Practices, Dynamics and Institutions of

Science and Technology in Developed and Developing Countries

(Abridged Version)

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This paper aims at contrasting the dynamics of scientific research and patenting behavior in developed and developing countries. Structural and institutional conditions account for differences in the generating processes of scientific publications and patents. The environment and practices of scientific and technological research in developing countries differ considerably from those in industrialized countries. The central purpose of this paper is to establish to what extent the dynamic evolution of publication and patenting series of a country reflect the institutional and structural characteristics of its science and innovation systems. After presented some stylized facts describing the main differences between science and technology practices and environment in developed and developing countries, it compares the dynamics of scientific activity and of patenting behavior of industrialized and developing countries, builds an index of the dynamics of publications and patents, and relates it to the performance of intellectual property institutions and different indexes of development. (Abridged).

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I. Science and innovation in developing countries

More than one decade ago, the literature on national innovation systems initiated the tradition of considering science and innovation activities as endogenous processes, where institutional and organizational environments largely determine output and trajectories. From this perspective, there is large room for national and regional distinctions and for comparative analysis, both in terms of institutional environments and organizational models, and in terms of the dynamics of the trajectories of national systems.

The practices of science and innovation in developing countries widely vary in form and purpose. Nonetheless, one could – as a first approximation – point out regularities in these practices and identify some similarities among them. Contrasting these practices and the resulting trajectories of scientific and technological output with those of industrialized countries could possibly lead to an understanding of the role of science and innovation in development and to some policy conclusions.

The purpose of this section is to contrast these stylized practices of science and innovation between developing and industrialized countries. Once the dynamics of science and innovation are analyzed in the following sections, especially 4 and 5, a somewhat finer grouping of countries, based on the dynamic characteristics of output trajectories is proposed. policy conclusions are proposed.

A systematic characterization of the differences in science and innovation practices between developing and industrialized countries may be attempted in four dimensions:

a. The institutional and economic environment of research.

b. The practices of science in the laboratories and technological innovation in industries.

c. The inputs of research.

d. Networking and collaboration in science and innovation.

1. The institutional and economic environment of research in developing countries

The surrounding economic and social environment of research, often defined as the *national innovation system*, differs considerable between industrialized and developing countries. More than an exhaustive characterization of differences in these four dimensions, the following sub-sections refer to those that might have larger effects on the output trajectories of these systems.

1. Besides direct products (such as scientific propositions, publications, public policies, industrial products and processes), research normally generates a joint-production of capacities, competences and know-how, which serve as a basis for further knowledge creation. These by-products have a wider variance in magnitude, and are sometimes affected by discontinuities and a low level of networking. The relative sparseness of scientific activities and the lesser development of industry put limits to the size of externalities. The capacity of knowledge absorption by the economy and society is thus considerably lower, and even scientists cannot easily reap the economic advantages of the non-rivalry of knowledge, in contrast with the assumption of non-rivalry of information and knowledge that reflects the practice of normal science in

industrialized countries. As a consequence, the capacity of knowledge absorption by the economy and society is considerably lower.

2. Incomplete financial and technology markets, prevent potentially valuable projects to reach the production sectors. Capital markets in developing countries are in general narrow; private venture capital willing to undertake technology projects is extremely rare in most of these countries. This restrictive market environment strongly affects the exchange of knowledge.

3. Uncertainty concerning the results of research projects has larger effects because of the lower size of capitals allocated to research activities. Also the impact of the lag between basic research and the diffusion of innovations based on it might not be longer but its effects on investments in R&D are stronger because of larger interest rates, shorter time horizons of politicians, and less stable political institutions, making long run investments less likely[1].

4. As a result of these differences, the impact of science and technology projects is not the same in industrialized and developing countries. This impact depends directly on the context, and the context has been shown to be different in respects that considerable affect these impacts. In these circumstances, the economic valuations of research by the market and by the government are lower than those of industrialized countries. This explains the reluctance of governments and industry to invest in research that is observed in developing countries, as well as the lower share of science, technology and innovation expenditures as a proportion of GNP. Unless a shadow price is assigned to the

[1] Mansfield calculated this lag to be between 18 and 30years, and more recently ASIF estimated it in 7 years.

change of this situation, a developing country will not invest large amounts in science and technology.

2. Science in the laboratories and innovation in the factories

A comparison between the industrialized laboratory and the developing laboratory one finds important differences, both in their practices and in expected results.

1. The replication of experiments is a fundamental activity in the development of science. But replicating is always costly in the laboratory of the developing country, since it often the creation of a new laboratory, even for simple normal science experiments. When the laboratories are already implemented, the cost still increases because of the sparseness of scientific infrastructure which requires buying new equipment more frequently than in industrialized country laboratories, since the available equipment was obtained in response to previous projects in that specific laboratory.
2. Empirical research frequently requires initiating the collection of ah-hoc statistical series. This is particularly frequent in econometrics, sociometrics and environmental research[2].
3. Despite these higher set-up costs, the expected results of research are most frequently "normal science" propositions, developed within dominant paradigms or confronting marginal aspects of these paradigms.
4. Sometimes, scientists from developing countries have advantages, stemming from the possibility of questioning paradigms from observations and

[2] Forero (2004).

empirical exploration of a different environment, and from studying problems specific to this environment that are not in the agendas of researchers from development countries. Health, environment, economic and sociological research are the most common fields where these advantages are found[3].

5. The model of innovation of industry in developing countries is based mostly on imitation or adaptation. The use of expired patents, the adaptation of non protected models, and the payment of expensive royalties for know-how (rather than for new or old patents) are among the main sources of innovation, while R&D expenditures, payment of royalties for the licensing of competitive technologies are generally low.

3. The inputs of research

1. Budgets of research projects in developing countries differ from those in industrialized countries in their structure. The costs of equipment, information, travel and communication account for a larger share of those budgets, while personnel costs are in general smaller, as a percentage of those budgets.

2. It was already noted that the replication of many simple experiments in developing countries usually requires creating specialized and costly laboratories. Sparseness of infrastructure and equipment affects equipment and information costs. It is common to find single numbers of scientific journals and incomplete collections in many libraries, and this is an example of the low density of virtual resources in developing countries. Complete or segmented journal-collection segments are often acquired with the budget of single research

[3] Forero and Jaramillo (2002).

projects, and not as the result of the collective management of information resources. When a new research group forms, following the return to the country of a recent graduate, an alliance between two experienced groups to undertake research in a new sub-field, when a well-established group initiates a new project, or when a researcher switches institutions, information and equipment resources have to be built practically from scratch.

3. The reliance upon information resources of research in developing countries is critical. It relies heavily on codified knowledge, generally published in journals and books, or in databases and other digital forms. Accordingly, the costs of documentation are high in these budgets, even for simple research projects.

4. The access to financial resources of both scientific research and innovation projects is more difficult, for reasons explained in the previous subsection.

5. Paradoxically, researchers in developing countries may have a comparative advantage in research using abundant information resources, when this access is made possible, because equipment is still relatively more expensive than information. Besides the presence of scientists from developing countries in international scientific databases in clinical medicine, and plant and animal biology, many countries have an important presence in many theoretical fields. Also, there is a relatively higher presence of developing country scientists in fields where information and communication-intensive methodologies are used. This is the case of evidence-based social practice and medicine; genetic

resources, econometric, environmental and climatic research using internationally accessible data. When there is open access to that information, scientists from these countries also participate in case-based or best-practices research in medicine and management, and many professionals in the fields of administration and business learn through this analysis[4]. Even when resources are scarce, the cost of information resources is still relatively lower than that of equipment and its maintenance.

6. *Inputs and Networking:* In many developing countries, information resources limit the performance of scientists, though in some of them it has improved considerably as the result of international scientific networks. The exception of fair-use in copyright has a positive influence in overcoming limitations of access to scientific information, and have allowed important contributions of scientists from developing countries to international research agendas. Though expensive and difficult, networking seems to be one way out of precariousness of certain research conditions for developing country scientists.

4. Neworking and collaboration

1. Recent works by epistemologists, social scientists and economists have stressed the nature of scientific practice as one of building social networks and communities. Even when their research is not opening new avenues, the efforts of networking of developing country scientists have to be larger than those of their counterpart in developed countries doing similar projects.

[4] Some Internet networking projects have provided this information to medical doctors practicing in Africa.

2. In general, the costs of travelling and international networking are larger in proportion to the results obtained. Attracting the interest of other scientists to an original line of research demands from those scientists modifying their own agendas and building or buying new instruments. The usual assumption of non-rivalry of knowledge looses part of its validity, since both transmission and reception of this knowledge is costly[5].

3. Once it occurs, international collaboration appears to be important for the impact of the research performed by scientists from developing countries, as is shown by the high proportion of international coauthorships in the "top-articles" written by these scientists[6].

4. As a result of institutional, organizational, input and opportunities for networking differences, the strategic value of international collaboration is very high for scientists in developing countries. Collaboration means access to scientific information, a wider recognition for their research and taking advantage of network economies in the creation of knowledge, though it is costly. Entering the circuits of world scientific activity or building networks of interested peers is accordingly difficult. The process of networking and gaining the interest of their peers[7] is very demanding.

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[5] Callon (2000).

[6] The International Scientific Institute includes in the top-articles category the group of articles that have received the largest number of citations, a measure supposed to reflect the scientific impact of an article. In the case of Colombia, only 3 out of 26 top-articles published in 1966-2002 did not include international coauthorships (CTS Colombia Project, 2004).

[7] "Building the universality of scientific propositions resembles more a public works enterprise than the miraculous conversion of spirits that are taken by evidence and the strength of logical arguments," Callon, 1999, p. 35.

5. The institution of "fair use" of copyrighted information is an important way to facilitate the access of researchers from developing countries to scientific information.

6. In the recent past, both developing and transition countries have created networks of expatriated scientists that have helped to mobilize international collaboration.[8]

7. Nonetheless, legal and economic obstacles to information flows remain and the trend towards a stronger protection of intellectual property over information combined with the concentration of databases in industrialized countries and network limitations faced by developing countries.

The consequences of these differences on the performance of developing countries, as shown by the series of indexed publications and patenting, are shown in the following sections. (Abridged)

II. Publications and Patents as Indicators of Science and Technology

Patent statistics have been used as indicators of technology and innovation for many years. In 1984, Griliches edited a book with a collection of studies treating patents as a direct indicator of technology and innovation[9]. Velho (1987), Bernardes and Albuquerque (2003) have followed this line of research in reference to developing countries. Nonetheless, despite the recognition of the value of scientific publication and patent statistics as indicators of science and technology activities of countries, doubts

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[8] Forero (1997).

[9] For a complete survey of patent statistics as economic indicators see Griliches (1990).

remain as to the power of these series to reflect many characteristics of complex science and innovation systems.

1. Patent statistics

Patent series have been viewed as statistics that may reflect the economic processes of cost reduction and product development through technological innovation[10]. They have been used as guides for resource allocation in technology and as a measure of the advances of the production possibility frontier. Econometric studies of patenting behaviour have nonetheless yielded interesting results[11], both using them as exogenous or endogenous variables, despite the heterogeneous quality of patented inventions and the differences in institutional systems may deceive these expectations in part.

The use of patent statistics has a further complexity stemming from the existence of multiple sources of patent information (USPTO and WIPO are the main sources), and the existence of different series reporting patents for residents and total, applications and grants of patents. (Abridged).

2. Publications

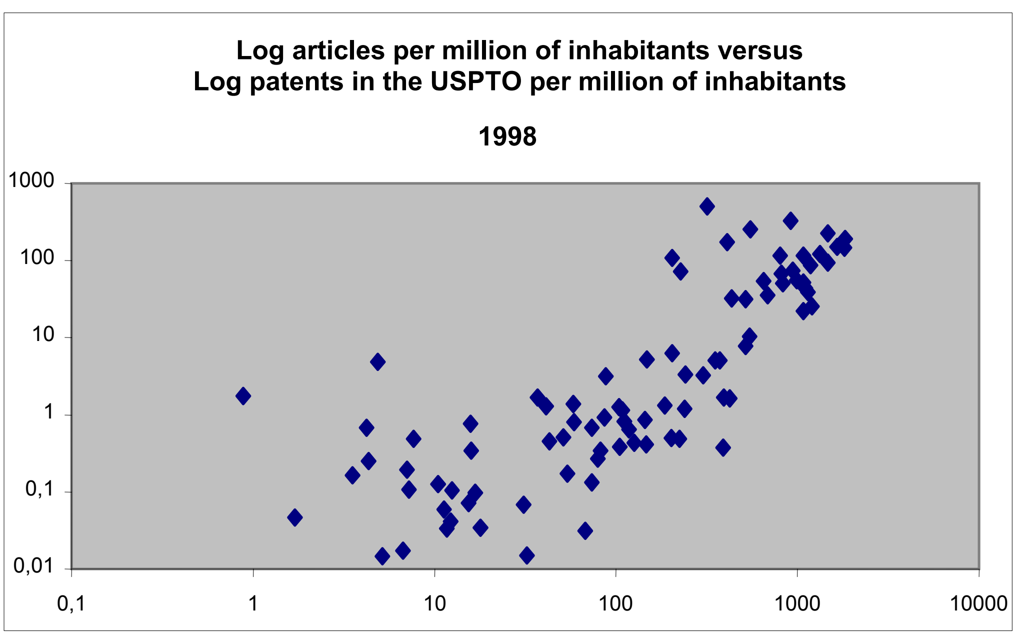
The recognition of publications as an indicator of scientific activity is more generalized in the academic community, though the indexes have not been less subject to criticism[12]. Several databases index scientific publications in the most prestigious journals. For

[10] Griliches (1990), p. 1669.
[11] Griliches (1984).
[12] An evalution is found in Velho (1987).

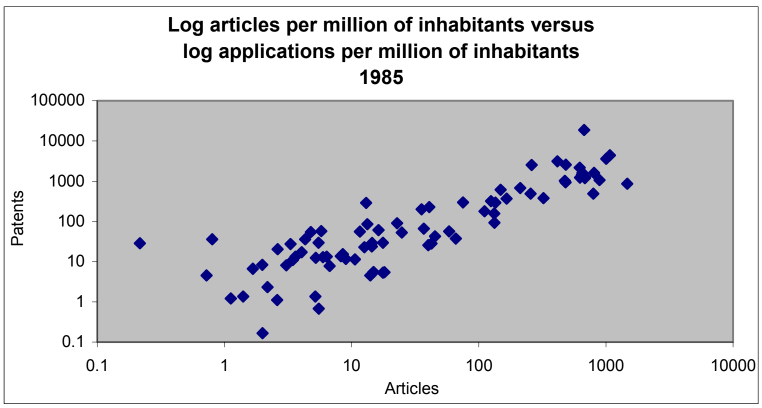
analytical and bibliometric purposes, The Institute of Scientific Information ISI Web of Science, which includes the National Science Indicators, is most frequently used.

III. The relationship between publications and patents

This section explores the relationship between scientific publications and patents series. A recent study by Bernardes and Albuquerque (2003) observes that, besides having a larger per-capita production of both publications and patents, industrialized countries have a larger elasticity of patents to publications than developing countries. One could interpret this relationship as reflecting closer ties between science and technology in industrialized countries than in developing countries. Though built with static data, this relationship may be given a strategic inter-temporal interpretation to say that a country surpassing a threshold level of publications per capita enters in a mode where new channels of interaction take place between science and innovation. We have found a similar relationship for 1998.



This relationship was validated for the years 1974, 1982, 1990 and 1998, for ISI publications series and patents granted in the United States statistics. Nonetheless, this relationship does not hold with WIPO series, which report local patenting in the different countries.



WIPO Total Applications

When exploring this relationship with local applications by residents, no break appears and also that the spread of the relationship increases in the nineties as compared to the previous decade, reflecting perhaps that policies in the 1980s were conducive to an equilibrium between science and technology but that in the 1990s each country evolved towards a different proportion between scientific and technological activities.

If no questioning of these statistical sources is made, one could also hypothesize that the scientific activity has a stronger relationship with technology that is developed for the international market than with technology oriented towards local markets. The relationship between scientific activity and local industry needs then to be explored using other quantitative instruments.

IV. Economic development and the dynamics of publications and patents

The relationship between the levels of publications and patents per capita and the stage of development of countries was discussed in the previous section. In this section, we explore the hypothesis that the dynamics of the series of publications and patents is also closely related to the stage of development of countries. From this perspective, the generating process of publications and patents is related to the trajectory of national systems of science and innovation of each country. The idea is to explore the sustainability of the processes generating the publications and patent series.

The Box Jenkins approach is used for this purpose. Following Box and Cox (1964), the series are first transformed to minimize skewness. The transformation of the series *x is* $\frac{x^{\lambda}-1}{\lambda}$, where λ is estimated to minimize skewness through maximum likelihood. This transformation stabilizes the variance and improves the approximation to a normal distribution. Then the Autocorrelation Function (ACF) and the Partial Autocorrelation Function (PACF) are examined to identify the model and lag orders. Finally, the existence of a deterministic trend is tested.

All the publication and patent series for all countries seem to fit well with a first order autoregressive AR(1) model of the form

$$x_t = \alpha + \rho x_{t-1} + e_t \qquad (1)$$

This is a Markov process, since the value of x_t is largely determined by the knowledge of x_{t-1}. The larger the coefficient of the AR(1) model, the greater the impact of the previous value of the variable. The error term represents the effects that other variables may have on the series, and are considered as shocks. These shocks may be caused by structural or institutional changes and by exogenous events and crises. The deterministic component α represents the trend of the series.

(1) implies:

$$x_t = \alpha(1+\rho+\rho^2+...+\rho^n)+e_t+\rho e_{t-1}+\rho^2 e_{t-2}+...+\rho^n e_{t-n}$$

$$x_t = \alpha t+e_t+\rho e_{t-1}+\rho^2 e_{t-2}+...+\rho^n e_{t-n} \qquad (2)$$

The level of the patent or publication series at time t depends on past shocks, but the effect of these shocks will disappear after a finite number of periods. When ρ tends to 1, the effect of these shocks lasts forever. This will tell us that the effects of past structural and institutional changes determine in a great level the actual value and that future changes will permanently affect the series. The closer a science or innovation system is to this value, the stronger the dynamics of the series. Occasional negative shocks would not affect the trend, though a persistent sequence of negative shocks will. Systems with low values for ρ will depend on current shocks and will be subject to more fluctuation.

The analysis uses indexed publications data from the ISI Web of Science from 1983 to 2002. Patent statistics come from USPTO (1981 2001) and WIPO (total and residents granted patents and applications). Different countries have data available for different periods and some countries do not have sufficient data to analyze the series.

Results and their interpretation

Countries exhibit different values for the autocorrelation coefficient ρ. These series also differ in the value of the trend α, which may be positive, negative or zero, meaning there is no trend in the series. When unit roots ($\rho = 1$) do not exist, the series fluctuates around a trend or a constant value. A positive trend $\alpha > 0$ in publications or patents implies sustained growth, while ρ will reflect the permanence of shocks. Series with a positive trend and a high autocorrelation coefficient reflect stronger and more autonomous science and innovation systems that will respond to positive exogenous stimuli during longer time periods.

Countries with publication or patent series showing positive trends and non significant autocorrelation coefficients have stable trajectories but have to make sustained intervention efforts to improve the performance of their science and innovation systems. In some countries, the series do not show positive trends but they have high autocorrelation coefficients. Their systems are guided by external shocks. Their sustainability will depend on the regularity of external positive shocks including interventions. The trajectory of series with neither trend nor positive correlation coefficient will show a random trajectory, and reflect no proper science or innovation system.

Sweden's WIPO resident applications for patents and USA USPTO patents granted are actually the only two series showing unit roots (ρ = 1). Countries may however be grouped according to the dynamics of the series that reflect the characteristics of their science and innovation systems.

Grouping countries

In order to capture different aspects of national innovation systems, a set of five patent series were explored for each country. In some countries, all the publication and patent series have a positive trend and high autocorrelation coefficient. This reflects a dynamic science and innovation system.

In other countries, the patenting system and market size seem to be more important than their autonomous technological system. The series of total applications and grants (resident plus non-resident) have a stronger dynamics than their local resident series of applications and grants or their patenting in the USA.

In others, the local patent system and market attraction might not be strong, but the innovation system is very dynamic. Their international competitiveness is tested by their USPTO performance.

Some countries are dynamically strong in patent series, reflecting the vitality of their technological systems, while their scientific publications are not. This leads to a classification of countries according to the dynamics of their science and technology systems, as reflected in the series of scientific publications and patenting. A grouping of countries is made according to a multi-indicator ranking of publication and patenting dynamics.

OECD and Asian newly industrialized countries predominate in the first three groups. Group A countries have a high correlation coefficient and positive trend in all examined publication and patent series. It is composed by South Korea, China, Australia and Holland. The science and innovation systems of these countries show a strong dynamics. Appendix A shows the

Group B (USA, Israel, Japan and Sweden) show a strong dynamics (positive trend and high autocorrelation coefficient) in all but one of the series. In the case of the USA, the series not showing a high autocorrelation coefficient is that of granted patents in USPTO figures. This is in contrast with the WIPO series which shows a positive ρ, but the higher reliability of USPTO series advices to put the USA in Group B. Japan is the only one where the failing series is publications.

The third group (C) is characterized by exhibiting two series with failures: either zero autocorrelation coefficients in their series of patents granted to residents or no trend. In the countries of this group, failures occur either in the USPTO series or in patents granted to residents, or both, but never in publications. In some cases, a zero ρ or no trend in resident grants is related to their also low ρ in resident applications (Norway, Austria, Switzerland, France and Italy), and in others (Canada, Denmark, Finland, England and Ireland[13]) this could be attributed to a lower quality of patent applications, more strict patent revision criteria or a longer bureaucratic lag in their patenting system, visible in the contrast of a dynamic application series and a stationary grant series. USPTO patenting by countries in this group shows either zero, intermediate ρ values or, in the case of England, no trend though the autocorrelation coefficient is high. All these

[13] WIPO does not present data for patents granted to residents in Ireland, but four of its series have positive trend and autocorrelation coefficient.

countries have a strong dynamics in their total application and grant series, reflecting the interest of foreign investors in their markets.

Group D is defined for those countries where three series fail. It forms a cluster of nine countries where both local resident and USPTO patenting are not dynamic, though two other patenting series, and publications except for two, have positive α and ρ. Still, they all seem to be attractive for foreign investment and patenting by non-residents. Group D includes Germany, Belgium, Turkey, Spain, and newcomers such as New Zealand, Thailand, Philippines, Mexico and Brazil[14].

Group E countries show a weak dynamics of publishing, patenting or both. Four out of six series fail to have positive trend and autocorrelation coefficient. Out of nine countries in this group, seven have zero autocorrelation in publications. Only one has a positive trend in resident applications. None of them has a positive trend in resident grants. This group is made of seven European countries (Luxembourg, Poland, Hungary, Portugal, Greece, Iceland and Rumania), Hong Kong, Singapore, India and Egypt. Nonetheless, their markets seem quite attractive for foreign patentees.

Group F is made of five countries, one European (Bulgaria) and four Latin American countries (Chile, Colombia, Uruguay, Argentina), none of which has positive trends in resident applications or grants of patents. Colombia, Argentina and Uruguay have intermediate values for autocorrelation coefficients of publications. For the others, $\rho = 0$. As a group, they are as attractive for foreign investments as countries in group E, as shown by positive trends in total applications, total grants or both, and $\rho > 0$ in these two series for all countries.

[14] WIPO figures for Brazil show extremely abrupt oscillations in the last four years of the series (1997-2001). If these figures are excluded, the series shows a positive trend and zero autocorrelation coefficient.

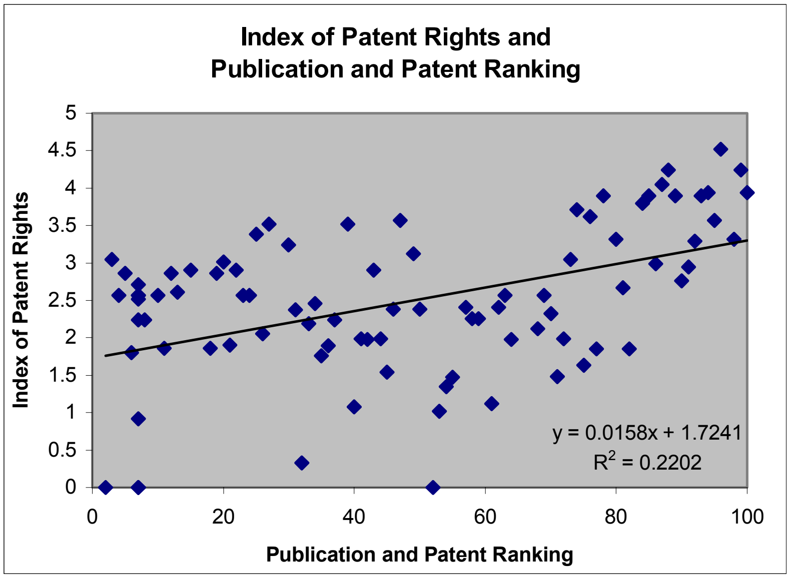
Group G includes five Latin American countries (Panama, Cuba, Costa Rica, Venezuela and Peru). Publications do not show a significant autocorrelation coefficient and WIPO series have no positive trend.

The 14 countries in the eigth and ninth groups (H and I) show similar characteristics and failures, but either WIPO or USPTO do not report some patent series for them. The other four categories (groups J, K, L and M) have very incomplete or no patenting data.

V. The relationship of the publications and patent ranking with intellectual property and development indexes

There are relationships between the ranking obtained in the previous section and different indexes related to economic and social development and institutions of intellectual property protection.

Ginarte and Park (1997) examine the factors determining institutions for the protection of intellectual property in a large number of countries in the world. One of their results is that "the more developed economies provide stronger protection" (p. 297). According to these authors, "… a country requires a certain critical size of an innovating sector before it has an incentive to provide patent rights" (p. 299). A statistical relationship is found between the publication and patent ranking developed here and Park and Ginarte's index reflecting the patent protection systems of each country.



The relationship fits well for countries in the upper part of this ranking, but for less developed countries there is more dispersion of data. One reason brought by Ginarte and Park in their analysis that can be invoked to explain this wider variance is that some developing countries, especially in Africa, have taken patent laws from France and the UK, "their former colonial ties" (p. 291), sharply separating them from other developing countries. The publication and patent ranking developed here clearly shows the threshold in patent protection hypothesized by Ginarte and Park, and confirms that variables related to innovative activities are more closely related to intellectual property protection than simple income per capita indexes. (Abridged)

VI. Causality

In section IV, it was reported that the only series showing unit roots are patent applications by residents in the USA and Sweden. Unit roots in two series are a condition necessary to explore co-integration of these two series and intend to prove long term causality. This condition is not met by any of the countries. No long term causality may thus be explored between publications and patents or vice-versa. Publications and patents are thus series that may be determined only by short run shocks.

Granger causality is defined as the capacity of one variable to predict the behavior of another variable. *x* is said to Granger-cause *y* if the lags of *x* can predict consistently the current value of *y*. Observe that "Granger's concept of causality does *not* imply a cause-effect relationship, but rather is based only on 'predictability'"[15].

Using USPTO statistics of patenting for 1974-1998, Rapini (2000) found that for two countries in the process of "catching-up", South Korea and Taiwan, patents are Granger-caused by publications and vice-versa, while for Brazil publications Granger-cause patents but there is no feedback. Bernardes and Albuquerque (2003) consider this double causality a condition for technological catching-up[16].

The exploration of Granger-causality between scientific publications and USPTO granted patents was made for 46 countries. Only two of those countries show mutual causality between publications and USPTO patent grants (Denmark and Brazil[17]). In 31 countries, publications Granger-cause USPTO grants; 14 of these countries were OECD members in 2002; China, seven other Asian newly industrialized countries, and six developing countries were also in this category. In South Korea and Uruguay USPTO

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[15] W. E. Griffiths, R. C. Hill and G. G. Judge (1993), *Learning and Practicing Econometrics*, Wiley, p. 696.

[16] "Therefore, the mutual feedback and the interaction between science and technology seem to be components of catching up processes", p. 872.

[17] In contrast with Rapini's result, though this may be due to different periods of analysis.

patents Granger-cause publications. For 12 countries (five of them OECD members) there was no Granger-causality between these two series.

In general terms, one can conclude that, in most countries examined, publications Granger-cause USPTO granted patents. Nonetheless, the expectation that either catching-up countries or highly-industrialized countries exhibit a short-run feedback is not sustainable in general, at least for granted patents.

Comparable explorations of causality between publications and patents were made with WIPO local patenting series of applications by residents, patents granted to residents and total applications and granted patents.

It was found that, in 32 countries, publications Granger-cause resident applications, while only in 7 countries, resident applications cause publications; in 3 countries double causality was found; and there was no Granger-causality in 11 countries.

Publications Granger-cause patents granted to residents in 19 countries. In 6 countries one observes the reverse. In 3 countries there is double causality. And there is no causality in 19 countries. This shows that resident applications are relatively more dependent on publications than patents granted are.

Publications Granger-cause total applications (resident and non-resident) in 26 countries, 6 less than for resident applications. For 12 countries, total applications cause publications. There is double causality in 4 countries. For 7 countries, there is no causality.

In 15 countries, publications Granger-cause total granted patents. The reverse relationship is observed for 15 countries. Two countries exhibit double causality. And in 29 countries, there is no Granger-causality in either direction.

No definite conclusions may be obtained from this analysis, concerning causality, since Granger causality may not be interpreted as reflecting structural relationships. But some inferences can be made showing that, perhaps as it was expected, scientific publications predict more closely the patenting behavior (both in the USPTO and in national patenting offices) of the residents of one country, than they predict the patenting of non-residents. On the other hand, double Granger-causality is not commonly found among publications and patents, and it is difficult to generalize on which countries exhibit this double relationship. (Abridged)[18].

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[18] **Appendix:** The following table ranks countries by the sign of the trend and of the autoregressive coefficients in their series of publications and patents. *nt* means that the series has no trend; a minus sign (-) after the coefficient means the trend is negative. Ranking and classification in groups was made according to the number and then the nature of failures in the six series. When the number of series failures was the same, countries were ranked first by trend and then by the ρ parameter. Countries with the same number of failed series but a double failure in one of them were ranked below. The last criterion that was used in the ranking was the value of the ρ parameter in publications. East and West Germany patent series were added for 1950-1982. Some isolated missing figures were estimated by interpolation assuming a constant rate of growth. (Abridged)

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