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**THE CURSE OF TECHNOLOGICAL RACE:
THE RED QUEEN EFFECT**

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THE RED QUEEN EFFECT**

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SUMÁRIO

1. INTRODUCTION.....	6
2. METHODS AND DATA.....	7
3. RESULTS.....	9
4. CONCLUSIONS.....	11
ACKNOWLEDGMENTS.....	12
REFERENCES.....	13

ABSTRACT

Economic prosperity is tied to scientific development, i. e., there is a strong correlation between science, technology and the wealth of nations. We collected data from scientific and technological production of 183 countries of the last thirty years (1974 to 2003) and applied a super-paramagnetic clustering technique on them, finding nations divided in three regimes, distinguished by the interactions between the agents of their National Systems of Innovation (NSI).

The identification of these groups allows us to define the dynamical behavior of the thresholds, that grow exponentially and whose growth rate we have calculated.

We show that for the period 1974-2003 the threshold between the immature and the developed NSIs increases by an annual rate of 6.6% (per capita). We identify clearly a “Red Queen Effect”. Finally we show that the transitions between the regimes are discontinuous, represented by a structural breakthrough. Therefore, the prerequisite to move from regime I to regime II, and then to regime III are structural changes within NSIs.

Key words: national systems of innovation; super-paramagnetic clustering technique; moving thresholds

JEL Classification: O0

RESUMO

Ciência e tecnologia determinam a riqueza das nações. Este pequeno artigo apresenta dados que sugerem uma forte correlação entre ciência tecnologia e renda per capita. Este artigo organiza dados da produção científica e tecnológica de 183 países (período entre 1974 e 2003).

A técnica de clusters super-paramagnéticos é aplicada nesses dados e são encontrados três grupos diferentes de países, que se distinguem em termos de padrões de interação entre os componentes de seus sistemas nacionais de inovação.

A identificação desses três grupos permite a identificação do padrão dinâmico dos limiares que dividem esses grupos. Esses limiares se movimentam. Para o período entre 1974 e 2003 o limiar entre os NSIs imaturos e os maduros teve um crescimento anual de 6,6% (per capita). A partir desse dado, é possível identificar um efeito “rainha vermelha”, na medida em que países podem ampliar a sua produção científica apenas para “permanecer no mesmo lugar”.

Finalmente, este artigo identifica o caráter descontínuo nas transições entre os diferentes regimes.

Palavras-chaves: Sistemas nacionais de inovação; técnica de clusters super-paramagnéticos; limiares

“Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!” (Lewis Carroll, 1982, page 145).

1. INTRODUCTION

“Economic prosperity is tied to scientific development”, says an editorial of this Journal (Sreenivasan, 2004). There is a broad literature on economics that supports this statement, such as the concepts of human capital and national system of innovation (NSI). The later is a concept that helps the understanding of the interactions among those agents engaged in scientific development and technological innovation.

The NSI is an institutional framework, and some of its components are firms, universities, research institutions, venture capital, and governments. The interactions of these agents and institutions generate knowledge flows and diverse positive economic feedbacks. Because of the complexity and variety of the institutional arrangements, the NSIs show strong historical path-dependences (Nelson, 1993; Freeman, 1995). Thus, the concept of NSI adds important insights on the ways science production interacts with other institutional dimensions (May, 1997).

Bernardes and Albuquerque (2003) discuss two key dimensions of the NSI: technology (mainly the product of firms) and science (mainly the product of universities and research institutions). Using statistics for technological production (USPTO patents) and scientific production (ISI indexed papers) they have found strong correlations between scientific and technological productions and the wealth of nations. Hence, the NSI must be taken into account for the study of economic development (Ribeiro et al, 2006).

Following Nelson (1993) and Freeman (1995), Bernardes and Albuquerque (2003) suggest the existence of three NSI “regimes” related to different levels of economic development. As the regimes change, the number and channels of interactions between scientific infrastructures, technological production and economic growth also change. As a country evolves, more interactions and feedbacks begin to operate in the NSI. The highest regime is the one where all connections are working properly. As the country upgrades, its scientific and technological resources become a more important determinant of economic growth, while those static and natural comparative advantages lose strength.

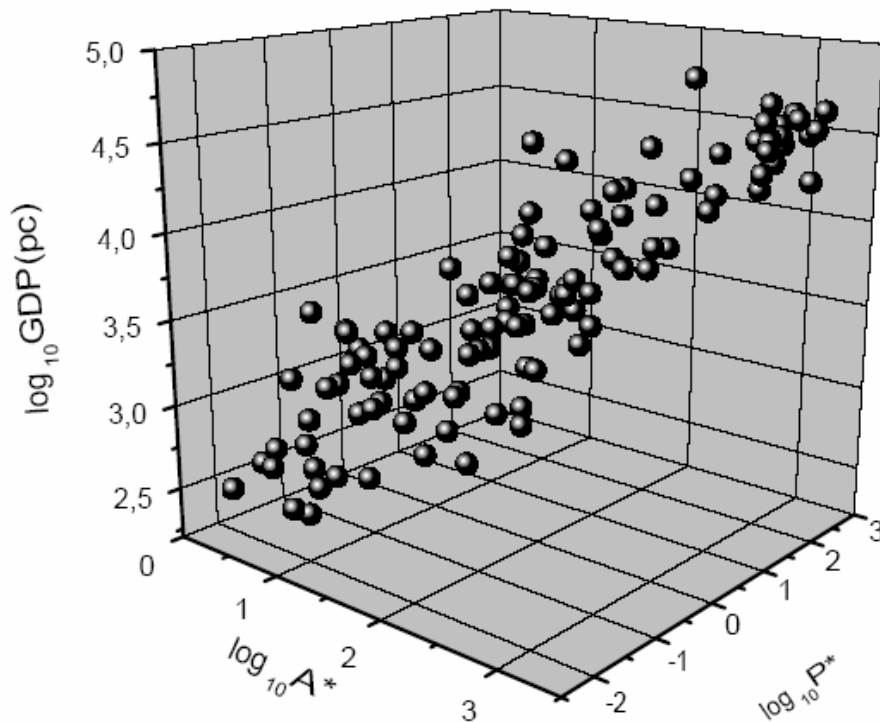
By applying the super-paramagnetic clustering of data technique proposed by Blatt and Domany (1996), we classify a sample of countries into three theoretical regimes. We observe the three regimes over time (1974-2003), which allow us to obtain the dynamical behavior of the thresholds between them and to estimate their growth rate. The movement of the thresholds leads to a “Red Queen Effect”. In biology, the "Red Queen Effect" sets how fast the evolutionary machinery must operate for a specific species in order to maintain its capabilities for competing to survival (Valen, 1973).

2. METHODS AND DATA

We analyze data on scientific articles and patents for several countries and years. Scientific articles and patents are not perfect measures of scientific production and technological capabilities, respectively. The literature has used these data and warned about their problems and limitations. However, we believe it is a worthy and simple way to compare countries and their NSIs. For a critical view on science and technology indicators, see Moed et al (2004).

For the years 1974, 1982, 1990 and 1998 we use data from Bernardes and Albuquerque (2003). That sample incorporates developed, developing, and catching up countries, the later ones are countries that have begun their process in the group of less developed countries and have ended up by achieving a position near the more developed ones. The data on GDP per capita, patents and scientific papers were collected in the World Bank (2005), USPTO (2005), and Institute for Scientific Information (2005). Only data for the so-called hard and applied sciences were used. Since scientific production and patents vary from one period to the other, the number of countries changes. The larger data set is the average of the period 1999-2003 (183 countries are in our database, 61 countries have zero patents, 8 countries with zero papers and 8 countries without available GDP). Figure 1 shows a three-dimensional plot with 119 countries with available data and scores different from zero. Figure 1 suggests a strong correlation between science, technology and the wealth of nations.

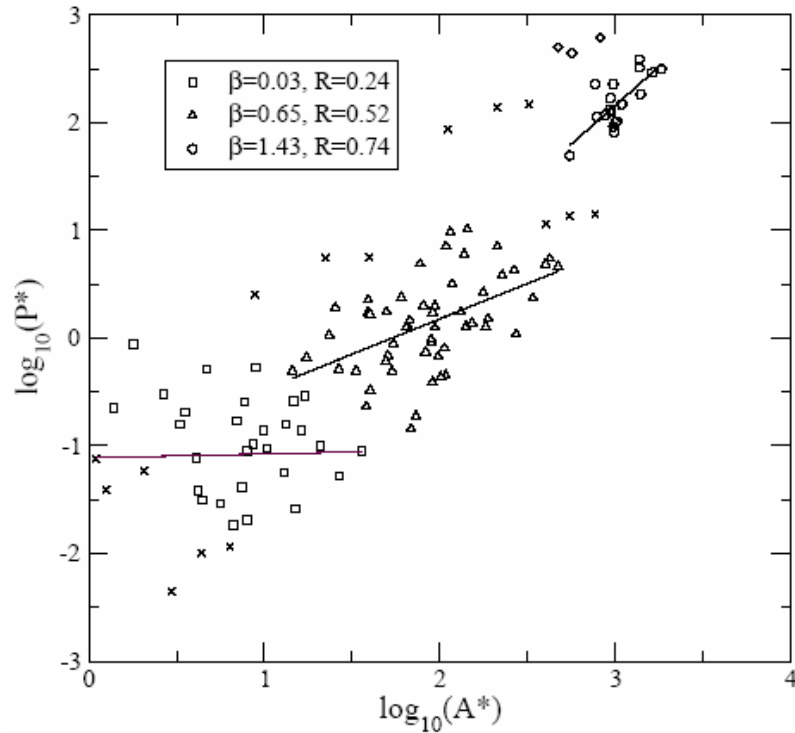
FIGURE 1
GDP per capita vs. Articles vs. Patents (1999-2003)



Plot of \log_{10} GDP per capita (2003) versus $\log_{10} A^*$ (articles per million of inhabitants) versus $\log_{10} P^*$ (patents per million of inhabitants). The data for articles and patents represent an average for the years 1999-2003.

Figure 2 displays the projection of the points on the A^*P^* plane. These points can be grouped by the super-paramagnetic technique in three groups. The super-paramagnetic technique is based on physical properties of an inhomogeneous ferromagnet. This method makes no assumption regarding the underlying distribution of the data. For a set of data points in a d -dimensional space, we assign a Potts spin (positive integer number less or equal to q) to each data point and introduce an interaction between neighboring points, whose strength is a decreasing function of the spatial distance between points.

FIGURE 2
Three Regimes (1999-2003)



Clusters obtained in applying the super-paramagnetic clustering technique. Three main groups are clearly distinguished in this figure. The triangles represent countries in regime I, circles stand for those in regime II, and squares represent countries in regime III. Note that a small group of three countries split at the top of the figure. They are Japan, United States and Taiwan.

At temperature $T = 0$ the ferromagnet is in its ground state, in which all spins are aligned. At high temperatures the system is completely disordered and the correlation between any pair of spins vanishes. If all data points belong to a single cluster, we expect a phase transition from the disordered phase to the fully ordered one. If there are several clusters of data, we expect to observe one or several intermediate phases and transitions among them.

3. RESULTS

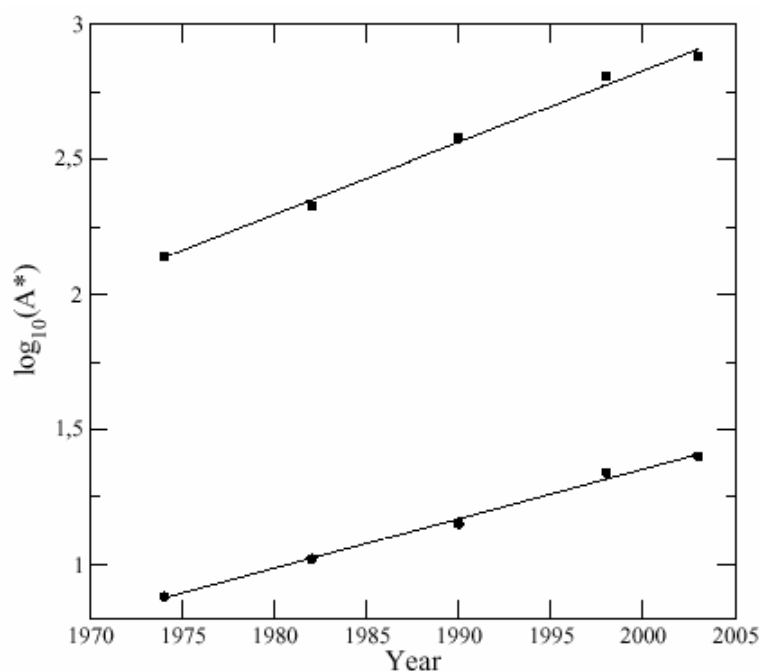
Figure 2 shows three large groups, corresponding to three technological regimes. For each basic group we applied a linear fit to the dataset, which represents a power law between patents and scientific articles with exponent β .

The first group (regime I) is formed by 29 countries. In these countries, the connections between the agents of the NSI are very weak, as one can conclude from the low value $\beta=0.03$ ($R^2=0.24$). There are 54 countries in the regime II, with $\beta=0.65$ ($R^2=0.52$). The highest value of β is 1.43 ($R^2=0.74$), and it is observed in the regime III, which is a small group of 19 countries. In this regime the connections in the country NSI are fully formed and there is a higher conversion from the scientific production into innovation. There are 18 countries that do not belong to any of the three main clusters, and “X” represents 15 of them. The other three countries are Japan, United States, and Taiwan, who are represented by diamonds at the top of the plot.

The same procedure was applied to the years of 1974, 1982, 1990, and 1998, in which the same groups were observed as in figure 2. The plots for the different periods show that there are structural differences between the three regimes, and a discontinuity region separate all groups.

In order to obtain a threshold between regimes I and II, we calculate the normal projection of the rightmost point of the group I on the linear regression line for the whole plot. For the threshold between regimes II and III, we proceed the same way, but with the leftmost point of group III. Figure 3 displays the thresholds between regimes I and II (circles), and II and III (squares) for the different periods. The thresholds grow exponentially with a rate II-III=6.6% per year for the upper line and rate I-II=4.2% for the lower line. It shows clearly that exists a continuous movement of both thresholds, and that it is more difficult to cross the separation between II and III than the one between I and II.

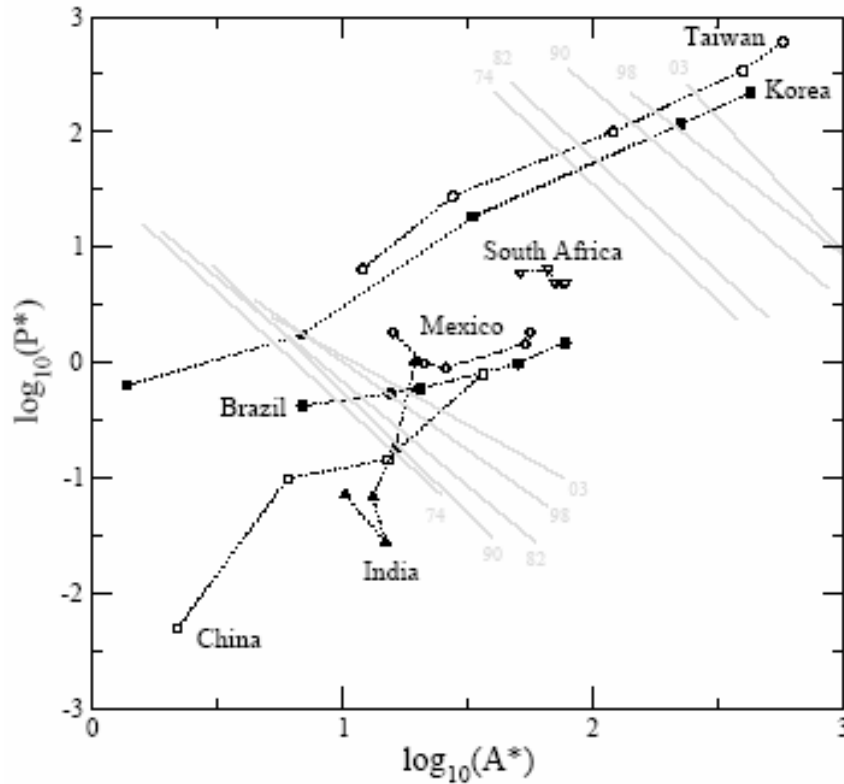
FIGURE 3
Evolution of the Thresholds (1974-2003)



Evolution of the thresholds between regimes I and II, and II and III for different years. An exponential model was used to fit the data points.

Figure 4 presents the moving thresholds and focuses countries with three different trajectories. First, there are the successful catch-up countries: South Korea and Taiwan. They achieved impressive rates of growth both in A^* and P^* . South Korea in 1974 was in Regime I, and moved upwards in the following four dates, reaching regime III in 1998. Taiwan began in Regime II, but showed a similar pattern, running faster than the moving thresholds. The second trajectory shows the immature NSIs of Brazil, Mexico, South Africa, and India. These countries have in common huge social inequalities and great social deficits that seem to constrain a more aggressive policy towards science and technology. The third trajectory is represented by China, who reached the regime II in 2003. *Ceteris paribus*, the projections show China joining regime III in 2050 (given its growth rate of scientific production from 1982-2003). On the other hand, Brazil would join the regime III only in 2144, India would stay in regime I, and South Africa would regress to regime I in 2044.

FIGURE 4
Evolution of the Scientific and Technological
Production for Selected Countries (1974-2003)



Evolution of the scientific and technological production for selected countries and the thresholds levels for different years. The leftmost point of each country corresponds to the year 1974, excluding the case of China, where the point corresponds to the year 1982.

These projections should be read with caution, given the myriad of factors that might impact the global economy and the changes within countries. However, they could be seen as an alert to policymakers, especially because the importance of science for technological development is growing (Narin, 1997).

4. CONCLUSIONS

This paper identifies three types of NSI and calculates the Red Queen Effect, the “curse” of the technological race. This finding shows that for the period 1974-2003 the threshold between the immature and the developed NSIs (regime II and III) increases at an annual rate of 6.6% per capita. This means that if a country scientific production increases by 82.5% per capita in a decade, it would be only “running to keep in the same place”. Thus, it is not effortless to stay in the same place, no matter if a country is at the bottom or on the top.

The relationship between level of development of the NSIs and the Red Queen effect helps to identify the risk of “falling behind” and the challenges to “stay ahead”. The effort to avoid “falling behind” is a condition for a successful catch up process, which demands to “run at least twice as fast as that!” Large less-developed countries, such as Brazil and India, certainly require a lot of additional energy to run faster.

Another finding is the transition discontinuities between the three regimes, represented by structural breakthrough. Thus, to move from regime I to II, and then to regime III, structural changes in the NSIs are required. In a nutshell, besides “running at least twice as fast as that”, a country eventually needs to jump! There is no easy road in the technological race.

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