermuda, Brazil, Brunei Darussalam, Bulgaria, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Egypt, Georgia, Greece, Hungary, India, Jamaica, Jordan, Kuwait, Latvia, Lebanon, Lithuania, Malaysia, Malta, Mexico, Namibia, North Macedonia, Oman, Panama, Poland, Qatar, Romania, the Russian Federation, Saudi Arabia, Seychelles, Slovakia, South Africa, Thailand, Turkey, Ukraine, the United Arab Emirates and Uruguay.

Lastly, "regime 1" countries are the least developed, with low per capita GDP, few patents granted and few scientific articles published, as shown in figure 1. The 30 countries in this regime are: Albania, Azerbaijan, Bangladesh, the Bolivarian Republic of Venezuela, Cameroon, the Dominican Republic, Ecuador, El Salvador, Eswatini, Ghana, Guatemala, Indonesia, Iraq, Kazakhstan, Kenya, Liberia, Madagascar, Nepal, Nicaragua, Nigeria, Pakistan, Paraguay, Peru, the Plurinational State of Bolivia, the Republic of Moldova, Sri Lanka, Turkmenistan, the United Republic of Tanzania, Uzbekistan and Viet Nam. There are seven countries, considered outliers, that are close to this regime.

Figure 2 shows a great deal of dispersion and heterogeneity among the countries of the periphery, covering regimes 1 and 2 (2a and 2b). This growing dispersion and heterogeneity of the periphery is one of the results of the dynamics of the metamorphoses of capitalism caused by the successive technological revolutions that are spread unevenly across the system.

These three regimes of interaction can be characterized by analysing the correlation between scientific and technological output within each regime. There are key differences in this correlation between groups of countries, depending on the regime of interaction to which they belong. Analysis of the dynamics between scientific and technological output in the 1999–2003 period for a group of 116 countries by Ribeiro and others (2006) produced an interesting result: the richer the nation, the greater the correlation between articles and patents. The correlation coefficient for regime 1 countries was 0.74 and for all of regime 2 it was 0.52. However, group 3 countries showed relatively low correlation, of 0.24. This result may be an indicator of the efficiency of developed countries in transforming their scientific output into technological output. It may also represent a consensus between structuralist and neo-Schumpeterian approaches.

## 3. Intertemporal trajectories of thresholds and countries

Based on the data collected for 1974, 1982, 1990, 1998, 2006, 2012 and 2014 and application of the clustering technique to these data sets, two interrelated questions are raised. Firstly, is it possible to delimit the interaction regimes with thresholds that characterize them? And secondly, are the thresholds static?

It is possible to define thresholds. First, a linear regression is performed, considering all the points (countries) in figure 2. To establish the threshold between regimes 1 and 2, the rightmost point of regime 1 is located. The line that passes through this point and is perpendicular to the line of the linear regression of all the points is then calculated. The definition is similar for the threshold between regimes 2 and 3, but uses the leftmost point of regime 3.

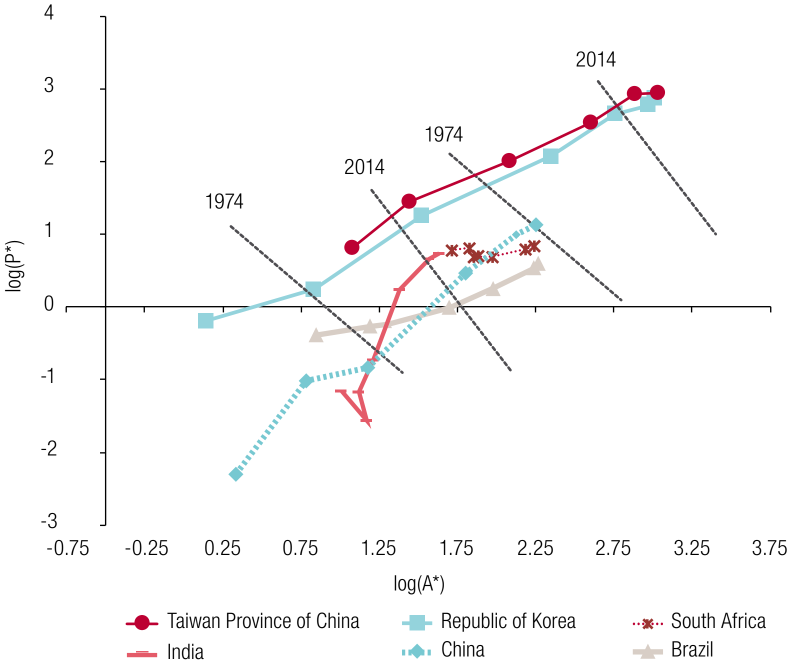
The threshold between regimes 3 and 2 can be expressed as the quantitative definition of the core-periphery divide, based on science and technology data.

A comparison of the position of the thresholds in 1974 and 2014 suggests that they are not static. This is consistent with the neo-Schumpeterian vision of an economic system that is in constant transformation as a result of successive technological revolutions. The movement of the thresholds over time is shown in figure 3.

Figure 3

Selected countries and territories:[a] intertemporal trajectories of the scientific and technological output thresholds

*(Per million inhabitants)*



**Source:** Prepared by the authors, on the basis of data from Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).

[a] Brazil, China, India, the Republic of Korea, South Africa and Taiwan Province of China.

The 2014 line in the upper right of figure 3 represents the threshold between regimes 3 and 2 in 2014, while the 1974 line immediately to the left represents the position of the same threshold in 1974. The 1974 line at the bottom left of figure 3 represents the threshold between regimes 1 and 2 in 1974, while the 2014 line immediately to its right represents the same threshold in 2014.

Movement in the thresholds has important repercussions. In particular, movement in the threshold between regime 3 and 2 shows that the core-periphery divide is not static. The core-periphery divide exists, transforms and moves. In other words, the challenge of implementing a convergence process is made more complex by the successive technological revolutions in the core countries.

Figure 3 also shows the position of selected countries and territories for all years between 1974 and 2014. This makes it possible to trace the trajectories followed by these countries and to assess the dynamic behaviour of the movement of countries and thresholds.

Brazil's trajectory, for example, shows its move from regime 1 to regime 2 between 1974 and 1982. However, the country remained in regime 2 throughout 1990, 1998, 2006, 2012 and 2014. In 2014, it approached the 1974 threshold that marks a shift from regime 2 to regime 3. However, it took the country 40 years to meet the conditions to become part of regime 3. The scientific and technological requirements for entering regime 3 in 2014 were much more stringent than in 1974. This is the case not only for Brazil, but also India and South Africa (the "Red Queen effect"): these countries are increasing their scientific and technological output, but not fast enough to move from regime 2 to regime 3 (Ribeiro and others, 2006).

As a speculative exercise, with all the care that is required owing to the weight of uncertainty over the dynamics of scientific and technological change, it is possible to calculate the speed of movement in the thresholds. Between 1974 and 2014, the threshold for transition from regime 2 to regime 3 rose exponentially at a rate of 6.6% per year (in terms of scientific output), while the threshold between regime 1 and regime 2 rose at an average rate of 4.2% per year.

This methodology makes it possible to determine the convergence processes, which translate into the ability to cross the threshold between regimes 2 and 3. Both the Republic of Korea and Taiwan Province of China managed to make this transition and have been in regime 3 since 1998. Perhaps because they preserved a high capacity for absorbing technology during the convergence process, these countries appear as model outliers in figure 2, positioned close to Japan and the United States.

Assuming that the countries continue to expand their scientific and technological output at the same rate as they did between 1974 and 2014, and that the thresholds continue to move at the same speed (both are extremely restrictive assumptions), Brazil would be in a position to enter regime 3 in 2144, if its average growth rate of 8.6% per year (from 1974 to 2014) is maintained. South Africa, with a growth rate of 2.8% per year, could fall back into regime 1 in 2044. India, with a growth rate of 3.4% per annum, is on course to remain in regime 2. As can be seen in figure 3, China began in regime 1 in 1982, moved to regime 2 in 2006 and is on course to join regime 3 in 2050, as its growth rate is 15% per year. Although these are purely speculative exercises, they at least serve to express concern about maintaining policies that are ineffective in implementing convergence processes.

# V. A note on technological intensity and the Red Queen effect: the case of Brazil

This section, which focuses on Brazil, seeks to establish a link between data on the country's position in the international context (see figure 3) with more disaggregated statistics on the position of the country's industry.

This data comparison is based on the hypothesis that the relative stagnation of Brazil shown in figure 3 is related to the absence of structural changes in national industry. This supposition is based on studies of successful convergence processes, in particular that seen in the Republic of Korea. The case of the Republic of Korea suggests that, for convergence processes to succeed, an innovation system must push the country's industrial structure towards economic sectors that are closer to the new sectors created by the most recent technological revolutions, i.e. high-tech sectors (Lee, 2013).

This is key to understanding why the Brazilian economy remained in regime 2 for most of the period analysed in figure 3, which may be linked to the middle-income trap. This refers to a situation where efforts made by middle-income countries to maintain trade advantages related to mass production and low production costs hinder their transition to the group of high-income countries (Paus, 2014). In contrast, countries that have succeeded in making this transition, such as the Republic of Korea and Taiwan Province of China, appear to have undertaken initiatives related to changes in the technological profile of local industry. In these countries, after an initial phase of industrialization, the realignment of industrial policy to favour sectors based on new, "short-cycle" technologies together with incentives for research and development seem to have been the key elements in overcoming the middle-income trap (Lee, 2013). According to this line of thought, specialization in such sectors opens up more opportunities for innovation, as technical change is faster, resulting in long periods of rapid income growth. It is thus possible to formulate a hypothesis concerning the link between the speed of movement shown in figure 3 and production specialization in high-tech sectors.

This section therefore compares Brazil's trajectory (set out in figure 3) with more disaggregated data on the country's industrial structure, provided by the Annual Report of Social Information (RAIS), which makes it possible to determine the distribution of industrial activities according to their technological intensity.

For this analysis, RAIS data on formal employment in the segments that make up the processing industry have been used, covering the period from 1995 to 2014. This information provides an overview of the industrial structure in the country and enables analysis of trends in high-tech sectors compared to other sectors. Therefore, the analysed sectors were grouped according to technological intensity, based on the classification proposed by Cavalcante (2014), which links the divisions of the National Classification of Economic Activities (CNAE) with the technological classification proposed by the Organization for Economic Cooperation and Development (OECD).[8] Thus, the processing industry sectors, classified in divisions 15 to 36 of CNAE 1.0, were grouped into four categories related to their degree of technological intensity.[9] The categories are: low, medium-low, medium-high and high technological intensity.

These data were used to determine the trend in employment in Brazilian industry at these four levels of technological intensity, in the period from 1995 to 2014. Taking into consideration the concept of the middle-income trap (Lee, 2013), this analysis will indicate whether during this period there were any changes in the country's industrial structure that could indicate a shift in the Brazilian economy towards the most dynamic of the aforementioned regimes.

Table 1 presents data on the total and industrial employment trends and the sector's share of total formal employment created in the country in the selected period. As shown, the absolute number of jobs created in the country more than doubled over the analysed period, while industrial employment grew at a slower rate (67% between 1995 and 2014). Owing to lower growth in the processing industry's capacity for absorbing workers, its share of jobs in the country declined: the sector's share of formal employment fell from 20.4% in 1995 to 15.87% in 2014. The industrial sector's share of formal establishments operating in the Brazilian economy also fell from 11.5% to 9% over the period in question.[10]

**Table 1**

Brazil: total formal and industrial employment, 1995–2014

| Year | Industry *(number of people)* | Total *(number of people)* | Industry's share *(percentage)* |
|---|---|---|---|
| 1995 | 4 853 311 | 23 755 736 | 20.43 |
| 1998 | 4 530 693 | 24 491 635 | 18.07 |
| 2002 | 5 241 560 | 28 683 913 | 17.85 |
| 2006 | 6 602 248 | 35 155 249 | 18.26 |
| 2010 | 7 840 220 | 44 068 355 | 17.31 |
| 2014 | 8 124 011 | 49 571 510 | 15.87 |

**Source:** Prepared by the authors, on the basis of Ministry of Economy (2016), Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

Figure 4 analyses the data on employment in the processing industry according to the levels of technological intensity of the component sectors.

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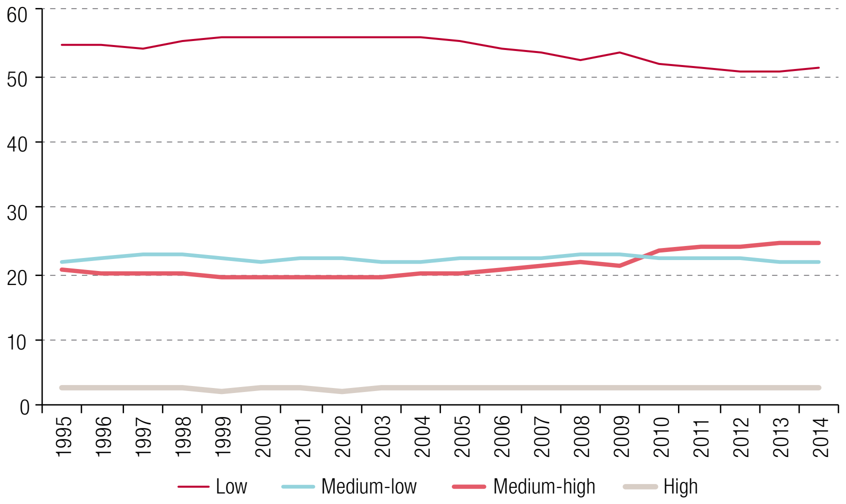
[8] Cavalcante's work (2014) is a technical note prepared under the aegis of the Institute of Applied Economic Research (IPEA), with a view to creating a classification of industrial segments that can be used when formulating public policies in Brazil.

[9] Given that the segmentation of RAIS data by CNAE 2.0 is only available for the years after 2002, a decision was made to use CNAE 1.0, which is available for all the years considered in this study.

[10] Information available on the databases of the Ministry of Economy, Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

**Figure 4**
Brazil: sectors' share of processing industry employment, by level of technological intensity, 1995–2014
*(Percentages)*



**Source:** Prepared by the authors, on the basis of Ministry of Economy (2016), Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

As shown, in the period from 1995 to 2014, the pace of employment growth in the four technology-intensive categories generated little change in the distribution of workers within them. As can be seen in figure 4, the main change is the inversion of the positions of the medium-low and medium-high technology intensity segments from 2010 onward. Between 1995 and 2014, while the medium-low intensity segment's share of national industrial employment fell from 22% to 21.7%, the medium-high segment's share increased from 20.7% to 24.4%. The share of medium-high technology intensity sectors improved because of faster employment growth in those sectors compared to other sectors. During the period under review, the number of jobs grew by 91% in the medium-high tech industrial sectors and 52% in the medium-low tech sectors.

The high-tech group's share of national industrial employment is stable, despite the increase in the number of jobs in the component sectors. Thus, technology-intensive sectors maintained a share of about 3% of formal employment in the processing industry over the analysed period. In this regard, the 65% growth in the number of formal jobs for the high-tech segments did not change their share of the national industrial total.

Overall, the data indicate that the changes in the distribution of formal employment in the Brazilian processing industry among the different levels of technological intensity were only superficial. The medium-low and medium-high technology intensity segments swapping positions cannot be considered a major change in this structure, as the two groups always accounted for similar shares of the country's industrial employment. In addition, the inertia in high-technology sectors' share of industrial employment in Brazil indicates that the production structure lag in relation to core economies increased over the period covered by the series. While technology-intensive sectors' share of total employment in industry remained around 3% in Brazil, it increased from 45% to around 60% in the Republic of Korea between 1995 and 2013 (OECD, 2015). This comparison with the Republic of Korea —which underwent a successful convergence process during that period— helps to understand why the Brazilian economy was unable to move in the same direction. In this respect, the absence of changes in the industrial structure that promote sectors that are more technology-intensive and more predisposed to innovation appear to explain Brazil's inability to narrow the gap that separates it from the most developed economies (Lee, 2013).

The constraints on Brazil's convergence process also seem to be exacerbated by the high proportion of low-tech sectors in the country's industrial structure. In a context of increased international competition, based mainly on dynamic comparative advantages rather than static comparative advantages, high dependence on low-tech sectors limits the country's participation in external markets. This is because these sectors, which are generally based on mature technologies, offer little room for innovation and limited product differentiation. Once more, it is instructive to perform a comparison with the Republic of Korea, where high-tech sectors accounted for 29% of the export structure in 2010, while in Brazil their share was 7% (Romero and others, 2015).

Hence, the period between 1995 and 2014 was not sufficient to bring about significant changes in Brazil's industrial structure. In that time, the low-tech segments continued to account for a large proportion of job absorption, as opposed to the small share of the high-tech sectors. In view of the changes in the world economy since the end of the twentieth century, this is indicative of a deepening structural lag in Brazilian industry, in terms of both production practices and internalization of sectors with greater technological dynamism.

Figure 4 therefore shows growth without any structural changes. Brazil's limited progress in science and technology can thus be attributed to high-tech industry's unchanged relative position, i.e. a movement in figure 3 that is insufficient to overcome the Red Queen effect. This is even more evident when comparing Brazil's record with that of the Republic of Korea over the analysed period.

This finding suggests that it is possible to reconcile the trajectories of national innovation systems —traced using science and technology statistics— with more detailed analyses of national industrial structures. The two approaches are compatible even in dynamic terms.

However, it should be borne in mind that the above analysis assumes that a specific techno-economic paradigm, based on the technological revolution triggered by the microelectronics boom, will continue to prevail. Therefore, the definitions of high, medium and low technology are influenced by the effects of this paradigm on the economic sectors (Dosi, 2006). Technological revolutions are characterized by their ability to modify existing production patterns, disseminating not only new products but also new processes (Pérez, 2010). In this process, new industries emerge while those hitherto considered high-tech may become obsolete or reach maturity. Other segments may simply cease to exist or undergo profound transformations (Freeman and Louçã, 2001). Consequently, technology classifications must be understood as evolving over time, as they can be greatly influenced by changes in techno-economic paradigms. Therefore, if a new technological revolution is confirmed, supported by recent phenomena such as the growth of Industry 4.0 and the search for new renewable energy sources, the industrial structure as it is today could be modified considerably. This type of change and the potential resulting instabilities create windows of opportunity that are aligned with the emergence of new technologies. The act of harnessing these emerging technologies opens up room for structural change in economic systems and thus for convergence, as happened in the Republic of Korea from the 1970s onward (Kim, 1993). In this regard, such technological shifts may offer a path to change in the structural framework of the Brazilian economy, making its convergence process viable.

# VI. Conclusions

Science and technology statistics can be used to monitor the intertemporal trajectories of national innovation systems and are an important tool for assessing countries' stages of development and levels of technological capacity-building.

The methodology for clustering countries proposed by Ribeiro and others (2006) helped to form a link between analysis of science and technology statistics and more structural assessments of the global capitalist dynamic —of the metamorphoses of capitalism— as defined by Furtado (2002). In particular, defining thresholds between the three "regimes of interaction" using a clustering technique contributes to assessment of a special dimension of these metamorphoses of capitalism: the persistence of the core-periphery divide and the changes in it.

Owing to the contribution of technological revolutions (Freeman and Louçã, 2001) to metamorphoses of capitalism (Furtado, 2002), science and technology have played an ever-increasing role in sustaining the wealth of nations. These changes are reflected by movement in the thresholds between developed countries and the rest of the world (see figure 3). Movement in the thresholds can translate into shifts in the core-periphery divide. Moreover, these changes in the position of the core-periphery divide highlight the growing challenge relating to the policies that are required in peripheral countries to overcome underdevelopment.

The methodology presented herein is also able to capture the growing heterogeneity of the periphery, shaped by the existence of two well-defined groups and an incipient subdivision of the peripheral group that is closer to the core.

Lastly, the methodology also detected the potential to overcome underdevelopment, i.e. the peripheral situation is not insurmountable. The trajectories of the Republic of Korea and Taiwan Province of China are examples of this. In other words, the methodology was able to capture successful convergence processes.

The set of data collected and analysed can serve as a starting point for discussion of the Brazilian case, based on a diagnosis of the relative stagnation of the national innovation system, which is still cursed by the Red Queen effect. This can be interpreted as an observation —in terms of science and technology statistics— of the middle-income trap, which can only be overcome by effectively building an innovation system.

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