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CROSS-OVER, THRESHOLDS, AND INTERACTIONS BETWEEN SCIENCE AND TECHNOLOGY: A TENTATIVE SIMPLIFIED MODEL AND INITIAL NOTES ABOUT STATISTICS FROM 120 COUNTRIES

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CROSS-OVER, THRESHOLDS, AND INTERACTIONS BETWEEN SCIENCE AND TECHNOLOGY:
a tentative simplified model and initial notes about statistics from 120 countries(***)

ABSTRACT

The hypothesis of this paper is the existence of thresholds of scientific production that must be overcome to trigger new channels of interactions between the scientific and technological infrastructure.

As the development process evolves, new interactions are initiated. The interactions between science and technology become stronger and more pervasive, reaching at last the mutual feedbacks and the virtuous circles typical of developed economies.

Using statistics of patents (USPTO) and scientific papers (ISI) for 120 countries (for 1974, 192, 1990 and 1998), this paper investigates the relationship between the scientific infrastructure and the technological production.

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INTRODUCTION

The interactions between the scientific infrastructure (universities, research institutes) and the technological production (firms, R&D departments) are a key feature of developed countries. The contribution of these interactions to the process of economic development must be investigated. Unfortunately, so far, the case of less-developed countries has not been well studied in this regard.

The literature about technological change has highlighted the role of mutual feedbacks between these two dimensions (Nelson, 1993; Rosenberg, 1982; Freeman & Soete, 1997; Klevorick et alli, 1995). The literature about endogenous growth emphasises the role of knowledge for modern economic growth (Romer, 1990; Jones, 1995; Aghion & Howitt, 1998).

Using statistics of patents (USPTO) and scientific papers (ISI) for 120 countries (for 1974, 1992, 1990 and 1998), this paper investigates the relationship between the scientific infrastructure and the technological production. This investigation may be connected with discussions about the relationship between science, technology and development.

The literature (Rosenberg, 1982; Nelson, 1993; for developed countries) and anecdotal evidences (Rapini, 2000; Banze, 2000; for developing and less-developed countries) suggest the existence of different levels of interaction between science and technology, alongside different levels of economic development.

The data for 120 countries enable the analysis to go beyond the case of developed countries. This greater sample permits a broader approach, uncovering initial evidences about important differences in the interactions between science and technology throughout the development process.

The hypothesis of this paper is the existence of thresholds of scientific production that must be overcome to trigger new channels of interactions between the scientific and technological infrastructure. As the development process evolves, new interactions are initiated. The interactions between science and technology become stronger and more pervasive, reaching at last the mutual feedbacks and the virtuous circles typical of developed economies.

One important motivation of this paper is that, so far, the economic literature has taken for granted the relationship between these two dimensions. The endogenous growth literature has not used statistics of scientific papers in their empirical studies (Barro & Sala-I-Martin, 1995), and has not modelled the scientific sector as distinct of the profit-making innovative firms sector (Romer, 1990). The neo-schumpeterian literature has accumulated theoretical elaboration and anecdotal evidences, but has not gathered statistic data for countries outside the OECD area (Fagerberg, 1988, 1994; Freeman, 1994). Therefore, both the use of an under-utilised source of data (scientific papers) and the extension of the number of countries to be investigated (beyond the OECD area) are interesting.

This paper is divided into five sections. The first section surveys the literature. The second section presents initial evidences about the role of science before and during the catching up process. The third section suggests a simple model of connections and interactions between scientific infrastructure, technological capabilities and economic growth. The fourth section presents the data, their initial description, and initial evidences of the existence of thresholds of scientific production. The fifth section concludes the paper.

I- A BRIEF SURVEY OF THE LITERATURE

The study of determinants of economic growth is both fascinating and complex. Abramovitz (1989) presents a broad view, suggesting a division between the “proximate sources of growth” (pp. 13-28) and the “deeper causes”, which involves “technological effort as investment” (pp. 28-41) and “national and historical determinants” (pp. 41-55). Abramovitz’s essays on growth summarise the multifarious and variegated sources of economic growth. The literature about economic growth, that boomed during the 1990s, shows the role and relevance of sources like innovation, income distribution, education, health and nutrition, institutions, investment, trade, etc. This literature also shows how complex are the definitions about the direction(s) of causality and how difficult it is to evaluate the interactions between these diverse sources.

The objective of this paper is focused in a very peculiar and specific dimension of this broad and complex picture: the relationship between the scientific and technological dimension and economic growth.

For this paper, two approaches are useful: 1) the literature about the economics of technological change; 2) the debate about the endogenous growth.

Nelson & Rosenberg (1993, pp. 5-9) point the intertwining of science and technology as a key characteristic of national systems of innovation. They summarise the complex interactions between these two dimensions highlighting that science is both “a leader and follower” of technological progress (p. 6).

Evidence of this double role can be drawn from the literature.

First, Rosenberg (1982, pp. 141-159) discusses “how exogenous is science”, indicating how technology leads and precedes science. Rosenberg presents the role of technology as: 1) a source of questions and problems for the scientific endeavour; 2) an “enormous repository of empirical knowledge to be scrutinised and evaluated by the scientists” (p. 144); 3) technological progress contributes to the formulation of the “subsequent agenda for science” (p. 147); 4) a source of instruments, research equipments etc. Rosenberg concludes that “powerful economic impulses are shaping, directing and constraining the scientific enterprise” (p. 159).

Second, in the opposite direction of the flow, Klevorick et alli (1995) present empirical evidence about the role of universities and science as an important source of “technological opportunities” for industrial innovation. This study shows how different industrial sectors rank the relative importance of universities and science to their innovative capabilities. Klevorick et alli rank the relevance of scientific disciplines to different industrial sectors, justifying why firms monitor and follow developments in the universities. Specially in high-tech industries, there are strong knowledge flows running from the scientific infrastructure to the industrial sectors.

Third, Pavitt (1991) investigates “what makes basic research economically useful”. Basic research is economically useful not only because it constitutes an “increasingly important direct input into technology”. According to Pavitt, “there are ... other two other influences that are equally, if not more, important: research training and skills and unplanned applications” (p. 114).

Fourth, Rosenberg (1990) discusses “why do firms do basic research”, and suggests that basic research is an “entry ticket for a network of information”. This point is related to Cohen & Levinthal (1989) discussion about the two sides of R&D, stressing the importance of this investment as a way to develop “absorptive capability”.

Finally, Narin et alli (1997) find empirical evidence for the “increasing linkage” between science (financed by the public sector) and the US industry.

For the objectives of this paper, these studies indicate the relevance of the two dimensions of the innovative activities, stress the division of labour between them and support the understanding of the strong and mutual feedbacks between science and technology in developed countries. Therefore, this literature suggests that for the modern economic growth these interactions must be working.

Romer (1990) formulates a model where growth is caused by human capital allocated in the research sector of profit-seeking private firms. Knowledge flows are key in this model. However, there is no distinction between the scientific infrastructure and technological sector, and therefore, the role of interactions can not be discussed. Pavitt (1998) interprets Romer’s model as one that suggests that the causation runs from the scientific dimension (knowledge producing) to the technologic dimension. Pavitt (1998) inverts the direction of causation.

Aghion & Howitt (1998) present two important points that are related to interactions between the two different dimensions. First, the contribution of education to the growth of labour productivity does not take place, “unless education is being explicitly linked to the rate of innovations and the speed of catch up” (p. 339). Second, they discuss the “low growth traps caused by the complementarity between R&D and education” (pp. 340-342).

II- INITIAL EVIDENCES ABOUT THE ROLE OF SCIENCE BEFORE AND DURING THE CATCHING UP PROCESS

So far, this topic has not been deeply investigated. It is important to be cautious and keep in mind the need for theoretical mediations to discuss the specific features of less-developed countries. It is not possible to make straightforward applications of the findings for developed countries to the less developed countries.

Regarding the non-developed countries, there are important differences in the role of science (Albuquerque, 2001). The main difference rests on the contribution of science to the catching up process. It acts as a "focusing device" in this process. Science at periphery is important to function as an “antenna” for the creation of links with international sources of technology. In a catching up and in a "non-mature" NSI, scientific infrastructure provides "knowledge to focus search" (Nelson, 1982). Instead of being a direct source of technological opportunity, as in "mature" NSIs, at the periphery science helps to identify the opportunities generated abroad. In other words, the main role of science in the periphery is to plug the NSI in the international scientific and technological flows.

There is a dual role of science in the catching up process. First, science might be a “focusing device”, helping to define policies for technological development, to identify the main international sources of knowledge, and to link the country with the international scientific and technological flows. Second, the scientific infrastructure is a major support for industrial development, providing the knowledge necessary for the entry in key industries for the process of development. However, to reach a level high enough to trigger a catching up process, investments and institutional building are a key prerequisite (Amsden, 1989; Kim, 1993; Wade, 1990; Hou & Gu, 1993).

Rapini (2000) contributes to understand some features of the interactions during the catching up process and to delimit the case of catching up countries (Korea and Taiwan) and the case of developing economies that have not yet reached the catching up phase (Brazil). Using patents and scientific papers statistics (between 1974 and 1998) Rapini (2000) investigates the relationship between scientific and technological production. She finds that, on the one hand, in Korea and Taiwan the scientific production Granger-causes technological production and that the technological production also Granger-causes scientific production. But, on the other hand, for Brazil Rapini finds that only the scientific production Granger-causes technological production.

Rapini (2000) delimitates the case of catching up countries and the case of other developing countries: for the catching up countries, the mutual feedbacks between these two dimensions are already in operation; for other developing countries, these mutual feedbacks are not working.

Banze (2000) presents data for even less-developed countries, in his study about African countries.[1] Banze points to three different stages of scientific and technology

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[1] It is justifiable to study less-developed countries with data from scientific papers because the existence of a scientific infrastructure hints: 1) the level of development of the educational resources of the country, 2) the quality of their universities, 3) their connections with the international flows of scientific knowledge, and 4) the commitment of these universities with research activities. This assumption implies that the number of published

development, using patent and scientific papers statistics. First, South Africa could be included in the same category of Brazil (between 1976 and 2000, an annual average of 2,436 papers and 46 USPTO patents). Second, countries like Egypt and Nigeria (respectively with averages of 1,440 and 782 papers, and both with 0.083 USPTO patents). Third, countries like Mozambique (with an initial scientific production -11 papers - and no USPTO patents).

Taking scientific production as a reference, the data from Rapini and Banze seem to suggest that three broad stages of interactions between science and technology could be delimitated (before and during catching up):

1) the country has an initial but very limited scientific infrastructure, enough to produce few scientific papers but insufficient to feed the productive sector to produce patentable innovations (Mozambique, Congo, Ethiopia) ;
2) the scientific infrastructure is stronger, enough to produce scientific papers and few USPTO patents, but the scientific output is not large enough to trigger mutual feedbacks between science and technology (Egypt, Nigeria, South Africa, Brazil);
3) the catching up case, where the scientific infrastructure has grown up to trigger the reverse causation running from the technological realm to the scientific dimension (Korea, Taiwan).

These three broad stages of scientific and technological development hint an evolutionary path. During this path, new stages are reached as certain thresholds are overcome.

These points could be integrated to suggest that the low level of investment in the scientific infrastructure could be one determinant (not the only, but important) of the low-growth trap that blocks less-developed countries (Fagerberg, 1994; Aghion & Howitt, 1998, p. 340-342).

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papers may be taken as an indicator of the general situation of the educational conditions of the country and of their usefulness to the economic development.

III- A SIMPLE MODEL ABOUT STAGES OF DEVELOPMENT AND INTERACTIONS BETWEEN SCIENCE AND TECHNOLOGY

This paper focuses a very specific subject: the interactions between science and technology throughout the development process. To perform the statistical analysis (in the next section), this section put forward a very simple model. This model describes the relationship and the interactions among science, technology and economic growth. It simplifies the complex and multifarious connections, interactions and causal chains that constitute the province of economic growth. However, this simple model helps to focus the discussion in the main theme of this paper: the nature and dynamics of the interactions between science and technology.

The theoretical background and the intuitions of this very simple model are discussed in sections I and II. From them, three stylised facts could be drawn:

1) developed countries have strong scientific and technological capabilities, and there are interactions and mutual feedbacks between the two dimensions (section I);
2) the role of science during the catching up process is crucial and it is two-folded: source of absorptive capability and provider of public knowledge for the productive sector (section II);
3) less-developed countries are caught in a “low-growth trap” given, *inter alia*, the low levels of scientific production (section II).

To suggest this very simple model, six steps are necessary. The support to each of these steps are presented in the literature and the data surveyed in sections I and II.

1) the first step is the recognition of two different dimensions of innovation-related activities – the scientific infrastructure and the technological production;
2) the second step is the identification of a division of labour between them;
3) the third step is the identification of interactions between the scientific and technological dimensions, as well as the dynamics of these interactions;
4) the fourth step is the suggestion that these interactions change during the development process, reaching at last a level of strong and mutual reinforcing relationships found in developed economies;

5) the fifth step is the conjecture that this evolutionary path is pushed by the scientific infrastructure (at least, the improvement and the growth of the scientific infrastructure is a *necessary* but not sufficient condition for triggering technological development), and that there are thresholds of scientific production that must be overcome to reach new stages (and new levels of interaction between science and technology);
6) finally, these interactions in the science and technology field might be integrated in the causal chains of economic growth.

These steps lead to a very simple model displayed in Figure I. This Figure I shows three different "regimes", ranging from the least developed countries ("regime" I) to the developed countries ("regime" III).[2]

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INSERT FIGURE I

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The very simple model uses four sets of variables: scientific production; technological production; economic growth; and "others" (representing a broad range of factors and variables left out of this simplified model - availability of natural resources, health conditions, demographic factors, income distribution etc).

The very simple model suggest that as the "regimes" change, the number and the channels of interactions between scientific infrastructure, technological production and economic growth concomitantly also change. As the country evolves, more connections are "turned on" and more interactions operate (the arrows in Figure I). The "regime" III is the case where all connections and interactions are working (they have been "turned on" during previous phases).

As long as the development takes place, the role of "others" in the causation of economic growth decreases. In other words, as a country upgrades its economic position, its economic growth is more and more "caused" by its scientific and technological resources. The mutual feedbacks between them contribute to explain why the modern economic

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[2] The term "regime" is not a good one, but it is useful to delimit the different forms of operation of the relationship and interactions among the four variables used in the model in its present (and very initial) level of elaboration.

growth is fuelled by strong scientific and technological capabilities (Fagerberg, 1994; Dosi, Freeman & Fabiani, 1994).

This very simple model is suggested to enable the data analysis of section IV, focusing the interactions between science and technology.

IV- DATA DESCRIPTION: SCIENTIFIC PAPERS, PATENTS AND GNP PER CAPITA

Data about GNP per capita (US$ dollars, PPP, according to the World Bank, for 1998), patents (for 1998, 1990, 1982 and 1974, according to the USPTO, 2001) and scientific papers (for 1998, 1990, 1982 and 1974, according to the *Institute for Scientific Information*, 2001)[3] were collected for 120 countries.[4]

Two initial remarks. First, this broad sample is important: on the one hand, studies about technological indicators are mainly concentrated in data about developed and OECD countries (for example, Fagerberg, 1988; Stern et alli, 2000); on the other hand, more broad samples as those provided by the Penn World Table do not use indicators of science and technology (Barro et all, 1995). Second, the range and usefulness of these indicators should be highlighted: there are 115 countries out of 120 that have published at least one scientific paper in 1998; and 89 countries out of 120 applied at least one patent at the

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[3] The pros and cons of patents and scientific papers as proxies of technological and scientific papers are extensively discussed in the literature (Griliches, 1990; for patents; Velho, 1987, for papers). Throughout this paper these observations should be kept in mind.

[4] The countries are: Albania, Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Belgium, Bolivia, Bosnia and Herzegovina, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Congo (Dem. Rep.), Congo (Rep.); Croatia, Cuba, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Finland, France, Germany, Ghana, Guinea, Haiti, Honduras, Hong Kong (China), Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea (Rep.), Korea (Dem. Rep.), Kuwait, Kyrgvzstan, Latvia, Lebanon, Lesotho, Libya, Lithuania, Macedonia, Madagascar, Malaysia, Malawi, Mali, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Senegal, Sierra Leone, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Taiwan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, UK, USA, Uganda, Ukraine, United Arabic Emirates, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Yugoslavia, Zambia, and Zimbabwe.

USPTO in 1998. Only one country (Trinidad Tobago) out of 120 has zero patent and zero paper in 1998.

IV.1- CORRELATION BETWEEN SCIENTIFIC AND TECNOLOGICAL PRODUCTION AND GNP PER CAPITA

Figure II shows a three-dimensional plot, where the $\log_{10}$ of the GNP per capita is plotted against the $\log_{10}$ of the number of articles per million of inhabitants (A*, henceforth) and the $\log_{10}$ of the number of patents per million of inhabitants (P*, henceforth). The data are for the year 1998. Only countries with data available and scores different from zero are represented.

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INSERT FIGURE II

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In Figure IIa shows clearly the correlation between the three variables. The higher is the scientific and technological production, the higher is the GNP.

Figures IIb and IIc show the projections of the points, respectively, in the GNP x Articles plane and in the Articles x Patents plane. In Figure IIc there is a concentration of points in the upper part of the plot, representing the developed countries. The same aspect could be observed in Figure IIa.

At this stage of the discussion, it is not the main interest to look for a function which might fit those points. In a three-dimensional plot it should be very hard to find it. However, at the present, it is clear the correlation between the variables.

Table I organises the data (patents per million inhabitants, scientific papers per million inhabitants and a ratio between these two data) according to countries income levels.

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INSERT TABLE I

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Table I shows the correlation displayed by Figure II, as the scientific and technological production are directly related to the income level. The scientific and technological production are higher for the richer countries (for GNP per capita greater than

US$ 19,000, A* = 937.99; P* = 154.42) than for poorer countries (for GNP per capita less than US$ 3,000, A* = 14,79, P* = 0.10).

Table I presents an initial hint about the existence of thresholds of scientific production. The third column presents the ration between A* and P*. This ratio may be understood as an indicator of efficiency in the transformation of scientific production into technological outputs. The more efficient a country is, the smaller is the ratio (the country produces more patents for a given stock of scientific papers).

Taking as reference the discussion of section III, this means that at the “regime” III (Figure I), there are more connections “turned on” and more interactions working. Therefore, the greater efficiency is achieved. On the other hand, Table I shows that as the income level falls, the efficiency of the transformation of scientific production into technological output also falls (the ratio A*/P* increases). In other words, there are less connections, less interactions: the case of “regime” II (Figure I) might be working. It seems to be necessary to have a great scientific production to reach a point of efficiency in the transformation of science in technology.

In addition, one remark is necessary. Countries with zero patents or zero scientific papers have been excluded from Figure II (115 countries out of 120 have published at least one scientific paper in 1998; and 89 countries out of 120 applied at least one patent at the USPTO in 1998). There are 26 countries with scientific publications but without USPTO patent, which constitute the “regime” I as displayed in Figure I. These 26 countries have not reached even the first threshold, the threshold necessary to trigger the beginnings of a technological production.

IV.2- PRELIMINARY EVIDENCES ABOUT THRESHOLDS OF SCIENTIFIC PRODUCTION

Figure IIc suggests the existence of two behaviours in the relation between A* and P*. The remainder of this section discusses and presents preliminary statistical evidences about the existence of thresholds between different stages of development, and about the changes in those thresholds as time goes by.

IV.2.a- THE THRESHOLD IN 1998 DATA

The cross-over and the threshold level can be better observed in Figure III.

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INSERT FIGURE III

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Figure III displays the data for the year 1998 in a two-dimensional plot in log-log scale. In this plot, it is possible to define two regions. Roughly speaking, they are separated by the point ($A^* \approx 100$ and $P^* \approx 1$). The technologically immature countries are at left/lower of this point and the mature countries at right/upper.

Those points can be fitted by two power functions $P^* \propto (A^*)^{\beta}$, what has been done by dividing the set of points in two subsets, which are shown with different symbols (filled squares and open circles) in Figure IV.

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INSERT FIGURE IV

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The fit of the first subset gives a exponent $\beta = 0{,}76$, with correlation coefficient $R = 0{,}65$. On the other hand, the second subset gives $\beta = 2{,}39$ with $R = 0{,}79$ (Table II, subsection IV.2.b).

The crossover between the two lines occurs at $A^* \approx 150$. The threshold from the technologically non mature to the mature countries is around this point (transition from “regime” II to “regime” III, according to Figure I, section III) .

IV.2.b- THE MOVING THRESHOLD: COMPARING 1974, 1982, 1990 AND 1998

This behaviour is not observed only in the year 1998. The same behaviour can be observed at different times, as shown in the sequence of Figures Va, Vb and Vc. In this sequence the number of patents per million of inhabitants is plotted against the number of articles per million of inhabitants for three different years: 1974, 1982 and 1990, respectively.

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INSERT FIGURE V

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In Figure V, again the plot is divided in two regions, and fitted with two power functions. As observed in figure IV, the points below the threshold are much more disperse, what leads to a lower correlation coefficient.

Again only countries with scores higher than zero are included. It is interesting to highlight that the number of countries increases from Figure Va to Vc (and to Figure IV, which refers to 1998 data).

More important is that the exponent for both regions increases consistently, from 1974 to 1998, as observed in Table II.

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INSERT TABLE II

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This behaviour implies that the thresholds change in time, as shown in Table III. One interesting aspect of this table is that the value of this threshold seems to double from one period to another.

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INSERT TABLE III

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This moving threshold could be interpreted as a signal of the increasing importance of the scientific infrastructure for the catching up process.

V- CONCLUSION: EVIDENCES ABOUT THE THRESHOLD AND FURTHER RESEARCH

This paper is a first step of an investigation about the role of scientific infrastructure for the development process, the interactions between this infrastructure and the technological production, and the dynamics of these interactions throughout different stages of development.

The hypothesis of this paper is not refuted by the data and analyses presented.

Three final remarks are necessary.

First, there are three preliminary and more general contributions of this paper:

1) the use of statistics of scientific papers to investigate countries in different levels of economic development (from least-developed to the leading countries);
2) statistics of scientific publications are an useful tool for the evaluation of less-developed countries, as it presumes the existence of other investments in education, participation in international flows of knowledge;
3) the use of statistics of science and technology to evaluate a sample of countries that goes beyond the OECD area.

Second, the main findings of this paper are:

1) the interplay between science and technology is an important feature of the development process, as the levels of scientific and technological production are correlated to income levels;
2) the existence of a threshold level in the scientific production (for 1998, in the neighbourhood of 150 scientific paper per million inhabitants), beyond which the efficiency in the use of scientific output by the technological sector increases;
3) the inter-temporal dynamics of this threshold, as it changes in time (comparing data for 1974, 1982, 1990 and 1998), and its value seems to double from one period to another.

And third, the results of this paper authorise and suggest further research. Three key lines of investigation are:

1) the investigation of connections and causal links that run from the scientific and technological dimension to the economic growth (and vice-versa);
2) the improvement of the simple model presented in this paper, taking initial steps to formalise it;
3) the main implications for public policy (specially in less-developed countries) of the existence of this moving threshold level.

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TABLE I

Averages and standard deviation of articles per million inhabitants (A*);
patents per million inhabitants (P*); and the ratio between articles
per million inhabitants and patents per million inhabitants (A*/P*),
according to the their income level (GNP per capita) in 1998.

GROUP OF COUNTRIES (GNP per capita)	A*		P*		A* / P*		Number of countries in the group
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	
> US$ 19,000	937.99	377.69	154.42	121.54	11.30	14.45	19
US$ 10,000 US$ 19,000	476.59	432.32	64.68	107.37	43.09	45.27	13
US$ 5,000 US$ 10,000	115.68	133.58	1.45	1.76	152.03	199.30 (a)	25
US$ 3,000 US$ 5,000	40.87	50.10	0.43	0.58	177.64	242.90 (b)	17
< US$ 3,000	14.79	25.06	0.10	0.18	137.08	131.01 (c)	40
GNP not available	14.81	28.89	0.04	0.10	0	- (d)	6

Source: World Bank, 2000; USPTO, 2001; ISI, 2001 (authors' elaboration).

NOTES: (a) 3 countries (with P* = 0) excluded,
(b) 2 countries (with P* = 0) excluded,
(c) 21 countries (with P* = 0) excluded,
(d) 5 countries (with P* = 0) excluded.

TABLE II

Exponents for the power functions which have been used to fit the two subsets of the plots articles per million of inhabitants versus patents per million of inhabitants (Figures IV and V). β_{left} represents the exponent of the left part of the plot (filled squares) and β_{right} the exponent for the right portion (open circles).

Year	β_{left}	β_{right}
1974	0,13	1,27
1982	0,56	1,63
1990	0,70	1,80
1998	0,76	2,39

Source: ISI, 2001; USPTO, 2001; WORD BANK, 2000 (authors' elaboration).

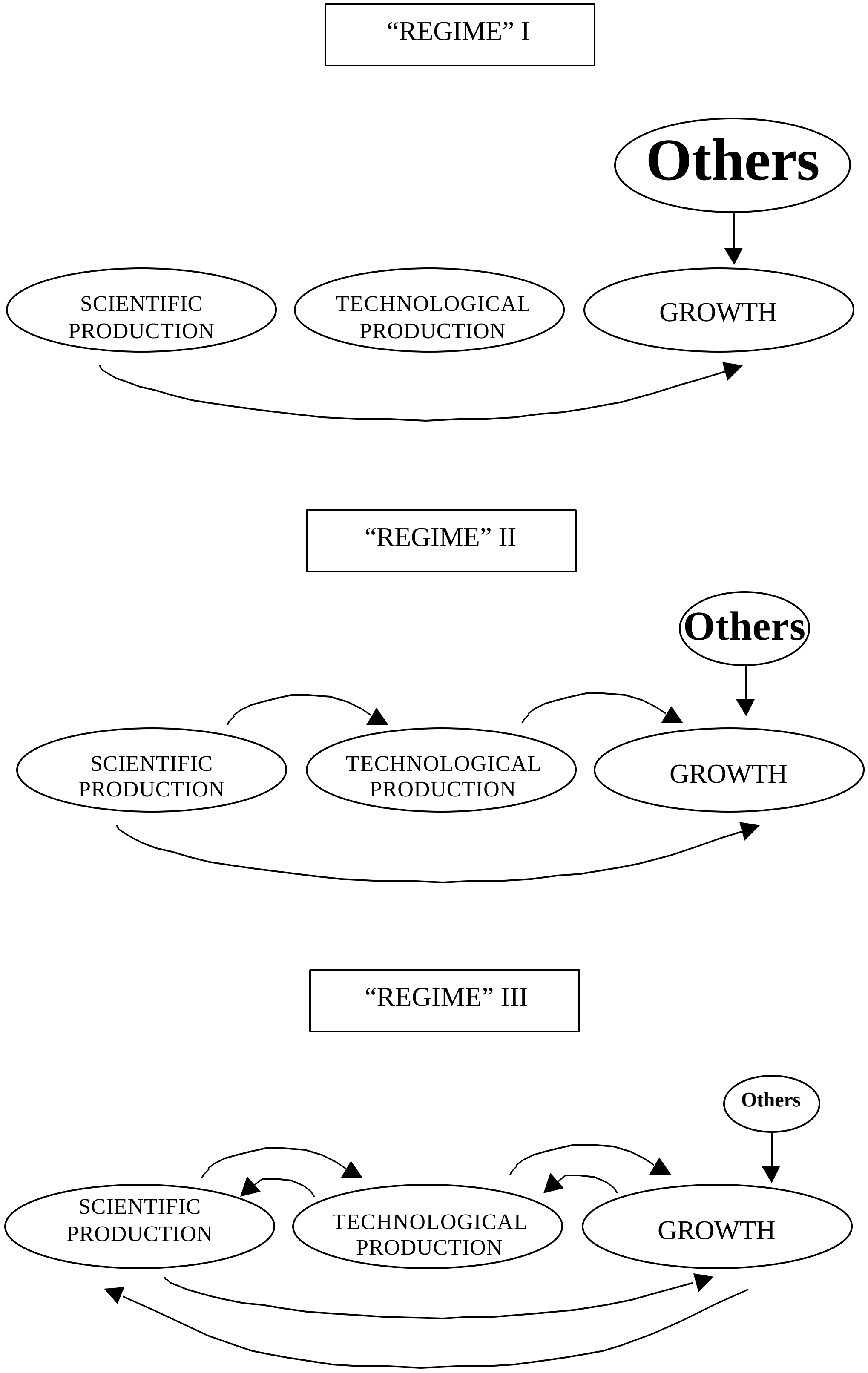
TABLE III

Crossover points between the two functions used to fit the two subsets of the plots of articles per million of inhabitants (A*) versus patents per million of inhabitants (P*) (Figures IV and V).

Year	Threshold (A*)
1974	7
1982	28
1990	60
1998	150

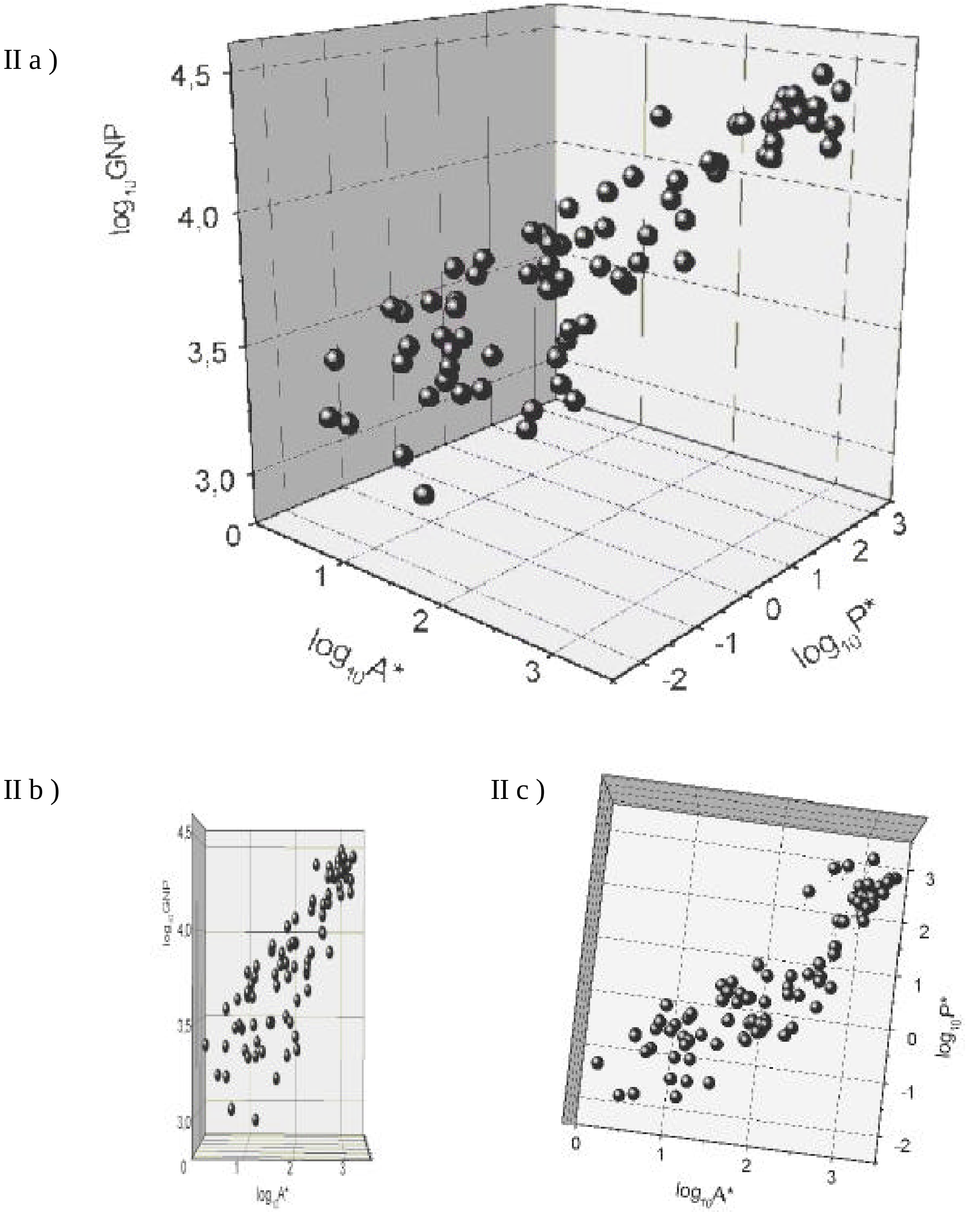
Source: ISI, 2001; USPTO, 2001; WORLD BANK 2000 (authors' elaboration).

FIGURE I



Source: authors' elaborartion

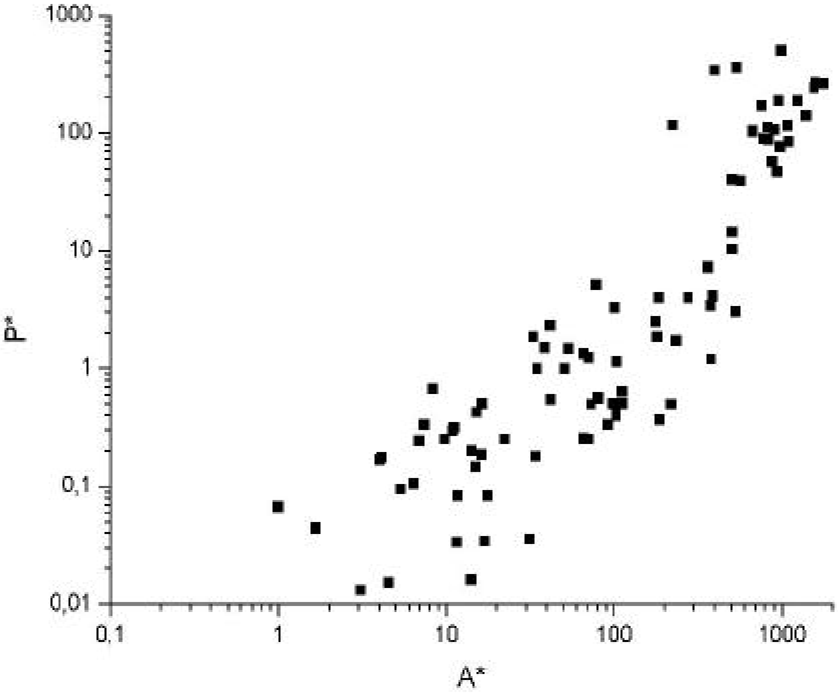
FIGURE II
Plot of $\log_{10}$(GNP) versus $\log_{10}$(articles per million of inhabitants)
versus $\log_{10}$(patents per million of inhabitants).
(a) gives a perspective of the 3D plot, while (b) and (c) shows projections in two planes.
The data were obtained for the year 1998.



Source: ISI, 2001; USPTO, 2001; WORLD BANK, 2000 (authors’ elaboration).

FIGURE III

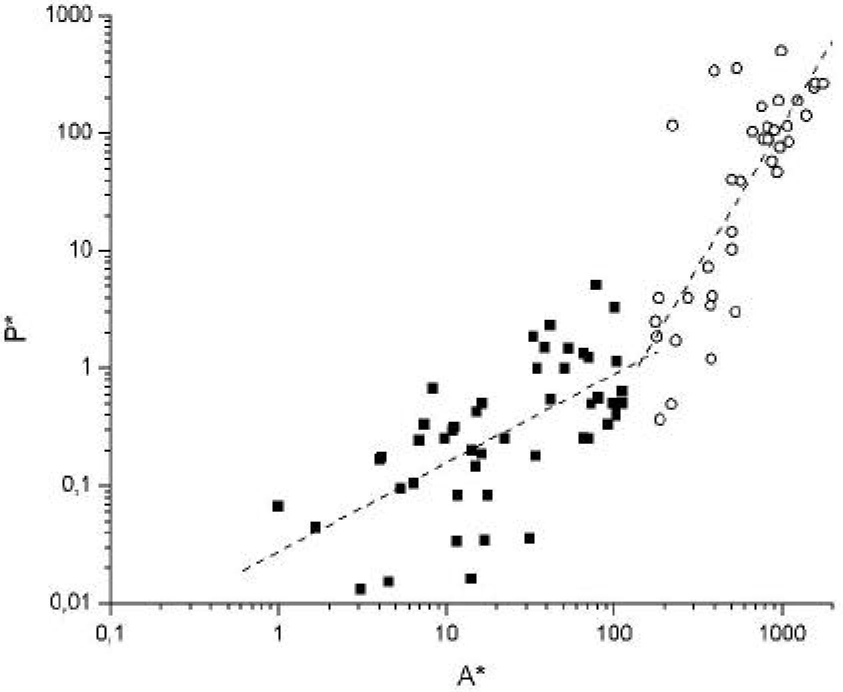
Log-log plot of articles per million of inhabitants versus patents per million of inhabitants for the year 1998. The points can be divided in two subsets, representing different stages of technological maturity.



Source: ISI, 2001; USPTO, 2001; WORLD BANK, 2000 (authors' elaboration).

FIGURE IV

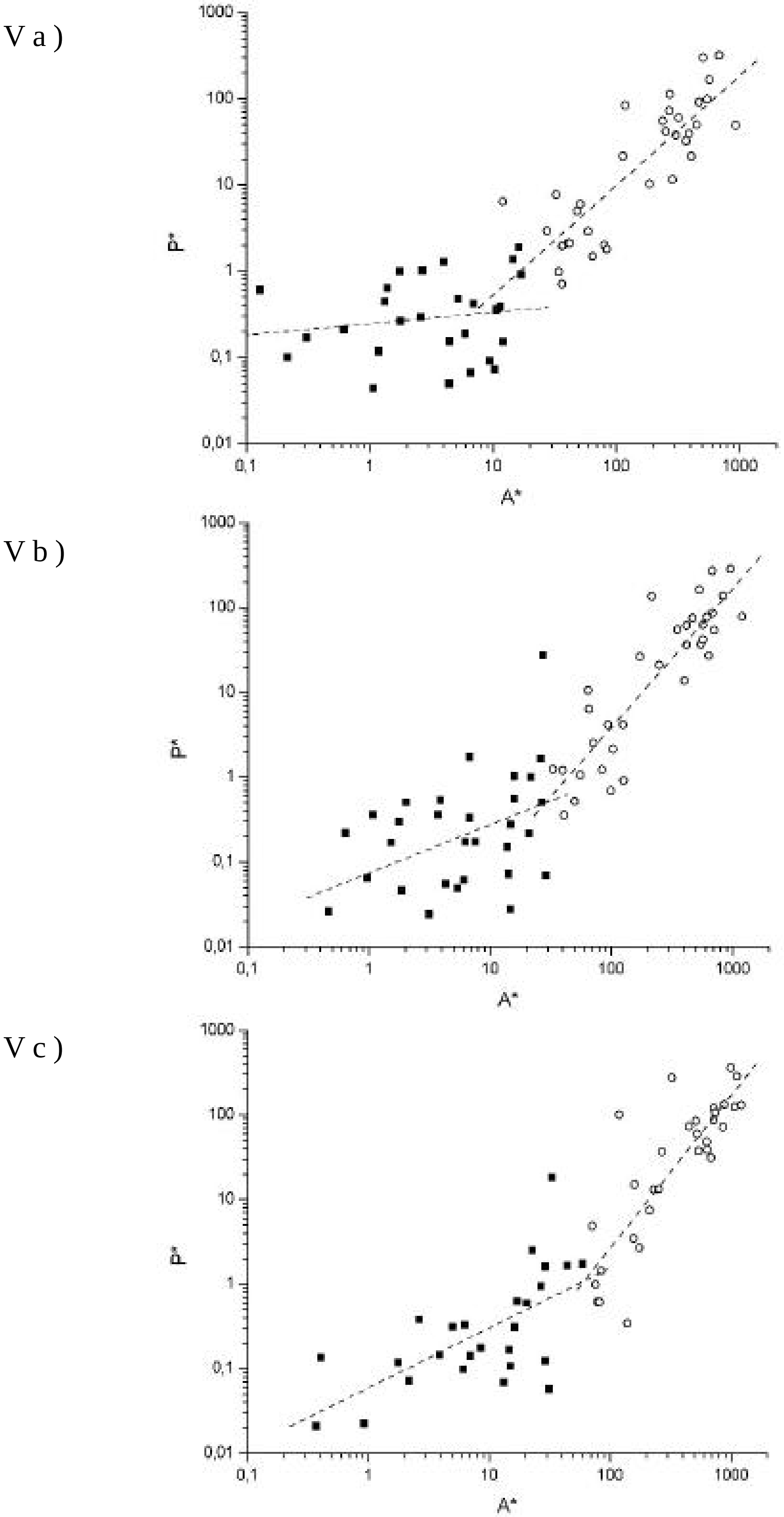
Log-log plot of articles per million of inhabitants versus patents per million of inhabitants for the year 1998. Here the two subsets are identified by different symbols. Two power functions have been used to fit the two subsets.



Source: ISI, 2001; USPTO, 2001; WORLD BANK, 2000 (authors' elaboration).

FIGURE V

Log-log plot of articles per million of inhabitants versus patents per million of inhabitants for the years 1974 (a), 1982 (b) and 1990 (c).



Source: ISI, 2001; USPTO, 2001; WORLD BANK (authors' elaboration).