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Convergence of innovation in the nanotechnology paradigm across countries [1]

Convergencia de innovación en el nuevo paradigma tecnológico de nanotecnología entre países

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Abstract

Innovation convergence implies a paradigm in which the findings and the creation of technology occur at the intersection of multiple disciplines and organizations. Nanotechnology is revealed as a new technological paradigm that offers a radical change in the solution of technological problems and that generates a new wave of processes, products, and social and organizational systems. Thus, innovation convergence in nanotechnology involves both scientific and technological sources of knowledge as well as organizational forms that enable the development of the technology. The objective of this article is to analyze the phenomenon of nanotechnology convergence in the dynamics of the technological innovation of countries, particularly if it is possible for countries to converge on innovation in this technological paradigm. The findings of this research allow corroborating the convergence in this new technological paradigm between countries in the long-term, in the measure that the less advanced countries reach

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greater rates of growth in terms of innovation in nanotechnology than the leading country, conditioned to achieving a greater accumulation of technological knowledge through the citation of patents prior to the patents granted in nanotechnology.

JEL Classification: O33; O47
Keywords: Conditional technological and innovation convergence; nanotechnology paradigm

Resumen

La convergencia de la innovación implica un paradigma en el que los hallazgos y la creación de tecnología ocurren en la intersección de múltiples disciplinas y organizaciones. La nanotecnología se revela como un nuevo paradigma tecnológico que ofrece un cambio radical en la solución de problemas tecnológicos y que suscita una nueva ola de procesos, pro-ductos y sistemas sociales y organizacionales. Así, la convergencia de la innovación en nanotecnología involucra fuentes de conocimiento científico, tecnológico y formas organi-zacionales que posibilitan el desarrollo de la tecnología. Este artículo se propone analizar el fenómeno de la convergencia de la nanotecnología en el plano de la dinámica de innovación tecnológica de los países, particularmente si es posible que los países converjan en la innovación en este paradigma tecnológico. Los hallazgos de esta investigación permiten corroborar la convergencia en este nuevo paradigma tecnológico entre países en el largo plazo, en la medida en que los países menos avanzados alcancen mayores tasas de creci-miento de innovación en nanotecnología que el país líder, a condición de lograr una mayor acumulación de conocimiento tecnológico mediante la cita de patentes previas de las paten-tes concedidas en nanotecnología.

JEL Classification: O33; O47
Palabras clave: Convergencia condicional tecnológica y de innovación, paradigma nanotecnología.

Introduction

The global technological progress recorded in recent decades has given rise to the emergence of new technological paradigms, closely linked to scientific findings transcendental in different areas of knowledge. Some countries have stood out due to their leadership in the innovative dynamics of information and communications technology (ICTs), biotechnologies and, more recently, nanotechnologies. Under the idea of converging in the incorporation of these technological paradigms and reach the innovation leading countries, the follower countries have been concerned with transferring foreign cutting-edge technology, developing learning and absorption competencies of such technologies, improving their institutional environments, channeling their efforts towards research and development, among other strategies; and in this manner develop technological and endogenous innovation capabilities. The dynamism in innovation and the diffusion of these new paradigms in the countries has been considered a crucial element in the explanation of their economic performance. This has been precisely one of the incentives for countries to promote technology and innovation convergence processes[2].

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[2] In the classic hypothesis of economic convergence between countries the role of technology is implicit. The ability of a country to grow more than the initial leader, under certain conditions, is identified as a central aspect of this hypothesis (Abramovitz and David, 1996). Historically, countries have developed differing abilities that have led them, in the long-term, to converge in the different technological paradigms.

The analysis of the causes, processes, and innovation convergence patterns has been the concern of different studies (Fagerberg, 1987), and particularly the confluence of different technologies, industries or instruments in a unified whole (Kim, Kim and Koh, 2014; Kim *et al.*, 2015; Lee *et al.*, 2015; Erman and Finsati, 2015; Park and Lee, 2015; Oh and Joo, 2015).

Innovation convergence implies a paradigm in which the findings and the creation of technology occur at the intersection of multiple disciplines and organizations. Nanotechnology is revealed as a new technological paradigm that offers a radical change in the solution of technological problems and that generates a new wave of processes, products, and social and organizational systems (National Research Council, 2014). Thus, the convergence of innovation in nanotechnology involves sources of scientific and technological knowledge and organizational forms that allow the development of the technology.

In the establishment and development of this new paradigm, the United States has had a leading role followed by other industrialized countries, with the marginal, but growing, participation of merging countries. The theoretical and empirical study that helps corroborating whether the convergence of other countries with the leading country is possible in the long-term in the new paradigm of nanotechnologies, as well as identifying the factors that condition such a convergence process, is considered relevant.

In this context, the purpose of this article is to first identify the technological and innovation breach and, subsequently, propose a model that proves whether the convergence in nanotechnologies between countries is possible. The key questions of this research are the following: Is technological and innovation convergence between industrialized countries and between industrialized and emerging countries in the new technological paradigm of nanotechnology possible in the long-term? And, to which factors is this technological and innovation convergence conditioned? We state as a hypothesis that the technological and innovation convergence in nanotechnologies between countries in the long-term is conditioned to the existence of technological capabilities, technology absorption capabilities, and social capabilities (Rogers, 2003; Abramovitz, 1986).

This work has four sections. In the second section, we reflect on the cognitive and social converge of nanotechnologies. In the third, the evolution, nature, and breaches in innovation between countries regarding nanotechnologies are identified. In the fourth section, the conditional convergence between countries on nanotechnologies is estimated and analyzed. Finally, the conclusions are presented.

Nanotechnologies and nano-sciences: convergence of scientific and technological knowledge

Nanotechnologies are revealed as an emerging paradigm (Poole and Owens, 2007; Maldonado, 2007; Takeuchi, 2011; Igami and Ozakaki, 2007; OCDE, 2013). Its transcendence is supported by the fact that they involve a scientific and technological revolution based on knowledge and abilities in order to measure, manipulate, and organize matter at the nanoscale of a millionth of a millimeter (Royal Society, 2004).

In the context of nanotechnologies as a new technological paradigm, convergence is posed in terms of the generalized adoption of a technology that offers a radical change in the solution of technological problems and that generates a new wave of processes, products, and social and organizational systems. Convergence implies a confluence in the cognitive,

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technological, and human activity planes (Roco and Branbridge, 2013).

Although in other previous technological paradigms a confluence between science and technology has been registered, in the case of nanotechnology the cognitive convergence is much broader given that different fields of science and technology interact. The precedent are nano-sciences, in whose development and findings physics, chemistry, biology, the scientific and engineering fields, computing, and systems at the nanoscale level converge (including those with thermic, electric, magnetic, optic, and chemical properties) (Roco and Bainbridge, 2001 and 2013). In the case of nanotechnologies, there are four fields in which the technological disciplines confluence and find various sectors of application: 1) nano-metrology / nano-analysis; ii) nano-biotechnology / nano-medicine; iii) nanomaterials / nano-chemistry / nano-electronics; and iv) nano-optics (Abicht *et al.*, 2006: 17). Currently, cognitive confluence is even greater: the confluence of nano-technology – biotechnology – information and communications technologies (ICT), known as Nano-Bio-ICT confluence (Nano-Bio-ICT Cognitive Confluence – NBIC) (Bain-bridge, 2007). Currently, the Convergence of Knowledge and Technology for the Benefit of Society (CKTS) project sponsored by institutions of different scientific fields and various countries, recognizes that such a convergence is the central opportunity of progress in the 21st century (Roco and Bainbridge, 2013).

Due to its interdisciplinary nature, nanotechnology opens ample research and development opportunities and other potential paradigms in nanomaterials, manufacturing products of massive application, health and molecular medicine, environmental and energy processes, biotechnology and agriculture, electronics, information and communication, and national security (Allarakhia, 2011).

The huge potential for innovation that opens with the new technological paradigm is based on the fact that matter possesses different properties at the nanoscale level[3]. There is the expectation that nanotechnologies could be strategic for the competences of the industry, the military and the space sectors[4]. Among the innovations being profiled towards a social benefit we find the following: production processes based on cheap, non-polluting energy and, generally, with a "better" understanding and preservation of nature (Roco, 2011: 427), with an elevated productivity in agriculture and the industry, greater speed in information and communications technologies, medical improvements, revolutionary methods to obtain energy, or to make water drinkable (Roco, 2007; Royal Society, 2004; Hall, 2005). Additionally, the development of instruments with a class of properties, functions and performance. All of this entails that, in the transition towards a production model in which the materials are made step by step and where the decision to build new materials, the atom is taken to obtain the desired characteristics (Müller and Righi, 2002)[5].

Regarding the paradigm of the ICTs or of biotechnology, nanotechnologies could be considered a meta-system that will expand or confluence towards various technological

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[3] Comparing each element at the macro level, which has a certain color, consistence, properties, at the nanoscale level, the systems, the instruments of this same matter could unfold in a completely different manner (Palmberg, Dernis and Miquel, 2009; Poole and Owens, 2007; Hall, 2005; Royal Society, 2004).

[4] "Nanotechnology is moving towards a general purpose in 2020, towards four generations of products with a greater structural and dynamic complexity: 1) passive nanostructures, 2) active nanostructures, 3) nanosystems, and 4) molecular nanosystems" (Roco, 2011: 427).

[5] G. Müller and M.L. Righi, "Nanochimie und Nanometeralien. Venture Capital, Magazine Nanotechnologie, 2002: 28-29 cited in Abicht, Freikamp and Schumann, 2006: 20.

paradigms, but with a cognitive leadership[6]. Thus, there is reference to nano-biotechnology, nano-microelectronics, etc. Various studies coincide on the importance of the benefits that will be obtained from the development of nanotechnologies, which would extend to different industrial and service areas in a manner that would modify the way of life of society, with a broad impact in the economic and social development (OCDE, 2013). In summary, it is expected that nanotechnology will be the key convergence between science, the economy, and the future of society (Bainbridge, 2007; Roco, 2007). However, this revolution does not only presuppose institutional changes, but it will also cause socio-institutional changes (Pérez, 2004).

Evolution, nature, and breaches in innovation regarding nanotechnologies between countries

The embryo of nanotechnologies can be traced in the nano-science projects in universities and institutes (Cooper and Barsen-Basse, 2006; Roco, 2011 and 2013). The master conference of Feynman (1959) was crucial for the future development of nano-sciences and nanotechnologies. Other pioneer works that contributed to the development of nanotechnologies were those by Drexler (1981, 1986) and the work of Drexler and Smalley (2003)[7]. The expenditure dedicated to the R&D of nanotechnologies is not easy to identify during the 1980s. In an initial stage, the entrepreneurs were uncertain about investing in this new field of knowledge, and did not strongly invest in the R&D efforts. Although, in the universities and research institutes new ideas were generated in which different fields of science coalesced until reaching the proposal of radical changes in technologies.

Up until the beginning of the 21st century there had been warnings regarding a substantial deployment of funding towards R&D activities in this emerging paradigm. From 1997 to 2009, the global government spending on R&D registered an average annual growth of 16.6%. The United States had an average annual growth of 19.5%; of 25.4% for the European Union; and of 24.7% for Japan. The most surprising growth is that of the group of newly industrialized (Korea and Taiwan) and emerging (China, Russia, India, among others) countries. In 2008, the global expenditure in R&D, with both private and public financing, was of 15 billion dollars, with the United States contributing 3.7 billion dollars of this total (Roco, 2011).

The expenditure on R&D per capita on nanotechnologies is another indicator that allows measuring the differentials in the effort allocated to the development of new knowledge in this emerging paradigm. In 2008, Japan is placed at the top with 7.3 dollars per capita; followed by Korea with 6 dollars per capita. In the United States, this indicator is of 5.1 dollars per capita; the European Union reports 4.6 and Taiwan 4.5. Finally, China has an expenditure of 0.4 dollars per capita, although its expenditure in R&D with public financing increased this year to 430 million US dollars (MUSD), greater to that of Korea (310 MUSD), Taiwan (110 MM), and is lower to that of Japan (950 M), the European Union (1700 M), and the United States (1550 M) (Roco, 2011: 38).

The inventive step on nanotechnologies was incipient during the 1980s, but registered a significant growth. Between 1980 and 1989, 193 patents were granted to residents and non-residents by the USPTO with an average annual growth of 22.8%. In the following decade, the

[6] For a broader discussion on the technological revolutions and technical-economic paradigms, see Pérez (2009).

[7] Feynman (1959) "Plenty of Room at the Bottom"; Drexler (1981) "Molecular Engineering: An approach to the development of General Capabilities for Molecular Manipulation"; Drexler (1986) Engines of Creation and Drexler and Smalley (2003) The Emerging Science of Nanotechnology: Remanking, cited in Toumey, 2005.

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number of patents notably increased by granting 3,463 patents, with an average annual growth of 27.8%. From 2000 to 2010 the number of patents obtained was more than double the previous period (8,331), but the growth was lower (11.7% annual growth).

The substantial growth of patents in the last two decades of innovation renders account of the expansion of nanotechnologies as a radical change in the solution of technological problems faced by companies, institutions, and individuals. Thus, the evolution of patents on nanotechnologies suggest a dynamic diffusion in the last decade. It is estimated that between 2000 and 2008, the global market of nanotechnological products had an average annual growth of 25%, going from 30 billion dollars to 200 billion dollars, of which 80 billion correspond to the United States, particularly on nanostructure products. It is estimated that in 2015 this market will reach 1 trillion dollars, with the United States having a participation of 800 billion dollars (Roco, 2011).

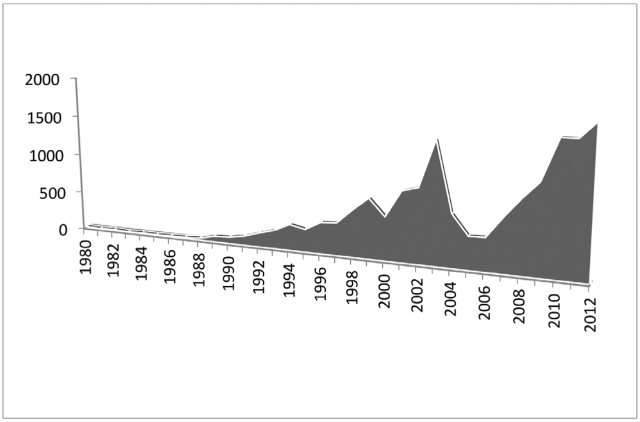

Figure 1. USPTO granted patents in nanotechnology to residents and non-residents, 1980-2012.
Source: Patent database of the USPTO in the technological classes CCL/977/700-863.

Technological generality index: tendency towards convergence in nanotechnologies. The expansion to the different technology sectors is a trait of the diffusion of a new technological paradigm. This is a central aspect in understanding how the confluence of different technological fields is occurring and, therefore, how it leans towards cognitive convergence.

In the case of nanotechnologies, we identified that more than two-fifths of the total patents correspond to nanostructure (41.5%), a third to nano-biotechnology, and a fourth to nano-chemistry. If we consider the classification of Jaffe and Trajtenberg (2002), it is possible to broaden the scope to identify the technological classes involved. Nano-chemistry has a major relative importance (37.2%). Nanotechnologies are also linked to other technological paradigms such as the ICTs (electric and electronic, 18.3%; computing and communication, 1.3%) and biotechnology (15.2%).

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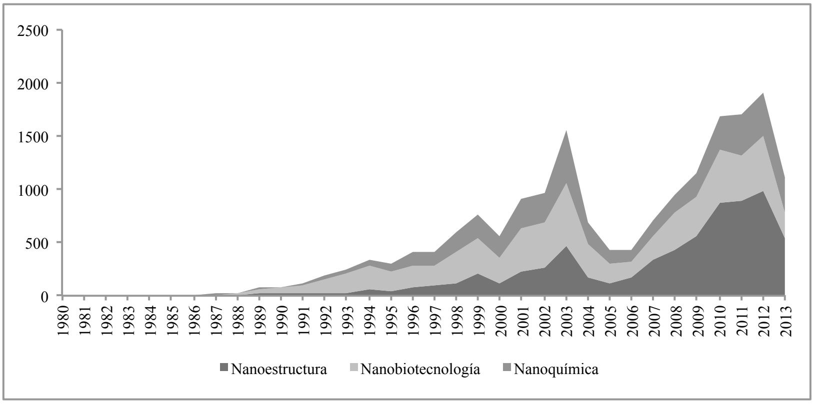

Figure 2. USPTO granted patents to residents and non-residents by technological class, 1980-2013
Source: Patent database of the USPTO in the technological classes CCL/977/700-863

The technological generality index (TGI) (Trajtenberg *et al.*, 1997) is another means to confirm the extent of nanotechnologies in various technological fields:

$$TGI = 1 - \sum_{j}^{n_1} S_{ij}^2$$

where S_{ij}^2 expresses the percentage of citations that patent *i* receives from other patents (forward patent citation) belonging to class *j*, among a group of n1 patent classes.

When *TGI* is equal or close to 1 it means that patent *i* has an ample impact on other technology sectors. Conversely, when *TGI* is close to 0 it means that patent *i* does not have an ample impact on other technology sectors. This indicator reminds us of the idea of cognitive convergence in nanotechnologies. According with our estimation of the *TGI* based on a random sample of 376 patents and considering the three main sectors, we found that the TGI is not close to 1, but that it does have a moderate impact on other sectors: biotechnology (0.4), nanostructure (0.39), and chemistry (0.33). However, there are patents whose TGI is close to 1, and whose novelty is reclaimed in different technological fields. Such is the case of patent 6203983 assigned mainly in the field of nano-chemistry, with a TGI of 0.71, and with a novelty impact in the electric and electronics, medicaments and medical products, and computing and communication fields. Conversely, patent 6383286 concentrates only in the nanostructure technology class and the electric and electronics sector, with a TGI close to 0. These data confirm not only the cognitive convergence of this technological paradigm, but that it is in a process of expansion.

Kim, Kim and Koh (2014) analyze technological convergence in the paradigm of ICTs. Through an analysis of how 43,636 patents from 1995 to 2008 are classified according to the International Patent Classification, the authors identify how these converge and relate in the different domains of technological knowledge. This study of technological convergence in the ICTs intends to be useful to the corporate sector to implement adequate strategies in the environment of the trajectory of technological change. Although this research does not

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examine this confluence in depth, we considered how a TGI close to 1 can have influence in the conditional convergence model proposed, that is, how the fact that different scientific and technological fields are involved in the patents have an influence and, in turn, that their application also involves a great variety of technological classes.

Inventive step, breaches, and diffusion in nanotechnologies between countries

The United States is identified as the leader in the inventive step of nanotechnologies, according to the patents granted by the USPTO to residents and non-residents. This country accumulates 63% of the total of patents of our sample. With a significant difference, we have Japan (10%), South Korea (7%), Germany (4%), Taiwan (3%) and China (2%), among others. Perhaps if we consider other intellectual property offices such as the European Patent Office (EPO) or the Japan Patent Office, the distribution could be different, but surely the United States would continue to be the leading country[8].

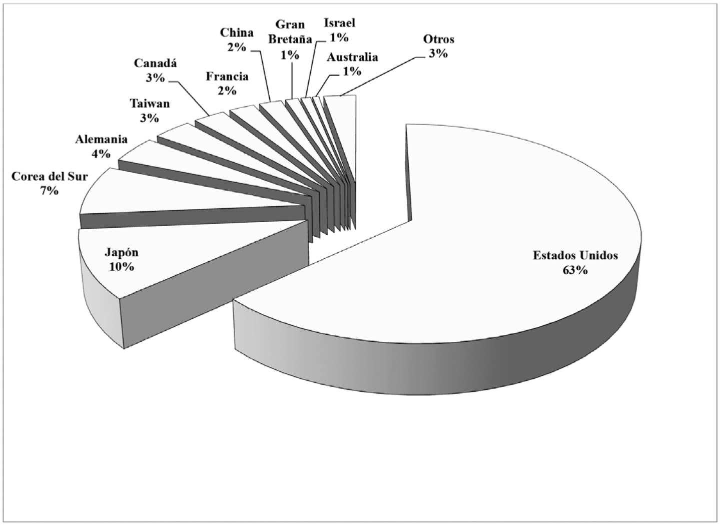

Figure 3. Distribution of UPSTO granted patents in nanotechnology to residents and non-residents by country, 1983-2012 (%)

Source: Patent database of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on a random sample of 376 patents.

The breach of the inventive step in nanotechnologies between countries is observed through the patents index, where the estimation of the number of each country is carried out based on that of the United States. The countries that can be considered as the closest followers (with a large difference still) are Japan and South Korea; the former reports 30% with regard to the United States in 2001 and 2003 and 28% in 2009; the latter with 30% in 2009. The inventive

[8] These results are similar to those estimated by Guzmán and Toledo (2009) between 1980-2008: United States with 60% of patents granted in the field of nanotechnologies; Japan with 18.6%, the European countries with 7.8%, and South Korea with 2.8%. The only difference is that this research considers the European countries individually.

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step of China allows it to be seen as a prospect that could take off in the long-term; in 2006 and 2009 it has 9% of the level of patents of the United States. Various countries maintain huge differentials with regard to the United States (see Figure 4).

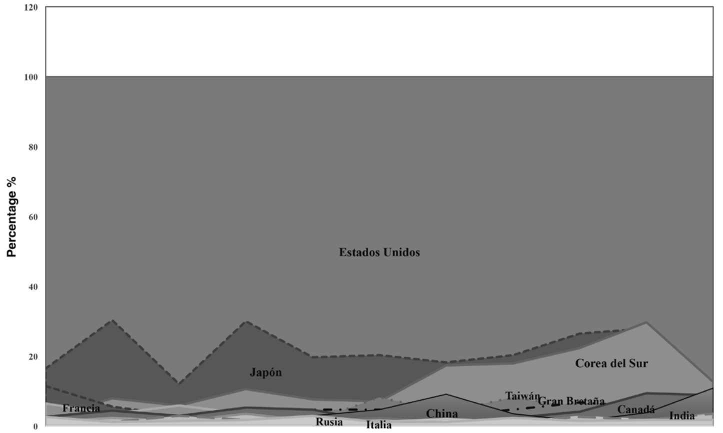

Figure 4. Breaches of the inventive step in the field of nanotechnology between countries.
Patent Index. United States = 100.0

Source: Own estimation based on the patents of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on a random sample of 376 patents.

Several studies have analyzed the flows of knowledge, using backward patent citations (citations to previous patents) and forward patent citations (citations received by other patents) as a *proxy* variable. This methodology has been criticized because not all patent citations have been carried out by the inventors, but rather by the reviewing officers of the USPTO, EPO and others (Breschi and Lissoni, 2004)[9]. Nevertheless, it can be considered a *proxy* indicator of how the technological knowledge contained in a patent could be the source of the new knowledge being patented or a proxy of the value of the cited patent (Hu and Jaffe, 2003; OCDE, 2007; Palmberg *et al.*, 2009; OCDE, 2013). The studies on patent citation provide empirical support to understand the patterns of diffusion of new technologies. Thus, the objective of this type of study is also to identify the patterns of sources of knowledge and thus analyze the convergence or divergence processes of the follower countries and their companies (Park and Lee, 2015).

In this research, the backward patent citations granted by the USPTO are considered a *proxy* variable of the accumulation of technological knowledge that the research teams acquire to create an innovation in the field of nanotechnology.[10] Concerning the backward patent citations granted in the USPTO, we find that the group of 376 patents between 1983-2012 of the sample register 6,551 backward patent citations. On average, 17.4 backward patent citations are recognized per patent, which suggests that each patent in this area takes into consideration a broader source of knowledge. There are patents that register a huge number of backward patent

[9] This is specially the case in the EPO more than in the USPTO.
[10] The citation to scientific articles also contributes to the accumulation of technological knowledge. However, in this research this indicator is considered a variable of the links between the academic-scientific sector and the industrial sector.

citations, as is the case of patent No. 7655934 in the nano-chemistry field assigned to a holder from the United States in 2010 with 311 backward patent citations (BwPCit). Contrary to this, there are 14 patents with no citations in the fields of biotechnology (3 patents), chemistry (5 patents), and nanostructure (6 patents). These probably deal with radical inventions and as such do not make citations to previous knowledge.

As has been observed, the greatest efforts in the innovation of nanotechnologies are those that have been carried out by industrialized countries and some newly industrialized and emerging countries of Asia. In addition to the differentials in the level of patents between industrialized countries, the breach also widens when the data of patent citations are compared. The United States comprises fourth fifths of the backward patent citations and registers 21.8 backward patent citations per patent, greater than the overall average. The country that follows, Japan, has 10% of the total backward patent citations and registers an average of 7.3 backward patent citations per patent. Other countries placed a long distance from the United States have a marginal participation in the total backward patent citations. The average backward patent citations per patent is of 11 in the case of Taiwan, 7.4 for Germany, and 0.6 for South Korea.

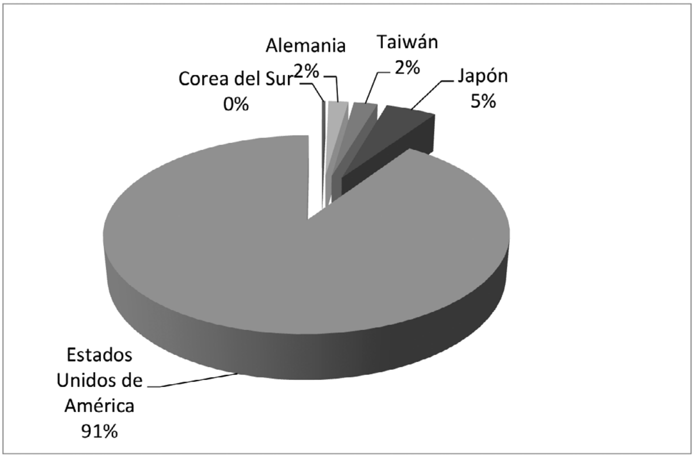

Figure 5. Distribution of backward patent citations for USPTO granted patents in nanotechnology by country, 1980-2012 (%)

Source: Patent database of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on our random sample of 376 patents.

Forward patent citations (FwPatCit) are considered an indicator of the technological importance, as well as of the future commercial value of innovations (OCDE, 2013; Trajtenberg, 1990; Hall *et al.*, 2005; Harhoff *et al.*, 2002). Forward patent citations are used in empirical studies of technological knowledge dissemination (Gay *et al.*, 2004; Gay and Le Bas, 2005; Duguet and MacGarvie, 2005). In this research, the indicator gives us an idea of how innovations in nanotechnologies are disseminated.

The average was estimated for the forward patent citations based on the 376 patents of the USPTO, finding 4,628 FwPatCit with an average of 12.3 FwPatCit per patent. Again, this indicator focuses on industrialized countries, mainly the United States with two thirds and

Japan with 10%. To a lesser degree, Taiwan, Germany, and Korea have a similar participation in the total FwPatCit (around 4%).

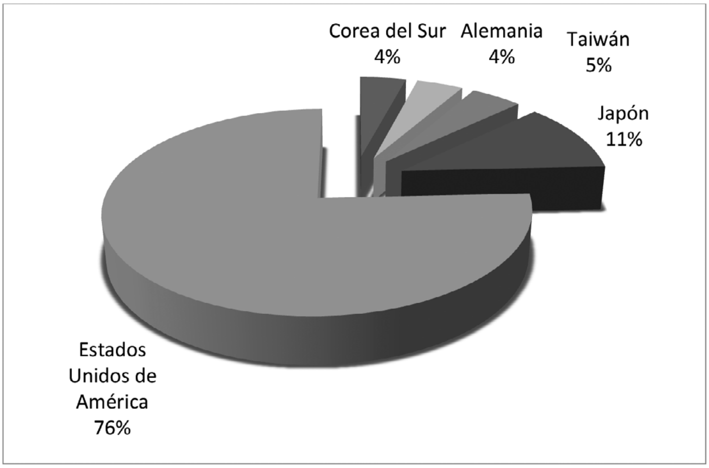

Figure 6. Distribution of forward patent citations for USPTO granted patents in nanotechnology by country, 1980-2012 (%)

Source: Patent database of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on our random sample of 376 patents.

The industrialized countries with more patents in nanotechnology show different specializations, as well as different dissemination patterns. With greater specialization, there is a greater dissemination of these technological fields. Concerning the United States, 43.6% of forward patent citations received by American patents belong to the field of nanostructure (1350 FwPatCit for 94 patents in nanostructures), which is the main sector in nano for this country and represents 29.1% of the sample total. In the case of Japan, 72% of FwPatCit were found in patents in the nano-biotechnology field and represented 8.1% of the total FwPatCit of the patents. The 322 FwPatCit in biotechnology obtained by the Japanese patents represent 15.8 FwPatCit per patent, a higher average than in nanostructure (6.6) and nano-chemistry (11.5). Hence the importance for the dissemination of Japan to focus on nanobiotechnology. For its part, Germany has the most dissemination in the fields of chemistry (46%) and nanostructure (36.6%), that is, 73 and 63 of the 172 FwPatCit obtained by Germany. However, the FwPatCit average per patent is greater in nano-biotechnology (15) than in nano-chemistry (11.2) and nanostructure (10.5). Therefore, three main sectors were identified.

Concerning the East Asian countries, South Korea and Taiwan stand out. Close to three fifths (58%) of FwPatCit received by Korean patents concentrate in nano-biotechnology (98 FwPatCit of the total 169 received) and represent 4.1 of the total studied patents. The average of FwPatCit received per patent is of 10.8, and focuses mainly in nano-chemistry, which suggest the importance of its inventions and how the new knowledge is disseminated. In this technological class, Taiwan shows major strength. In fact, close to two thirds (56.6%) of the total FwPatCit received by this country concentrate in the nano-chemistry sector. This sector has an average of 35.6 citations received per patent.

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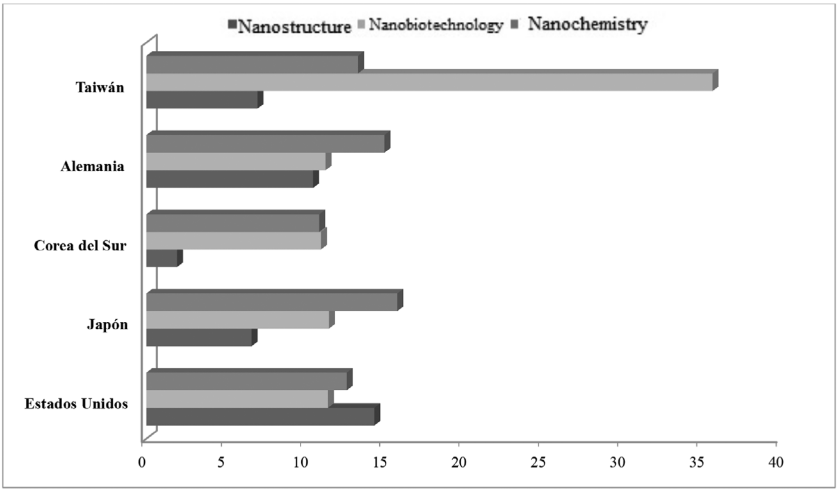

Figure 7. Main technological sectors that, on average, receive a greater number of citations in USPTO granted patents by country, 1983-2013 (% of the total per country)

Source: Patent database of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on a random sample of 376 patents.

Time lag in dissemination between countries

The time it takes for one patent to cite another previous patent for the first time is considered a *proxy* indicator of the time lag of the BwPatCit (Gay and Le Bas, 2005). With the precedent of the time lag studies regarding patent citations, taking the year of request of the cited patent and the patent making the citation (Hu and Jaffe, 2003)[11], we estimate the time lag with which countries cite the nanotechnology patents. This measurement illustrates the speed with which new knowledge in nanotechnology is disseminated, but also gives us an idea of the capacity of the countries to learn from new knowledge and incorporate it in their endogenous innovations.

According to our estimations, the time lag of BwPatCit in the studied group of patents in nanotechnology is of 1.53 years. However, there are differences between countries. The average time lag of BwPatCit in the United States is of 1.5 years, very close to the general average, but this lag is lower in nanostructures (1.38 years). In the case of Japan, the time lag of BwPatCit is of 1.94 years with a lower lag identified for nanostructures (1.6 years). Germany has an average of 2 years, but has an average of 1.5 years in nanostructures and biotechnology, similar to the general recorded average of the group of countries. Conversely, the speed of dissemination of new knowledge to generate innovation is greater in Asian countries. South Korea registers an average lag in BwPatCit of 0.9 years and Taiwan of 0.6 years. In the case of Korea, it is even lower in biotechnology (0.6 years) and in Taiwan this is the case in nanostructures (0.5 years).

[11] According to the experts, a granted patent is recognized not only for being an invention, but also for its potential to be exploited at an industrial scale.

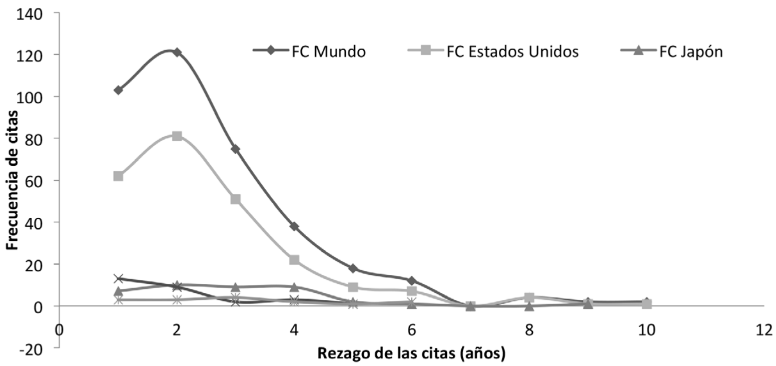

Figure 8. Time lag regarding the backward patent citation of countries to generate new patents.

Source: Patent database of the USPTO in the technological classes of nanotechnology CCL/977/700-863 based on a random sample of 376 patents.

Convergence and technological and innovation scope in nanotechnology

After identifying the technological and innovation breaches between countries concerning nanotechnology, and based on the analysis of patents granted by the USPTO in the respective classes of nanotechnology, this section proposes a technological and innovation convergence model. Said model seeks to prove if it is possible for countries to converge in innovation in the paradigm of nanotechnology and identify the factors that would condition such convergence through the estimation of an econometric model.

The estimated model analyzes the existing relation between a dependent variable and its growth rate. Coefficient "β" of the dependent variable reflects the characteristics of convergence. These models are known as type "β" convergence models. In other words, a "conditional β-convergence" model was estimated, in which the dependent variable is the average annual growth rate of the number of patents requested in nanotechnology of country *i* as an approximation of the growth of the inventive step in nanotechnologies, with the natural logarithm of the number of patents as an approximation of the growth rate of the inventive step as independent variable. As various control variables were included, the model has a conditional nature, since the behavior of these variables influences the coefficient of the variable associated with the growth of the inventive step.

Various considerations were necessary to include the control variables associated with the technological capabilities of the countries. Studies that analyze convergence indicate that the different economies will not achieve the same levels of GDP per capita in the long-term without first having technological and social capabilities (Barro and Sala-i-Martin, 1995; Mankiw, Romer and Weil, 1992). In turn, the technological catch up hypothesis states that poor countries can close the breach with the more advanced countries by taking advantage of the technological knowledge spills generated in the wealthy countries. However, this hypothesis recognizes that the international dissemination of technology does not occur instantaneously, but rather that its dissemination process develops with different patterns between the different economies, considering the differentiated technological capabilities accumulated (Fagerberg *et al.*, 2012) or of absorption (Rogers, 2003).

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The problem of convergence in nanotechnology has been addressed by Gholizadeh, Bonyadi and Moni (2015) while the case of convergence in information and communications technologies (ICTs) is addressed by Kim, Kim and Koh (2014). The two studies examine the phenomenon of convergence differently. The first is a study directed towards the estimation of the technological breaches between Middle Eastern countries, other countries of the region and the United States, to then propose a convergence model and a scope of the countries following the leading country. The estimation of the breaches is based on investment, human capital, and technology (requested patents in nanotechnology) variables, as well as on industrial and scientific (scientific articles associated with nanotechnology) variables. In contrast, the convergence study on ICTs seeks to identify the degree of mergers and relations between the different technological domains through the analysis of patents, using the International Patent Classification (Kim *et al.*, 2014). Whereas the first study concerns itself more with the technological and innovation convergence between countries, in the second, technological and innovation convergence is analyzed from the perspective of how a paradigm extends to different fields of technological knowledge and, therefore, how companies can have greater possibilities of application.

Evaluating the contributions to economic science concerning the analysis of economic convergence, this study takes up some proposals and complements them with studies that are more specific to technological innovation (Rogers, 2003).

Data source

For the specification of the β-convergence model, we considered the information provided by the patents in nanotechnology of resident and non-resident inventors in the *United States Patent and Trademark Office* (USPTO)[12] for the 2000-2010 period. This study is based on a sample of 376 patents from a population of 18,467 patents granted by the USPTO from 1983 to 2013 in class 977, where patents from the nanotechnology field are classified.[13]

Additionally, other indicators and sources of information from 2000 and 2010 were included: human capital per country (*KHi*), expenditure in research and development per country as a percentage of the GDP (*GI&Di*), obtained from the Indicators of the World Bank, the human development index (*IDHi*), obtained from the United Nations Development Programme (*UNDP*), the global competitiveness index per country (*GCIi*), the degree of technology per country (*TECHi*), the degree of efficiency of the public institutions per country (*Pii*), and the degree of macroeconomic stability per country (*MEi*) estimated in *The Global Competitiveness Report* of the World Bank.

Seventeen countries that registered nanotechnology patents were included: The United States, Japan, South Korea, Germany, Taiwan, France, Great Britain, Canada, China, Israel, Spain, Holland, Ireland, Italy, Sweden, India, and Russia. Of these, eight are industrialized, three are of recent industrialization, and six are emergent. The variables included in the specification of the model were considered for each of these countries, that is, the data are of the cross-section type.

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[12] Resident and non-resident patents in class 977 of the USPTO were sought. Guzmán and Toledo, 2009.

[13]The sample size was estimated based on Anderson et al. (2008) as: $n = \frac{Z_\alpha^2 Npq}{i^2(N-1)+Z_\alpha^2 pq}$, where: $\boldsymbol{N}$ is the size of the population considered (18,414 patents); $\boldsymbol{Z}$ is the value related to the Gauss distribution, $Z_{\alpha=0.05}$ .96; $\boldsymbol{p}$ is the expected prevalence of the parameter to evaluate. If the latter is unknown, it is assumed that: $\boldsymbol{p}$= 0.5; $\boldsymbol{q}$ is taken as: q=1. In this case it is 5%, therefore, *i*=0.05.

Specification of the conditional convergence model

The central hypothesis of the model is the following: *the technological and innovation convergence in nanotechnologies between countries towards the leading country in the long-term, conditioned to the existence of technological and innovation capabilities in nanotechnologies, technological and technological absorption capabilities*, and social capabilities is expected (Rogers, 2003; Abramovitz, 1986). That is, if the coefficient associated with the growth rate of the inventive step (β-convergence) is < 0, then the lagging countries will tend to catch up with the most advanced and, therefore, there will be convergence; on the other hand, if β-convergence is > 0, then there will not be convergence.

In order to verify this hypothesis, the following equation is formally specified:

$$PatNano_{i,2000-2010} = \beta lnPatNano_{2000,i} + \alpha_1 X_{1,i} + \alpha_2 X_{2,i} + \alpha_3 X_{3,i} + \varepsilon_i$$

Where:

PatNanoi$_{2000\text{-}2010}$ = Growth of the number of requested patents in nanotechnology of country *i* in the 2000-2010 period[14]. The average annual growth rate of the number of requested patents in nanotechnology for country *i* is a *proxy* variable of the average growth rate of the number of patents requested in nanotechnologies in country *i* and the growth dynamics of the inventive step in nanotechnologies.

lnPatNanoi$_{2000}$= natural logarithm of the number of requested patents in nanotechnology for the starting year (2000) for country *i*.

β = estimated study coefficient, that is, the parameter that provides information regarding the convergence in the inventive step in nanotechnology between countries.

$X_{1,i}$, $X_{2,i}$ and $X_{3,i}$ = matrices that contain control variables associated with the inventive step phenomenon in three areas: technological and innovation capabilities in the studied sector, technological absorption capabilities at a national level, and social capabilities, respectively. Below, the variables contained in each of these matrices are listed.

$X_{1,i}$ represents the technological and innovation capacities in nanotechnology of country *i*, including the following variables:

AtechNano$_{i2000\text{-}2010}$ is the accumulation of technological knowledge in this sector of country *i* between 2000 and 2010. The *proxy* variable is the TCPA of the number of backward patent citations of the requested patents in nanotechnology of country *i* (2000-2010).

ScTecLinkNano$_{2000\text{-}2010}$ is the accumulation of the links between the scientific activity and

[14] The period of study was defined based on the information provided by a random sample of 2,000 patents obtained, based on a study population extracted from the *United States Patent and Trademark Office* (USPTO) for the 1974-2013 period. The 2000-2010 period was defined based on the criteria of including the greatest number of countries possible. Thus, it was achieved to include 17 countries with inventive step in nanotechnologies in the database to estimate the convergence model proposed. In order to make the information homogenous, no other countries that have recently begun to patent in nanotechnologies were considered. This represents a statistical problem and a restriction to carry out the estimations of the model.

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the inventive step in this technological sector of country *i* during 2000 and 2010. The *proxy* variable is the TCPA of the number of citations to scientific articles made by the requested patents in nanotechnology of country *i* (2000-2010) (Guzmán *et al*., 2016).

$SizeRTNanoi_{2000\text{-}2010}$ is the accumulation of the inventive capacities of the researchers in this technological sector of country i in the 2000-2010 period. The *proxy* variable is the TCPA of the size of researcher teams in nanotechnology of country *i* (2000-2010).

$ClNanoi_{2000\text{-}2010}$ is the accumulation of innovations generated in this technological sector in country *i* during the 2000-2010 period. The *proxy* variable is the TCPA of the number of claims of the requested patents in nanotechnology of country *i* (2000-2010).

$X_{2,i}$ is another group of variables that represents the technological absorption capacities, at the national level, and is comprised of the following variables:

$R\&D/GDPi_{2000\text{-}2010}$ is the accumulation of the technological capacity of country *i*. The *proxy* variable is the TCPA of the expenditure in R&D/GDP of country *i* for the 2000-2010 period.

$Hki_{2000\text{-}2010}$ is the accumulation of the human capital of country *i* for the 2000-2010 period. The proxy variable is the TCPA of the number of researchers in R&D/million inhabitants of country *i* (2000-2010).

$ProdCompi_{2000\text{-}2010}$ is the accumulation of the productive and competitive capacity of country *i*. The *proxy* variable is the TCPA of the global competitiveness index of country *i* (2000-2010).

$TechHeighti_{2000\text{-}2010}$ is the accumulation of the relative technological level of country *i*. The proxy variable is the TCPA of the technological index of country *i* for the 2000-2010 period.

$TechAbsCapFi_{2000\text{-}2010}$ is the accumulation of the technological absorption capacity of the companies of country *i* (2000-2010).

$X_{3,i}$ is a group of variables that represents the social capabilities of country *i*. It is comprised of the following variables:

$DHIi_{2000\text{-}2010}$ is the growth of the human development index of country $_i$ (2000-2010). It is a synthetic indicator of the average achievements obtained in the fundamental dimensions of human development, specifically: having a long and healthy life, acquiring knowledge, and enjoying a dignified standard of living.

$IPEi_{2000\text{-}2010}$ is the growth of the degree of efficiency of the public institutions of country *i* between 2000 and 2010.

$MacStrengthi_{2000\text{-}2010}$ is the growth of the degree of macroeconomic stability of country *i* during the 2000-2010 period.

$InstWeaki_{2005\text{-}2010}$ is the growth of institutional weakness. The *proxy* variable is the growth rate of the degree of corruption in country i during the 2000-2010 period.

α_1, α_2 and α_3 are the estimated coefficients.

εi is the error factor.

It is expected that:

If β < 0, the follower countries will tend to catch up with the leading countries. That is, there is convergence.

If β = 0, there is no convergence given that, in this case, the growth rate of the inventive step of the follower countries is the same as that of the leading countries, thus, the difference in the initial inventive step would remain. The breach remains.

If $\beta > 0$, there is divergence, since the leading countries would maintain elevated growth rates in the inventive step, positively associated with the high levels of their initial inventive step. On the other hand, the follower countries would maintain low growth rates in the inventive step, which would be positively associated with the low levels of their initial inventive step. With time, the breach would grow larger.

However, according to different theoretical and empirical works on technological convergence (Abramovitz, 1986; Rogers, 2003; Manca, 2009; and Fagerberg *et al*., 2012), it is recognized that this process is a complex phenomenon: not only does it depend on the relation between percentage changes of the initial inventive step and the average annual growth rates of the inventive step, but it is also conditioned by contextual variables that favorably influence the growth rate of the inventive step and the convergence process studied through the β parameter. Therefore, these variables condition the convergence process.

Descriptive statistic of the variables of the model

In this section, the behavior of each variable in the group of studied countries is analyzed based on the average, variance, and standard deviation. The purpose is to analyze the distribution of data and carry out study of the statistical behavior of the variables.

A variable that does not present dispersion problems is a natural logarithm of the number of patents of the initial year (2000) assigned to the nanotechnology of country *i*. The maximum value is of 4.4., where we find the United States, the leading country in the inventive step in nanotechnology, followed by countries that place above the average, such as Japan and Germany. These countries, in turn, maintain a breach with respect to the countries that placed in the average value (1), such as Israel and France. Below the average we find South Korea, Great Britain, Canada, China, Ireland, Italy, India and Russia, whereas with a minimum value (0) we find Spain, Holland, Sweden, and Taiwan. Although the breach between the United States and the other countries is large, as a whole, the data are not very dispersed.

Regarding the accumulation of the demands of innovation in the patents in nanotechnology of country *i*, *ClNanoi2000-2010,* the leading country is Sweden with a maximum value of 10.2, well above the average (-2.7) where we find Holland, with the minimum value being presented by Taiwan (-10.8). In this context, the United States has a value of -4.3. The behavior of the data suggests that, although the United States maintains the greatest growth rate concerning the inventive step in nanotechnology, it has a below average rate regarding the innovations generated in this sector.

Concerning the accumulation of the technological capability in country *i*, R&D/ *GDPi2000-2010*, the country that achieved the most growth in this period was China (6.6), well above the average value (1.7), with Russia having the minimum value (-0.7); the United States obtained a value of 1.02, that is, below average. Again, the data reveal that the United States is not the leading country in terms of the growth rate in the expenditure in R&D as a percentage of the GDP. The *proxy* variable is the technological capability of the country.

Regarding the accumulation of the relative technological level of country *i*, *TechHeighti2000-2010*, the country that rates with the highest value is Japan (0.5), with South Korea, Taiwan, and Holland in the average (1.6), and Italy and Spain with the minimum value (-4.3); the United States is below average with a value of -1.1.

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With regard to the growth of the degree of efficiency of public institutions of country *i*, *IPEi2000-2010*, the leading country is once more China (0.8), with Italy (-4.2) having the lowest value and Russia (-1.4) at the average value, with the United States being below average with a value of -2.4. This suggests that while China improves the efficiency of its public institutions at a growing rate, the United States does so at a decreasing rate.

The accumulation of human capital of country *i, Hki2000-2010,* has South Korea as the leading country with a maximum value of 8.7, with the average value (2.9) being France, and Russia (-1.1) with the minimum value; the United States is below average with a value of 1.07.

The variable that tends towards greater dispersion is the accumulation of technological knowledge in nanotechnology, *AtechNanoi2000-2010*, with Holland having the maximum value at 26.5, Russia with the minimum (-100), and India with the average value (-2.7); the United States places above average (12.8), but well below the growth rate of Holland.

This brief description of the statistical behavior of these variables reveals a couple of strengths and weaknesses in the countries. Although the United States is the leading country regarding the growth rate in the inventive step in nanotechnology, from this dynamic perspective, other countries such as China reveal strength in other contexts such as the expenditure in R&D or the improvement of the efficiency of public institutions. However, it also confirms weaknesses exhibited by countries such as Russia.

Table 1. Descriptive statistics of the variables of the model

Variables	Average	Standard Deviation	Min.	Max.	Correlated to PatNanoi	Least correlated variables to lnPatNano0i	Most correlated independent variables
PatNanoi$_{2000\text{-}2010}$	2.952183	12.33009	-16.3749	24.13658	1		
lnPatNano0i	1.034852	1.124854	0	4.369448	-0.5313		
AtechNanoi$_{2000\text{-}2010}$	-2.732757	28.15804	-100	26.48431	0.2885	0.0654	AtechNanoi2000-2010- (TechAbsCapFiri2000-2010i, InstWeaki2005-2010i, Hki2000-2010)
ScTecLinkNano$_{2000\text{-}2010}$	-0.3683211	19.27962	-28.31288	59.41741	0.326	-0.0729	ScTecLinkNano2000-2010- TechAbsCapFi2000-2010
SizeRTNanoi$_{2000\text{-}2010}$	-0.8855955	7.018558	-11.49119	10.21627	-0.0156	0.2155	
ClNanoi$_{2000\text{-}2010}$	-2.695339	5.712577	-10.81618	10.1927	0.3921		
R&D/GDPi$_{2000\text{-}2010}$	1.740858	2.276702	-0.7444506	6.566485	0.2624	-0.1882	
Hki$_{2000\text{-}2010}$	2.8799	2.380275	-1.128547	8.657481	0.3456		Hki2000-2010 - AtechNanoi2000-2010
ProdCompi$_{2000\text{-}2010}$	-0.3223454	0.8452005	-1.450085	1.28345	-0.1352	0.0863	
TechHeighti$_{2000\text{-}2010}$	-1.57779	1.340337	-4.278659	0.4748854	-0.2862		
TechAbsCapFi$_{2000\text{-}2010}$	1.178936	3.760121	-6.251515	9.928233	-0.2804		TechAbsCapFi2000-2010 - InstWeaki2005-2010
DHIi$_{2000\text{-}2010}$	-0.0455707	0.3218544	-0.6505249	0.7252795	-0.0826	0.0013	
IPEi$_{2000\text{-}2010}$	-1.382026	1.220617	-4.176039	0.7622488	0.2073		
MacStrengthi$_{2000\text{-}2010}$	0.4524907	1.554512	-2.095046	2.970453	0.0563		
InstWeaki$_{2005\text{-}2010}$	-0.9656611	1.39441	-4.599892	1.455526	-0.0034		

Source: own elaboration based on the USPTO, 1974-2013, indicators from the World Bank, 2000-2010, the United Nations Development Programme (*UNDP*), 2000-2010, and The Global Competitiveness Report of the World Bank, 2001, 2005, and 2010.

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Estimation of the model

The proposal by Rogers (2003) was used in order to specify the model to be estimated. To estimate the β parameter in a convergence model on the economic growth between countries, the author appraised a set of regressions in which, through trial and error, the β parameter variable and one other independent variable for each of the regressions were estimated in order to observe the conditioned effect on the value of β. The estimations improved significantly when using this procedure.

In the first regression, the robustness of the model in which the dependent variable is the growth of the number of patents assigned in nanotechnology of country *i*, $PatNanoi,_{2000\text{-}2010}$ was estimated in terms of the natural logarithm of the number of patents of the initial year (2000) assigned in nanotechnology of country *i*, $lnPatNano_{2000},i$. The value of the β parameter was of -5.72 and was statistically significant (*p-value* of 0.032). Following the procedure by Rogers, various regressions in which the proposed independent variables were included one by one in order to observe the conditioned effect on the β value–that is, on the convergence parameter–were calculated. The results show that variables such as the accumulation of technological knowledge in nanotechnology of country *i*, $AtechNanoi_{2000\text{-}2010}$, the growth of the human development index of country *i*, $DHIi_{2000\text{-}2010}$, the accumulation of the inventive capabilities of the researchers in this technological sector of country *i* for the 2000-2010 period, $SizeRTNanoi_{2000\text{-}2010}$, the growth of the degree of macroeconomic stability of country *i*, MacStrengthi2000-2010, and the growth of the corruption index of country i, $InstWeaki_{2005\text{-}2010,}$ show a favorable conditioned effect on the β value (see Table 2).

There is another group of variables, such as the accumulation of the links between the scientific activity and the inventive step in this technological sector of country *i* during the 2000-2010 period, $ScTecLinkNano_{2000\text{-}2010}$, the growth of the global competitiveness index of country *i*, $ProdCompi_{2000\text{-}2010}$, and the accumulation of the technological absorption capacity of the companies of country *i*, $TechAbsCapFi_{2000\text{-}2010}$, which combined with *lnPatNano2000,i*, obtained a statistically significant, but lower, β parameter. This suggests that these variables do not favorably condition convergence. Finally, another group is identified, comprised of variables such as the accumulation of innovations generated in this technological sector in country *i* during the 2000-2010 period, $ClNanoi_{2000\text{-}2010}$, the accumulation of the technological capability of country *i*, $R\&D/GDPi_{2000\text{-}2010}$, the accumulation of the relative technological level of country *i*, $TechHeighti_{2000\text{-}2010}$, the growth of the degree of efficiency of the public institutions of country *i* during the 2000-2010 period, $IPEi_{2000\text{-}2010}$, and the accumulation of human capital of country $_i$ during the 2000-2010 period, $Hki_{2000\text{-}2010}$, which do not influence the dependent variable (*PatNanoi*, 2000-2010) and, therefore, do not favorably condition the convergence process (see Table 2).

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Table 2. Regressions (Rogers method). β values.

Table. Results of the convergence model

Variables/Regressions	1	2	3	4	5	6	7	8	9	10	11	12	13	14
lnPatNano0,i (2000)	-5.7220 [0.032]	-5.2567 [0.067]	-5.4264 [0.07]	-5.1491 [0.092]	-6.1144 [0.029]	-5.4131 [0.042]	-5.7584 [0.06]	8 -6.1098 [0.06]	-5.497716 [0.069]	-4.642984 [0.135]	-5.580504 [0.044]	-5.702473 [0.044]	-5.731043 [0.067]	-5.751022 [0.051]
$ClNanoi_{2000-2010}$		0.4759 [0.3]												
$R\&D/GDPi_{2000-2010}$			1.1730 [0.238]											
$TechHeighti_{2000-2010}$				-1.4342 [0.509]										
$AtechNanoi_{2000-2010}$					0.1638 [0.012]									
$ScTecLinkNano_{2000-2010}$						0.1556 [0.2]								
$DHIi_{2000-2010}$							-3.2080 [0.743]							
$SizeRTNanoi_{2000-2010}$								0.2194 [0.56]						
$IPEi_{2000-2010}$									0.8555458 [0.75]					
$Hki_{2000-2010}$										1.15817 [0.328]				
$ProdCompi_{2000-2010}$											-3.04961 [0.225]			
$TechAbsCapFi_{2000-2010}$												-0.8815083 [0.16]		
$MacStrengthi_{2000-2010}$													-0.0202632 [0.993]	
$InstWeaki_{2005-2010}$														-0.2862377 [0.889]

Source: own elaboration based on the estimations of the model.

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Based on the information obtained using Rogers procedure and considering the previous descriptive statistics analysis of the variables of the model, attempts were made to estimate a model that simultaneously considers a set of variables. Finally, the following specification was obtained:

$$PatNano_{i,2000-2010} = \beta lnPatNano_{2000,i} + \alpha_1 AtechNano_{i,2000-2010} + \alpha_2 ScTecLinkNano_{i,2000-2010} + \alpha_3 SizeRTNano_{i,2000-2010} + \alpha_4 InstWeak_{i,2005-2010} + \varepsilon_i$$

The results of the estimation are satisfactory. The independent variables explain 50% of the variance of the inventive step (R^2=0.5). It was confirmed that the estimators are homoscedastic (Ho p-value, 0.39), the absence of multicollinearity (see annexed), the functional form of the errors is that of a normal form (*p-value* -0.45), and the correct specification of the model (Reset, *p-value*, 0.17). The estimated value of β is of -6.3, statistically significant, and below zero as expected. Only one of the independent variables has a direct influence on the average annual growth rate of the inventive step in nanotechnology: the variable of accumulation of technological knowledge in this sector of country *i* between 2000 and 2010, *AtechNanoi*, *2000-2010*, with an estimated parameter value of 0.18, that is, a positive value. This suggests that its impact on the dependent variable is positive, as was expected in the hypothesis that corresponds to this variable (see Table 3).

Table 3. Regression. Estimated coefficients of the convergence model.

Dependent variable PatNanoi2000-2010		
Independent variables	Coefficient	p-value
lnPatnano0i	-6.31	0.038
$AtechNanoi_{2000\text{-}2010}$	0.18	0.009
$ScTecLinkNano_{2000\text{-}2010}$	0.15	0.25
$SizeRTNanoi_{2000\text{-}2010}$	0.17	0.63
$InstWeaki_{2005\text{-}2010}$	-1.57	0.276
Robustness, r		
17 observations		
R-square: 0.4954		

Source: own elaboration based on the estimations of the model.

Interpretation of the results

In order to interpret the results, the elasticities were calculated.[15] The elasticity associated with $lnPatNanoi_{2000\text{-}2010}$ is of -2.14. This value suggests that if the productivity in the inventive

[15] The value of the β coefficient estimated in the regression cannot be interpreted according to the studied phenomenon, given that the dependent variable *PatNanoi,2000-2010* represents a growth rate, while the independent variable *lnPatNano2000*,i is found in the natural logarithm. With this purpose, the elasticity is calculated by dividing the β value by the average of *PatNanoi,2000-2010*. Thus, if the value of the elasticity is higher than 1, then it is elastic and if it is lower than 1, then it is inelastic.

step in nanotechnology of the group of countries studied increases by 1%, the growth rate of the requested patents in the 2000-2010 period falls by 2.14%.

By increasing by 1%, the heritage of accumulated technological knowledge in nanotechnology of the studied countries in the 2000-2010 period, $AtechNanoi_{2000\text{-}2010}$, the growth of the inventive step in this technological field, increases by 0.17% in the same period (see Table 3). This result refers us to Romer (1990), who suggests that the rate in which researchers discover new ideas depends on previous ideas. In this sense, the productivity of the researchers in the creation of new ideas will benefit from previous technological knowledge. The growth rate of this productivity will be a factor that will be conditioned to the technological and innovation convergence between countries in the new technological paradigm.

In this manner, it can be stated that if a follower country in nanotechnology intends to take advantage of the windows of opportunity opened by the dissemination of this new technological paradigm, it must increase its heritage of accumulated technological knowledge in this sector, that is, it must pay attention to the accumulated learning and experience in the inventive step in nanotechnology. In turn, this can be reinforced by policies that incentivize the inventive step in the sector.

Conclusions

Presently, nanotechnologies are an emerging paradigm characterized by a cognitive and technological convergence; it is expected that they will converge in benefit of social welfare. The research on technological and innovation convergence acquires great transcendence in the measure that it allows countries to identify and analyze the factors that can help the follower countries with lower development to acquire convergent tendencies towards the leading countries in the new technological paradigms. In such processes, the goal is for the countries with lower income per capita to manage to converge in the economic and social performance of the countries with higher income per capita.

In the context of the new paradigm of nanotechnology, certain countries have displayed notable efforts concerning research and development as well as innovation, with substantial advantages in the technological areas of nanomaterials, massive application in nanomanufacturing, molecular medicine and health, environmental and energy processes, biotechnology and agriculture, electronics, information and communications technology, and national security technology. The leadership in innovation of the United States is evident, followed at a considerable distance by Japan, South Korea, Taiwan, and China. Other industrialized and emerging countries show a growing effort to manage to incorporate themselves into this new technological paradigm, not only in terms of its adoption, but also in converging in the line of innovation.

This study contributes, in the topic of technological convergence, to the development of a model that intends to corroborate whether the convergence of other countries with the leading country is possible in the long-term in the new paradigm of nanotechnologies, and to the identification of the factors that condition said convergence process.

The different econometric estimations allowed the formulation of a reliable model, and thus some variables were discarded. Therefore, our hypothesis on conditional convergence between countries in nanotechnology appears to be partially confirmed.

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Particularly, the findings of this study allow corroborating the convergence between countries in this new technological paradigm in the long-term, insofar as industrialized and emerging countries–and others of greater time lag–achieve greater growth rates of innovation in nanotechnology than the leading country, conditioned to achieving greater growth in the accumulation of technological knowledge. That is to say that the technological and innovation convergence of the countries to the new paradigm of nanotechnology is conditioned to a greater accumulation of technological knowledge in nanotechnology (measured by the backward patent citations made by the patents in the field of nanotechnology).

The inventive capabilities of the researchers, through the support given to the research teams in nanotechnology and the links between the scientific and technological activity, as well as the fight against institutional weaknesses (for example, cases of corruption), are variables that although not significant, could be favorable in the long-term to the convergence in the inventive step in nanotechnology between countries, insofar as this paradigm extends to more countries. Nevertheless, these variables could be considered in the design of economic policies directed to favoring the inventive step in this sector.

The convergence towards the new paradigm of nanotechnology is a challenge for all countries. This process will have great positive externalities, among which is the incorporation to the dynamics of cognitive convergence that nanotechnology presupposes.

Annex

Annex 1. VIF Test

Multicollinearity: VIF Test		
Variable	VIF	1/VIF
BkwPatCiti2000-2010	1.14	0.875715
InstWeaki2005-2010	1.13	0.884724
lnPatNano0i2000-2010	1.11	0.89687
SizeRTi2000-2010	1.1	0.909468
ScTecLinkiNanoi2000-2010	1.02	0.977862
VIF Avera	1.1	

Source: own elaboration based on the estimation of the model

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