



TECHNOLOGICAL GAPS AND CONVERGING PROCESS BETWEEN EMERGING AND INDUSTRIALIZED COUNTRIES IN BIO-PHARMACEUTICAL INDUSTRY*

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ABSTRACT

This paper contains a discussion and test of the technology gap approach to the innovation and growth in the bio-pharmaceutical industry between industrialized and developing countries (Mexico, Korea, India, China, Brazil, Argentina, Ireland) for the period 1980-2005. We find among the industrialized countries convergence path with respect to the leader, the United States. But from the developing countries, South Korea and Ireland the innovation tends to be systematic and increasing. The technological backwardness is more obvious in Mexico and Argentina than in India and Brazil. In both block of countries the dynamics in the processes of innovation is explained by the advances in knowledge and the efforts to innovate.

Introduction

The aim of this paper is to examine if there is a convergence process and/or catching up tendency across industrialized and developing countries in the context of a high tech industry. We test technological convergence across countries in the pharmaceutical industry during the 1980- 2005 period, using the technological innovational gap approach. Among the questions to be examined in this research are the following: Is convergence and catch-up of developing countries with respect to industrialized countries possible in a high industry? What are the main factors underlying convergence or divergence?

This research proposes to confirm the hypotheses stated for the focus on technological gaps, but at the industry level: the growth divergences of the pharmaceutical sector of the developing

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countries compared to the industrialized countries are strongly linked to the technology and innovation gaps. The catch-up possibilities in this high technology industry for developing countries can only be explained with rates of economic growth higher than those registered by industrialized countries, linked to an important development of technological and institutional capacities. The correlation that is established between R&D and patents contribute to develop the capacity for innovation and helps to create a virtuous circle that, joint to technological transfer and productivity growth, could lead developing countries along the path to convergence and catch-up.

The work is presented in three sections. In the first the theoretical discussion of the research is presented. In the second the empirical evidence of the technological gaps and the tendencies to convergence or divergence of the pharmaceutical industry across countries are analyzed. Finally, the conclusions of the work are presented. The methodology and the sources used in the research are specified at the end.

I. The Technological Gap Approach

The processes of economic convergence or divergence have been associated, along with other factors, with differentials of technological development and human resources (Abramovitz, 1986; Maddison, 1982; Baumol, 1986). The technological gap approach developed by Posner (1961), Gomulka (1971), Cornwall (1977), Abramovitz (1986) and other authors proposes that the significant differentials in the levels and technological tendencies that characterize the international economic system will only be overcome with radical transformations in the technological, economic, and social structures¹. Other authors involved in technological catch up theoretical discussion are Veblen (1915), Nurske (1955), Gerschenkron (1962) and Rostow (1971). The approach assumes the existence of a close correlation between the economic and technological level growth rates. The relative technological backwardness of the poor countries brings with it an opportunity for their quick economic growth (Abramovitz, 1966 y 1986). Indeed, these countries have a great potential because of the very fact of their backwardness, to the extent that it is possible for them to imitate the more advanced countries and adopt the best techniques². So the imitative strategy would make it possible

¹ The works of K. Pavitt and L. Soete have proved the hypotheses presented by M.V.Posner (1961) and S. Gomulka (1971), quoted in J. Fagerberg (1987).

² B. Amable, R. Barré and R. Boyer (1997), p. 62.

for technologically backward countries, with respect to the global innovation frontier, to increase their rate of economic growth. However, the possibilities of convergence and catch-up are conditioned by the capacity to transform the social, institutional, and economic structures. The existence of infrastructural capabilities (Abramovitz, 1986) and the reform of institutions (Maddison, 1982) are necessary conditions for rapid economic and catch-up growth.

The neoclassical growth models (starting with Solow, 1959) predict an economic growth long run positive rate only if technological change occurs. The recognition of technology progress influence, like an exogenous variable, on economic growth, was tested in various empirical researches. The new growth models (Romer, 1986, 1990; Lucas, 1988; Barro, 1988, among others) point out the accent on knowledge generation, as an endogenous variable; even if the firms produce the knowledge, they could be benefited from knowledge spillovers coming from the whole economy. The technological catch up is defined as “the process by which countries may benefit from the existence of a stock of production knowledge available in the rest of the world (that is generally called technology gap” (Rogers, 2003: 43). In this context, the explanation of technological dynamics differences across countries involves a main empirical question: “how countries learn and absorb technology from the rest of the world?” (Ibid).

Factors that Contribute to Technological Convergence

When a long period in which the capital to product relation does not change is considered, the variation between countries can be explained by innovation.³ In that sense, *the gap is an aggregate indicator of some of the factors that influence the rate of international technology transfer, and hence the growth rates of innovation and labor productivity in the technology-importing countries* (Gomulka, 1990, p. 155). In this way a virtuous circle between capital investment and innovation is established.

In the logic of the virtuous circle that is established between capital investment and innovation, the investment decisions regarding physical capital and R&D imply a conditionality and

³ Nowadays the innovation process is conceived of as the result of a permanent interaction between the supply of available knowledge, the fruit of scientific investigation, and the strategic decisions of the enterprise.

complementariness in the strategy of the firms in order to compete in the marketplace. In effect, the production of a new product derived from R&D often requires the amplification of productive capacities or the adaptation of plants, but this in turn requires the support of specialized technological studies (Guellec, 1993).

II. The Empirical Evidence. Technological gaps and converging trends in the pharmaceutical industry across countries

The nature of the world pharmaceutical industry competitive environment has changed in the last three decades associated to three main facts. Firstly, the scientific and technological advances in biotechnology and genetic medicine fields have fostered a new technological pharmaceutical paradigm (Landau et al., 1999; Morange, 2003). Secondly, the pharmaceutical firms fusions, acquisitions and strategic alliances process since the 80s, linked to technological competition and the need to join R&D efforts, has favored the drugs market concentration (Weinmann, 2002). Thirdly, there has been a globalization tendency where the production is essentially based in the large pharmaceutical firms (multinationals) from industrialized countries (where United States has an important leadership), but there is an increasing importance in emerging countries like India, China, and Brazil as generic drugs producers bound to the investment flows coming from the industrialized countries. Even if the R&D has been concentrated in developed countries, some drug development and production steps have been placed in developing countries (Eastern Asian, Eastern European and Latin American countries) opening them to new productive and knowledge opportunities. The bio-pharma R&D activities delocalization are highly associated with the human capital levels and capabilities in different countries (commonly, in the developed countries) and low researcher wages advantage (specially, in the developing countries) and, boosted by the information and communication technologies (ICT) environment.

However, even while technology flows in the pharmaceutical industry occur essentially between industrialized countries, some developing countries participate as clinical trial centers, and as important producers of generics (OCDE, 2001). In this context, countries such as India and China are significant as pharmaceutical exporters to other Asian and African countries and Mexico and Brazil in the case of Latin American countries. Coming from an initial production based on an

imitation strategy since the postwar era, some developing countries as Korea, India, Taiwan, Argentina, Mexico, Brazil, and more recently China, have become important generics producers. Nevertheless, some of these developing countries followed a passive strategy regarding technological progress, and others, simultaneously strengthened their production of generics and oriented themselves toward an active strategy based on R&D and innovation (Zúñiga, Guzmán & Brown, 2007). Taking into account the pharmaceutical R&D efforts and the innovation activity of each country selected in this study we are now going to identify the countries innovation dynamic and to test if a convergence or catching up process across the countries has been occurred.

Technological performance trends in pharmaceutical industry

The technological gaps between industrialized and developing countries are every day more evident in industries such as the pharmaceutical, one because of enormous differentials in R&D expenditure as a percentage of GDP of the sector and the per capita patents. The divergent tendency manifests itself, as has been pointed out earlier, when social capacities are lacking and a low rate of technology transference and a reduced per capita GDP are registered. This tendency is accentuated with strong intellectual property protection policies, especially in the lengthening of the duration of the patents.

The study of technological gaps in the pharmaceutical industry is a long-term analysis during the 1980- 2005 period. Two blocs of countries are considered. The first one concerns the industrialized countries, characterized by a sophisticated pharmaceutical industry, with significant R&D expenditures, a relative homogeneity in the strength intellectual property systems and a significant patenting activity (The United States, Japan, Canada, Germany, France, the United Kingdom, Belgium, Denmark, Spain, Finland, Netherlands, Norway and Australia). The second refers the developing countries, identified as countries with strong imitative capabilities, differentiated levels of GDP per capita, R&D, and intellectual property rules and each one has introduced at least one new molecule (Mexico, Korea, India, China, Brazil, Argentina, Ireland).

We have estimated three technological indicators measured as average and with a coefficient variation in three different periods (1980-1990; 1991-2000 and 2001-2005) to identify the

pharmaceutical innovation capabilities and trend of each country selected.⁴ Firstly, we have calculated the pharmaceutical inventive capacity performance based on the USPTO patents per one hundred thousand inhabitants and weighted by exportation's country. Secondly, we have estimated the pharmaceutical innovation productivity level (bio-pharmaceutical USPTO patents per number of employees engaged⁵). Thirdly, the pharmaceutical R&D effort (pharmaceutical R&D expenditure as a percentage of the pharmaceutical value added) is considered as the innovation's inputs of each country.

According to our estimations of the pharmaceutical inventive capacity countries performance, based on the patents, weighted by its population and the export coefficient, we point out the following:

Among industrialized countries there are different innovative paths. In which concern to the patents weighted by the size of the country, Japan stands out as that one which has the higher level on inventive capacity during the two sub-periods, but in the last one has registered a big slowdown. This high indicator of inventive capacity of Japan could be explained because the pharmaceutical export coefficient is very little and therefore the relative measure of patents is high. United States maintains an extensive leadership in pharmaceutical inventive activity over the other industrialized countries during the whole period studied, even if the index is relatively low compared to Japan in the two first periods. It is suitable to underline the significant increase that United States has registered in the second period, during the nineties when most of countries, adhered to OMC, have strengthened the intellectual property in the framework TRIPS's adoption, that was designed to discourage imitation in other countries. A similar path could see with the case of Canada. Indeed, Canada is follower very next to the United States. Special inventive performance can be appreciated by the Nordic countries (Danmark, Finland and Norway) in the second period. Spain shows a little increasing inventiveness for the long of the period studied, but still weak until now.⁶ Finally, we observe (table 1) that in the last sub-period (2001-2005), the whole countries,

⁴ We have not included in this estimations Argentina, Brazil, China and Ireland because we have not complete all the statistical data.

⁵ We have include, as we specify in the methodology, 4 USPTO patent classes; those belonging to pharmaceutical field and those corresponding to biotechnology field due to the proximity in the knowledge production. Between these four classes there are important flows of knowledge that are use in pharmaceutical industry.

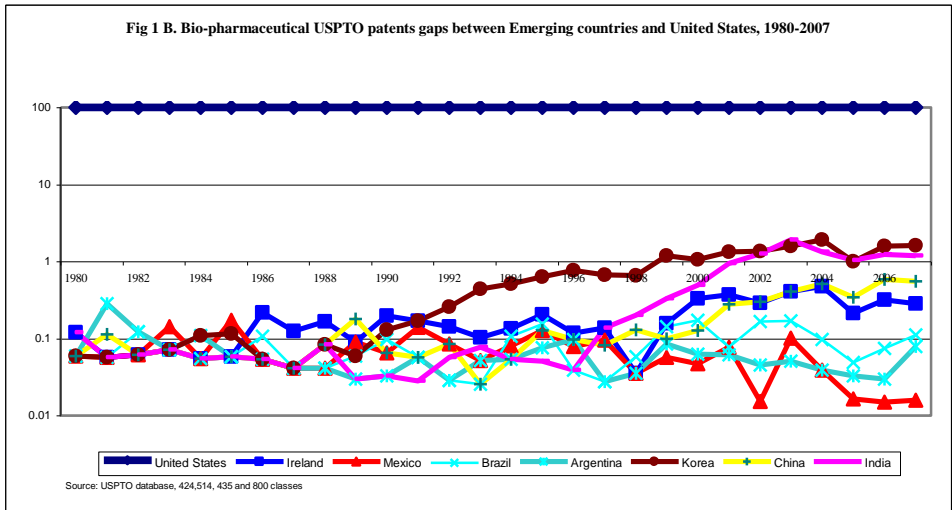
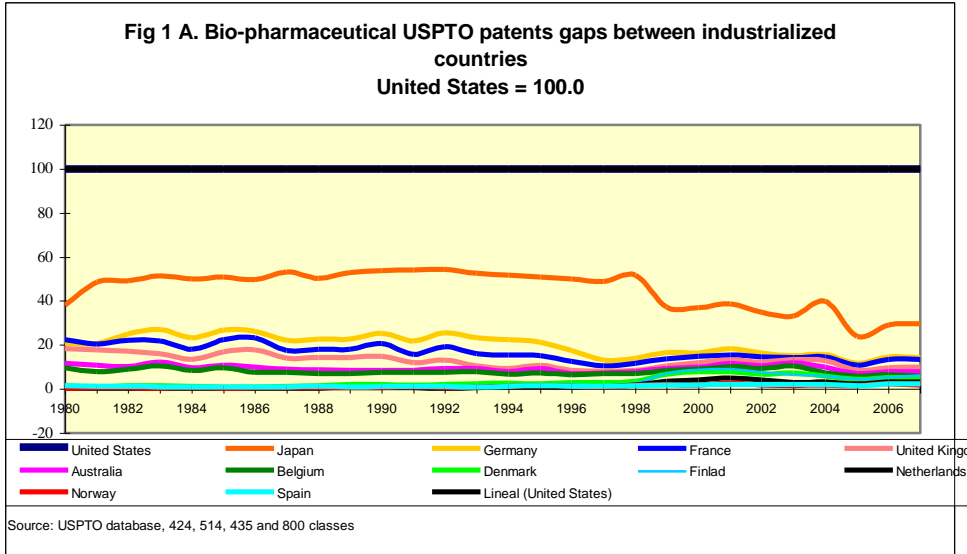
⁶ To compare the level of patenting of industrialized countries we must consider that the propensity to patent for US firms and inventors is much higher in their home country. Some other countries like Japan, even if his R&D spending and patenting are high, there are very few new chemical entities that can be attributed to this country.

with exception of Germany, have decrease this indicator of inventive capacity level. It has to be considered the existence of diminishing returns in the inventive activity and the necessity of external recharges coming from others fields or progress in the basic sciences. Consequently, investment in R&D should increase not only in the pharmaceutical field, but also in scientific fields that permit new finds that strengthen inventive activity. Investment intended for scientific programs such as the human genome will undoubtedly offer new technological opportunities for the development of new medicaments.

Otherwise, the inventive activity of the three developing countries is almost nil in the first period, and is expressed in an incipient manner in the second period in Korea and lower in India. The differentials between these countries are revealed in the third period, in which South Korea takes off in a surprising way, whereas Mexico remains stagnant and India stays marginally.

If we estimate the number of USPTO patents of each country related to the United States, we can appreciate the huge differential of this country with all other developed countries and even more with the developing countries, including China, Brazil, Argentina and Ireland.⁷ Indeed, on comparing the absolute number of patents among these three developing countries the backwardness of Mexico can be appreciated, because since the end of the 90's it has been greatly surpassed by South Korea.

⁷ During the early 90s the numbers of American pharmaceutical patents granted has almost been stagnated and his dynamics growth has been recuperated after 1996, even if the new patents do not mean new chemicals entities. It is very probable that the process of mergers and acquisitions in this industry has contributed to the slowdown of patents growth of American firms, but in a second time (the second half of the 90s) the effort of invention have been increased with a favorable framework of intellectual property laws in his country and others countries.



In relation to the pharmaceutical innovation productivity of each, measured by the number of patent per employee, United States and Japan show high productivity in the first two sub-periods versus to other developed countries. In the third one only the American country keeps the leadership, instead Japan lost drastically its productivity level and Canada gains productivity. In which concern to European countries, France register a productivity step up in the second sub-period and it is maintained in the third one. By its side, Denmark, Finland and Spain increase marginally their productivity. Similar performance is that of Korea and in a lower level is India. By the contrary, Mexico has a very marginal increase in the second period but it keeps stagnant in the third one.

In comparing the two measures of technological indicators based on patents, the inventive capacity level, and the innovation productivity, we admit that there are not so much differences between the tendencies. But we observe greater productivity in Canada that innovating success performance. Otherwise, Denmark has a mayor performance than productivity.

From the R&D effort come the following observations (see Table 1):

The levels of intensity of R&D expenditure relative to the GDP of the pharmaceutical industry among industrialized countries are more homogeneous. An notable R&D effort is made by Japan, in first place, United States, Belgium and Spain.

The effort on R&D spending in the four developing countries coincides with what is expressed in the inventive activity performance, based on patents. Korea has increased the R&D effort and India also, but in a lower level. Finally the worst situation is for Mexico who, far from having an increase, has an alarming diminution in the spending on R&D in pharmaceutical industry and is not associated to the growth rate of GDP.

Table 1. Pharmaceutical technological and innovation indicators average performance

Country	Inventive capacity level			Pharmaceutical innovation productivity			R&D effort		
	(Patents/(Pob *(ExpIF/ VAF))			(patents/employee)			(R&D/VAF)		
	1980-1990	1991-2000	2001-2005	1980-1990	1991-2000	2001-2005	1980-1990	1991-2000	2001-2005
United States	0.5760	1.2578	0.5474	4.0471	6.9792	5.5451	0.0104	0.2656	0.5735
Canada	0.5033	1.1530	0.5824	0.7677	0.1316	0.6419	0.0043	0.2089	0.0335
Japan	7.4717	6.5893	0.0506	7.1281	6.3549	0.5195	0.0063	0.2579	1.8567
Germany	0.5263	0.5324	0.0541	0.9876	1.0291	1.0343	0.0132	0.2938	0.3042
France	0.3560	0.4802	0.0453	0.6636	1.0067	0.9659	0.0170	0.2833	0.2886
United Kingdom	0.0253	0.1789	0.0234	0.0073	0.0428	0.0502	0.0168	0.3907	0.4705
Mexico	0.0054	0.0075	0.0007	0.0043	0.0062	0.0061	0.0034	0.0033	0.0013
Korea	0.0160	0.3207	0.0695	0.0101	0.2075	0.4556	0.0028	0.1540	0.0874
India	0.0006	0.0040	0.0015	0.0056	0.0407	0.1487	0.0031	0.0658	0.0727
Australia	0.1753	0.1418	0.0092	0.2731	0.2298	0.1554	0.0046	0.2656	0.3643
Belgium	0.0945	0.1032	0.0237	ND	0.1075	0.1248	0.0237	0.2534	0.6344
Danmark	0.1263	0.5695	0.0621	0.0892	0.2715	0.2400	0.0128	0.3162	0.3413
Finland	0.1548	0.3327	0.0218	0.2208	0.4237	0.2577	0.0145	0.3626	0.4275
Netherlands	0.0995	0.1614	0.0132	0.1177	0.1753	0.1331	0.0132	0.2394	0.2737
Norway	0.1472	0.3760	0.0082	0.0309	0.0534	0.0095	0.0079	0.2499	0.1494
Spain	0.0619	0.0865	0.0005	0.0626	0.0878	0.0053	0.0038	0.0629	0.8440

Spearman variation coefficient	1980-1990	1991-2000	2001-2005
Index RI&DF/AI514,424,435,800	<i>0.389286</i>	<i>0.475000</i>	<i>0.060714</i>
Index R&DEF/GDPPERCNAT	<i>0.264286</i>	<i>0.350000</i>	<i>-0.071429</i>
Index IA514, 424, 435,800/GDPPERCNAC	<i>0.657143</i>	<i>0.800000</i>	<i>0.532143</i>
Index IAPT514, 424, 435,800/GDPPERCNAC	<i>0.546429</i>	<i>0.464286</i>	<i>0.367857</i>

The Spearman variation coefficient, suggest a near relationship between patents and R&D. In this research there is an interest in determining to what extent these indicators of technological level foster the innovation rate, which joint to capital investment (technology transfer) and productivity, make it possible to explain the convergent or divergent tendencies at the level of technology, and, therefore, the growth of the pharmaceutical industry.

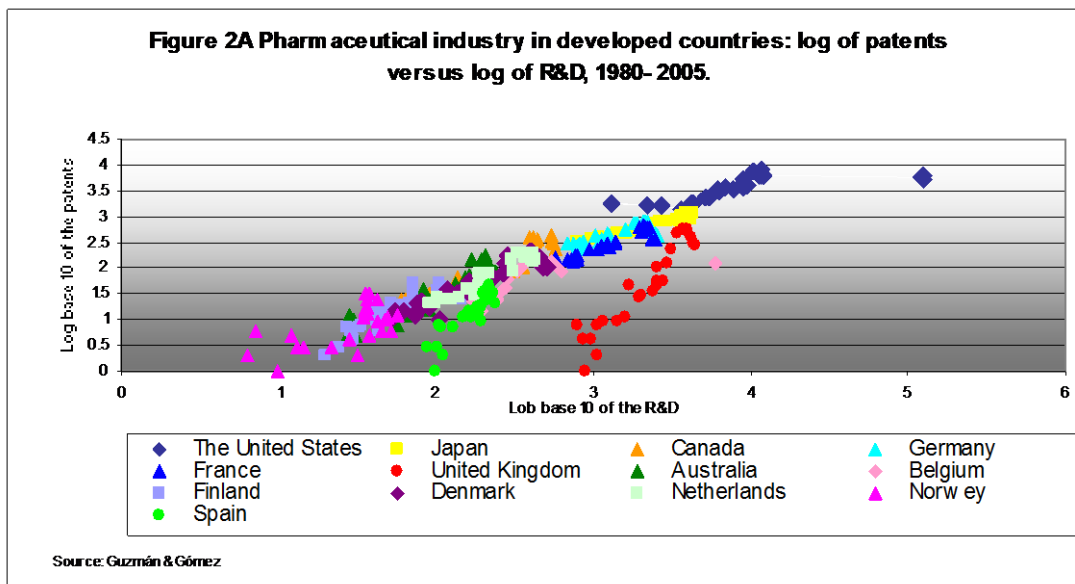
The validation of the patents and the ER&D as an indicator of the results and the input of the innovation process, respectively, have been made by means of various empirical studies (Schmoockler, 1966; Bound, et. al. 1986). Generally, the results have demonstrated that a correlation exists between the number of patents obtained and ER&D. In these studies it was detected that the calculation of patents possesses a noise component that is not explained by the level of ER&D, but rather by the variations inside the industry and the system of patents. The differences in the factors of supply and demand, which indirectly affect the ER&D, also exert an influence, and consequently on the level of patents.

The growth rate of ER&D affects the growth rate of patents in the pharmaceutical industry of country *i* in period *t* in a positive way, that is to say, the calculation is expected to indicate that the correlation is positive. The validation of this assumption is shown by doing dispersion diagrams, which identify the effects of the R&D growing rhythm on that of the patents in the industrialized and developing countries in the pharmaceutical industry for the period studied.

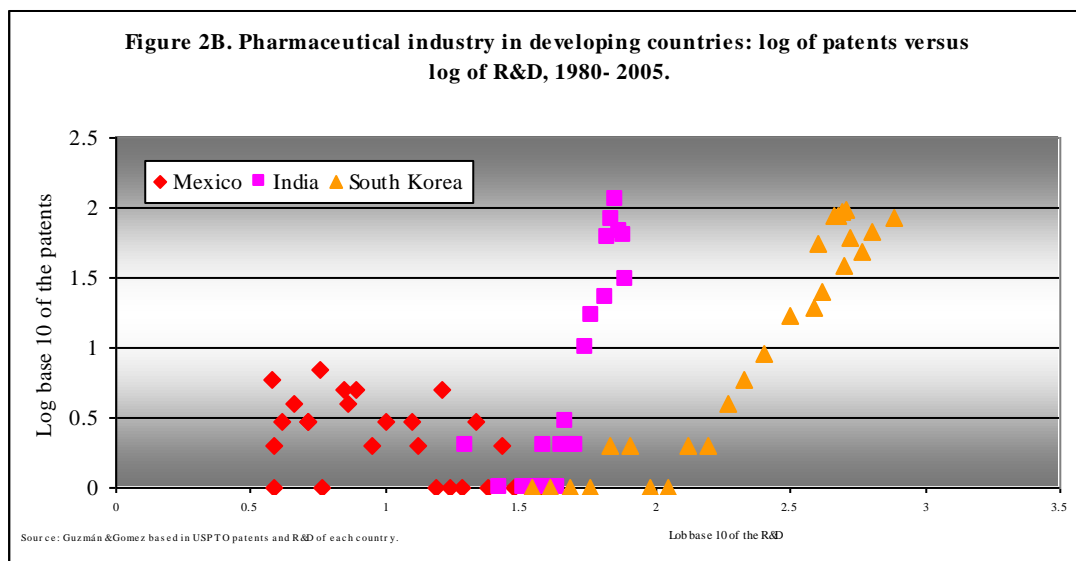
On analyzing these diagrams we observe (see figure 2A and 2 B):

Firstly, in almost all the industrialized countries the R&D has a positive influence over the level of patents except in the case of Spain. In the Spanish case it seems to be linked to the heterogeneity of the pharmaceutical firms in this country; there are firms with better performance and research capabilities that have started on the path of innovation but still remain a greater extent of firms far from of virtuous circle (D'Este, 2003). The United States corroborate his leadership in

the pharmaceutical industry at the same time that shows a very strong correlation between R&D and patents. In which respect to European countries we observe a homogeneous growing tendency, very close to that of Japan, except for the cases of Norway and Belgium where the dynamics in which R&D impacts patents has been positive but irregular. It is important to underline the United Kingdom case, where the influence of R&D on patents has significance but his innovation path is different to those of the European countries because of lower effects of the growth rate in R&D on creation patents.



In developing countries two tendencies associated with the dynamics of ER&D of the pharmaceutical industry are observed, and they are reflected at the level of patents. On the one hand, South Korea with an important exponential growth in ER&D and India as follower in the bloc of developing countries, which is, accompanied by a significant growth in patents, especially since the 90's. On the other hand, there is Mexico with an erratic performance. Mexico observes a slow growth of ER&D in the pharmaceutical industry (and even negative growth for Mexico since 1992) and a meager growth in patents (see Figure 1B).



Technological gaps and convergence in pharmaceutical industry across countries

The aim of this section is to test the unconditional and conditional convergence. The first concept, defined also as β -convergence, according to Barro (1984), Baumol (1986), De Long (1988), Barro (1991) and Barro and Sala-i-Martin (1992), “applies if a poor economy tends to growth faster than a rich one, so that the poor country tends to catch up with the rich one in terms of the level of per capita income or product”.⁸ The second concept, the σ -convergence or conditional convergence concerns cross-sectional dispersion and occurs if the dispersion –measured, by the standard deviation of the logarithm of per capita income or product across a group of countries or regions- declines over the time (Easterlin, 1960; Borts and Stein, 1964; Streisser, 1979; Barro, 1984, Baumol, 1986, Dowrick and Nguyen, 1989; Barro and Sala-i-Martin, 1991, 1992).⁹

The β -convergence has been tested for developed countries by Baumol (1986), Barro and Sala-i-Martin (1991), among others. Barro and Sala-i-Martin (1992) developed a model of σ convergence which supposes that economies with different structure could converge, even the existence of factors

⁸ R. Barro and X. Sala-i-Martin, 1995: 383.

⁹ Cited in Barro and Sala-i-Martin, 1995: 383.

that determine the economic steady state of the countries.¹⁰ This sort of models involves factors affecting economic growth. In this research we analyse a sectorial economic growth, where growth rate of patenting and research and development could affect the converging or diverging tendencies.

In this case we propose the innovation variable as a conditional factor of pharmaceutical steady state differences of each country.

Unconditional convergence (β convergence)

Following Barro and Sala-i-Martin (1991), the β convergence process in the pharmaceutical industry could happen when a country has low initial pharmaceutical value added per employee (Y_t/L) and its growth rate is faster than in a country with a higher value added per employee.¹¹ On the contrary, the divergence process occurs when the countries with higher initial value added per employee grow quicker than those with lower value added per employee. This kind of analysis could be applied to patents and R&D expenditure to test the technological convergence. Countries with bigger growth rate patents (or R&DE) in the case of initial reduce patents (or R&DE) level in relation to those countries with log initial higher patents (or R&DE) but smaller growth rate patents (or R&DE), are closing the technological gaps and therefore are in a converging or catching up process.

According to our estimations of the linear relation between the average growth rate value added per employee (1980 and 2005) and the log initial value added per employee (1980), figure 1 shows a converging process in most of the cases. Indeed, among the sixteen countries selected, the countries with a fewer value added per capita has reached a higher average growth rates, with the exception of India. Norway stands up by its log initial low value added but a speedy increase rate.

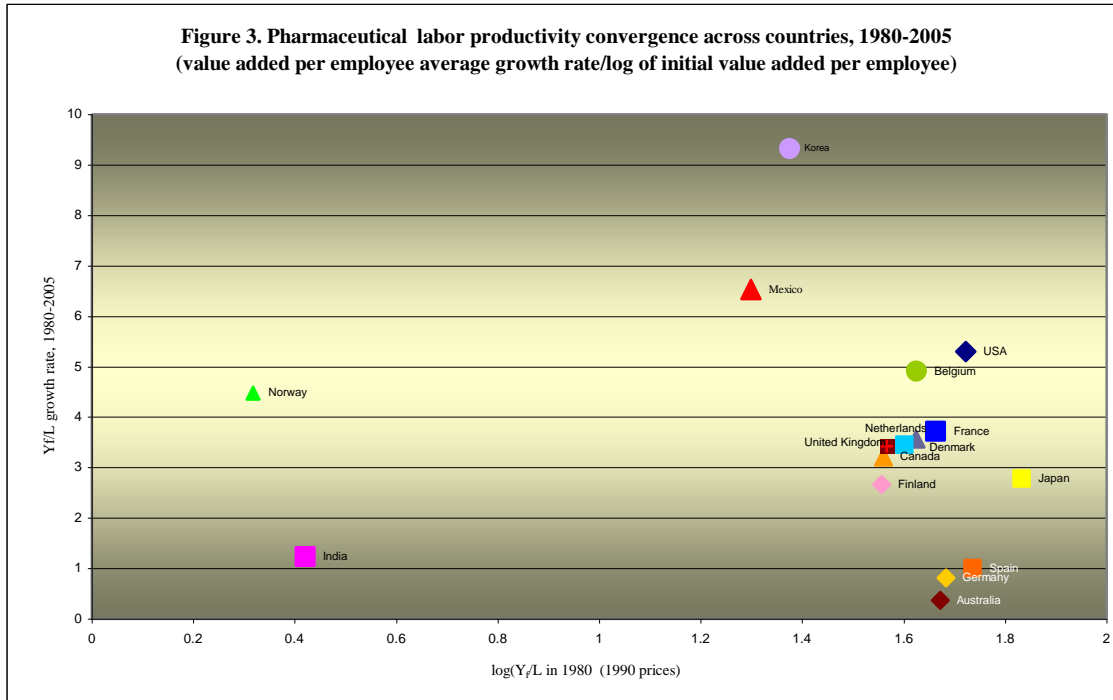
¹⁰ En México, se realizó un estudio sobre convergencia absoluta y condicional entre los Estados. See Mendoza, E y V. Torres, 2002. Innovación tecnológica y crecimiento regional en México, 1995 – 2000, *Revista Mexicana de Economía y Finanzas*, Vol 1, No. 3: 187 – 201.

¹¹ In the case of de GDP, Barro and Sala-i-Martin- use the income per capita. In this study, the pharmaceutical valued added per employee could be considered as a labor productivity indicator.

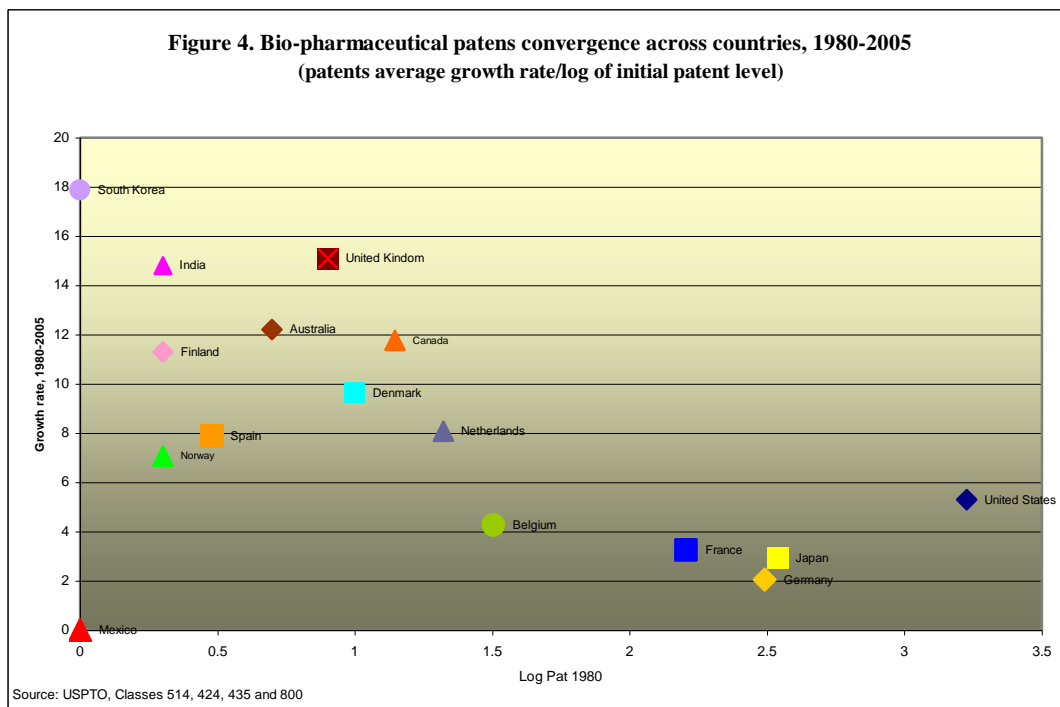
The whole developed countries, without Norway, have reached an initial value added per employee high (specially, Japan) even if their growth rate is not as faster as that one from the United States and Belgium, therefore the dispersion among these countries is reduced. Japan, Spain, Germany and Australia show bigger initial labor productivity but they grow slowly than the others. The speed growth tendency from the United States confirms its international pharmaceutical leadership, followed by Japan and the European countries, associated to technological performance (patents and R&D). Particular importance have, the Scandinavian countries converging process (Denmark and Finland) which have converged to other European countries (Germany, France, Royal Kingdom).

In which concern to developing countries, we observe two tendencies. The first one is a catching up process from Korea and Mexico in relation to the levels of developed countries and, the other one, is a diverging process from India. Korea and Mexico have reached a higher growth rate than the whole countries selected. Nevertheless, the nature of this converging tendency is associated to different kind of factors. By one hand, the Mexican huge growth rate could be explained because of the pharmaceutical multinationals market expansion in this country, in a globalization process framework, specially, with the NAFTA agreement. The pharmaceutical market (by its sale volume) in Mexico has register high growth rates (more than 10% in some years) and it is considered as the top ten world markets joint to an important export activity; meanwhile the level of imports has increasing faster and, therefore, this country has a negative trade balance. This fact reveals the internal weakness of the pharmaceutical industry linked to a technological an innovation performance, which is going to be analized later. By the other, Korea, a recent industrialized country, has been recognized by its strong R&D and innovation effort, so it is easy to explain that the higher growth rate in pharmaceutical productivity is associated to the technological catching up. Finally, the case of India is surprising, because this Asian country has increasing its imitating capabilities to produce an important level of generics drugs in last two decades and has become one of the main generic export countries. But it is necessary to take into account that the Indian market is not so large because the low income per capita and also there some population who refuse to take therapeutic treatments link to certain religious ideas; the generic drugs prices are significant lower than those patent drugs, therefore

the sale volume is relatively low in comparison to those countries like Mexico where the patent drugs segment is more important.



Considering the technological gaps focus, we wonder if the pharmaceutical labor productivity converging tendencies of the developing countries compared to the industrialized countries are explained with rates of economic growth higher than those registered by industrialized countries, linked to an important development of technological and institutional capacities. So, we proceed to test the β convergence hypothesis in the case of bio-pharmaceutical patents (identified as an innovation indicator) by considering the linear relation between the growth rate of patents and the log of initial patents. Figure 2 shows how there are countries with a low initial level of patents but their patents growth is faster than others who have a bigger initial level of patents.



Conditional convergence (σ convergence)

By estimating the standard deviation of the logarithm of the value added per employee or value added across the countries selected we can test if the dispersion across the group of these countries declines over the time; in that case we are in σ convergence. The innovation variables effects (R&D stock and patents) could have a decisive influence (Barro y Sala-i-Martin, 1991). To test the innovation impact in converging process hypothesis in pharmaceutical industry we develop the next model based on the Fagerberg (1989) proposal. If there is a convergence tendency, the explanatory variables coefficients are expected to be negatives.

The differentials in the technological level of the pharmaceutical industry between industrialized and developing countries cause the need for other explanatory variables associated with the specific conditions of each country. In this context the explanatory variables for the pharmaceutical technological gaps or value added per employee converging tendencies are considered as a function of the value added per employee, the availability of knowledge, and the

efforts to innovate. Therefore, three variables are included: i) pharmaceutical value added per employee, with a lag period ($VA_F/L_{F,t-1}$); ii) the previous year's patents ($PAT_{F,t-1}$); and iv) the stock of research and development spending of the industry ($RDSTOCK_{F,t}$).

According to convergence model we assume that value added per employee (VA_F/L_F) growth rates are explained by the previous year's level ($VA_F/L_{F,t-1}$), moreover, we assume that a country with stable economic growth (high GDP per capita) will have a greater responsibility to obtain positive results from innovational activity¹²; in other words, we assume the gap is going to increase.

As has been verified in the previous models, the new knowledge, reflected in the previous year's patents (technological opportunity), is an input for the innovations of the present period (PAT_F). Lastly, the $STOCKID_F$ is the principal input for innovation¹³ and reflects the efforts of the industry to stay in the marketplace.

Based on the preceding, the model proposed for the study of technological gaps or σ convergence in the pharmaceutical industry for developing and developed countries is the following:

$$TVA_F / L_{F,t} = f (VA_F / L_{F,t-1}, PAT_{F,t-1}, STOCKID_{F,t})$$

The model is analyzed by means of the econometric calculation of the panel of data using the following equation:

$$TVA_F / L_{F,t} = c(1) + c(2) * LOG(VA_F / L_{F,t-1}) + c(3) * LOG(PAT_{F,t-1}) + c(4) * LOG(STOCKID_{F,t}) + e_{it} \quad \{1\}$$

where:

$TVA_F / L_{F,t}$ = matrix, which represents the pharmaceutical value added per employee growth rate of country i in period t.

$LOG(VA_F / L_{F,t-1})$ = matrix of the \log_{10} of pharmaceutical value added per employee of country i in millions of US dollars at 1990 prices in period t.

$LOG(PAT_{i,t-1})$ = matrix of the \log_{10} of patents in the pharmaceutical industry of countries i obtained from the USPTO (classes 514 or 424 or 435 y 800) in period t minus 1.

$LOG(STOCKID_{i,t})$ = matrix of the \log_{10} of ER&D stock of countries i in millions of US dollars at 1990 prices in period t.

e_{it} = matrix of the errors of countries i in period t.

¹² This idea is known as Schmoockler's hypothesis. See Schmoockler, J., *Invention and Economic Growth*, Harvard University Press, 1966, pp. 28-30.

¹³ This happens especially in the pharmaceutical industry.

Empirical evidence

The three variables are positive and significant, which means, that the pharmaceutical value added per employee in the previous period ($t = 1.1429$), the patents granted in the previous period ($t = -1.3321$) and R&D stock ($t = 1.1390$) have an impact on the value added per employee growth rate, and therefore, they contribute to reduce or increase the technological gap and so, the converge or divergence.

Indeed, the results show that VAF/LF and the R&D, both in the previous period, contribute to increase the technological gap and therefore to the diverging tendency. Both coefficient signs are positives (1.6514 and 1.2186), which suggest that countries with lower level in both variables will grow less quick than countries with higher initial levels. That mean, that the innovation variable R&D stock is significant in the diverging economic process. The countries with more R&D expenditure are those ones with more value added per employee, and this favor to extend the pharmaceutical gap.

By the opposite side, negative sign of the patents variable (-1.369970) reveal that more patents do not necessary become in bigger growth rates. Even if the patents gives monopolist commercial protection, there are important knowledge spillovers associated to the patent disclosure, which the technological follower countries can take advantage of. Figure 2 showed patent converging tendency.

Table 2. Dependent variable: Value added par employee growth rate

$$TVA_F/L_F_{it}$$

Method: Pooled Least Squares

Period = 1981 – 2005 = 25 observations. Whole total : 279

Include 16 countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$LOG(VA_F/L_F_{i,t-1})$	1.651401	1.444806	1.142991	0.2540
$LOG(PAT_{i,t-1})$	-1.369970	1.028376	-1.332168	0.1839
$LOG(STOCKID_{it})$	1.218606	1.069861	1.139033	0.2557
Durbin-Watson stat	2.374589	F-statistic		-1.717319

Nevertheless the value added per employee growth rates (Figura 1) suggest converging process in almost all countries, with exception of India and Norway, it is suitable to consider the differences across countries according to σ convergence. However, the fact cannot be ignored that in the panel a group of economies with heterogeneous pharmaceutical industries is being considered, especially among developing and developed countries.

The differences detected in the dynamics of patents in the pharmaceutical industry of developed and developing countries during the period analyzed are convincingly explained by the differences in the efforts at innovation (ER&D stock) and the taking advantage of technological opportunities (the previous year's patents). So, whereas there is a high level of innovation in developed countries, the developing countries are associated with a lack of substantial technological innovations.

Nevertheless, it is indispensable to consider the differences in development between the industrialized countries, with a high technological level, and the developing countries that depend basically on the transfer of technology from outside and their ability to assimilate it. Therefore, it is convenient to evaluate the model in blocks, that is to say, separating developing and developed countries.

Technological Gaps in the Pharmaceutical Industry of Developed Countries

Table 3. Depent variable: Pharmaceutical value added growth rate per employee

$$TVA_F/L_F it$$

Method: Pooled Least Squares

Period = 1981 – 2005 = 25 observaciones. Whole total: 249

Include 13 countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$LOG(VA_F/L_F i-it)$	-0.553626	1.985869	-0.278783	0.7806
$LOG(PAT_{i,t-1})$	-1.009253	1.066952	-0.945922	0.3451
$LOG(STOCKID_{it})$	2.219898	1.256397	1.766876	0.0785

Durbin-Watson stat	2.362457	F-statistic	-1.334792
		Prob(F-statistic)	1.000000

In the bloc of the industrialized countries at a panel level, we observe that the innovation variables affect positively the technological development, but in a way more than proportional [STOCKIG_t (2.219898)]. In fact, R&DE is the sole significant statistical variable to explain the VAF/LF growth rates differentials across countries ($t=1.766876$). Thus, the results show that the initial pharmaceutical value added par employee and the bio-pharma patents level are not statistical significant to contribute the gap among the countries ($t = -0.278783$ y $t = -0.945922$). This gap, in other words, growth rates divergences, is explained by the R&DE, thus, the countries with higher initial R&D effort (R&DE) could reach bigger growth rates. This fact looks to confirm, that in the innovation process, R&DE is an ex – ante condition.

Technological Gaps in the Pharmaceutical Industry of Developing Countries

When the model at a panel level is calculated for the same period but only for the developing countries (Mexico, India, Korea) the results are substantially different. The innovation variables (patents and R&D expenditures), are not statistical significant to explain the pharmaceutical value added par employee ($t= 0.0342$ y $t= -0.0272$). This is probably due to the fact that for these countries, the imitation strategy, by means of the technology transfer, has been important in their take-off towards innovation. The divergence tendency among these three countries is explained by the initial VA_F ($t=1.580605$). In the Mexican case, even if the VA_F average growth rate is large, (1980-2005), the R&DE and the patents level have an erratic performance.

Table 4. Dependent variable: Value added par employee growth rate

$$TVA_F/L_F it$$

Method: Pooled Least Squares

Period = 1981 – 2005 = 25 observations. Whole total: 249

Include 13 countries



Variable	Coefficient	Std. Error	t-Statistic	Prob.
<i>LOG(VA_F/L_{F i,t})</i>	3.613289	2.286017	1.580605	0.1256
<i>LOG(PAT_{i,t-1})</i>	0.190695	5.568419	0.034246	0.9729
<i>LOG(STOCKID_{it})</i>	-0.115349	4.239178	-0.027210	0.9785
Durbin-Watson stat	2.446870	F-statistic		0.806043
		Prob(F-statistic)		0.457080

The results of developing country at panel level give different paths evidence among them, explained by their particular technological development, including the ability to learn and absorb foreign technology. By one hand, Korea look for diminishing the gap with respect to the industrialized countries. By the other hand, the countries that far from having convergence tendency they show an erratic performance, widening the technological gap: Mexico.

Many studies have identified the wide expenditure on education, on ER&D, on transferring technology as the main sources of Korean economy's growth (See Amsdem, 1987; World Bank, 1993). Nevertheless the strength of the intellectual property rights (IPR) in pharmaceutical industry was too early (1987) -because of the pressure of the United States- when Korea "was incapable of developing new internationally marketable drugs" (La Croix & Kawaura, 1996). Therefore, even if Korea registered wealth losses, this Asiatic country has started since then a path of convergence because of his technological capabilities build in the previous years. An opposite strategy was followed by India, which has retarded the adoption of stronger IPR and they continued with intensive imitation in a protection environment for the domestic firms (Lanjow, 2000). Finally, Mexico was pressured too to strengthen its IPR with the negotiations of North – America Free Trade Agreement (NAFTA). Mexico adopted the Trips in 1991 even if the domestic firms expected them until 1997, ten years after the entrance to GATT. The absence of a virtuous circle in the Mexican pharmaceutical industry could be understood because of the weak investment on R&D (See Guzmán & Brown, 2003). But also because of the kind of entrepreneurs which have grown in protectionism environment during several decades and they used to have his market place in the wealth public sector in generics drugs with generous profits without building necessarily

technological capabilities (Guzmán & Zúñiga, 2004). So, Mexico has invested in the formation of scientists (physicians, biologists, chemical) with international scientific production but it has not been capitalized by the industry to generate synergies.

Conclusions

In this empirical investigation the hypothesis that the feedback that is established between R&D and patents propels the innovative capacities of industrialized countries in pharmaceutical industry is corroborated.

The technological and innovational leadership of the United States here is conclusive. Nevertheless, other countries, in particular Japan, have made a great spending effort on R&D, surpassing the growth rates of this indicator and of patents of the leading country, and with this they are starting out on the road to convergence. Even the technological homogeneity of the European countries (except Spain), Japan and Canada, we distinguish especially four of them that have developed a convergence path: Japan, France, Germany and the United Kingdom. But there are also the Nordic countries and Canada with a convergence tendency at a lower level.

The gaps are even greater if developing countries are considered, especially when the R&D and patent levels are meager compared to the industrialized countries, and even more when we compared to the leading country.

In order to explain the convergence or divergence growth patents tendency between countries we find that at a panel level the main factors are: the availability of knowledge and the efforts to innovate. Given the technological backwardness from the developing countries, the empirical evidence of panel by bloc and countries shows different paths of growth and innovation.

In the bloc of the industrialized countries at a panel level their innovation path is associated only by the innovation variables (the previous year's patent and the stock on R&D). By considering each country as a whole of the industrialized countries, the United States confirms its position as the technological leader in the pharmaceutical industry, link to their high level on R&D expenditures and the stock on patents. Without the United States the results are maintained. But at a country level, we find, by one hand, that only for Japan, France, Germany and the United Kingdom the innovation variables rested significant. By the other hand, the industrialized countries followers

still explain their technological development of the pharmaceutical industry not only by innovation variables but by one imitation variable too, GDP per capita (Finland, Spain, Norway, Australia, Belgium, Denmark, Netherlands and Canada). Only Spain shows impact from the imitation variable (GDP per capita).

Nevertheless, by considering the developing countries panel we find that technological gap, measured by patents level, is explained by the gross fixed investment, the previous year's patent and the stock on R&D. In observing the differences of the path the developing countries selected we find, by one hand, these which look for diminishing the gap with respect to the industrialized countries: India and Korea (explained by the GDP per capita, the stock on R&D and the previous year's patents). By the other hand, the countries that far from having convergence tendency they show an erratic performance, widening the technological gap: Mexico. Even if South Korea remains lagged with respect to level of the developed countries, his growing and innovation path tends to be systematic and increasing. India follows to strengthen the imitation's way meanwhile Mexico is stagnated. The differences between developing countries could be understood in considering the way in which each country builds its technological capabilities in a virtuous circle between capital investment and innovation.

METHODOLOGY

Data and Sources

The ER&D level was calculated using the method of perpetual inventories (Mohen, 1990):

$$STOCKID = \sum_{\zeta=0}^3 \delta^{\zeta} (ER\&D_{i,t-\zeta})$$

Where $ER\&D_i$ is the research and development expenditure of country i in period t , in millions of US dollars, deflated to 1990 prices. The number of regressions applied is 3 ($\zeta = 0, 1, 2, 3$)¹⁴. According to Griliches (1979) the rate of obsolescence is assumed to be 15% annually (δ). For the purpose of this calculation it should be taken into account that the level of stock on R&D implies that one observation were lost (1980), thereby reducing the size of the sample from 25 to 22 observations.

*One of the main problems is that an aggregation of patents, as well as the other measures of technological innovation, includes items of very heterogeneous value: to add up patents implies that inventions with different economic and technological significance are merged*¹⁵. By this reason, patents, even if it is a good raw ingredient for quantitative analyses is not as the same for qualitative analyses. In this study

¹⁴ This assumption being taken from the work of Griliches (1979) in which it is argued that the effects of ER&D persist for approximately 3 to 4 years.

¹⁵ Archibugi (1992), p. 359

we have chosen the idea of common market to compare the patenting activity of all the countries selected with the patents granted by the US patent office. Finally, all countries are submitted in the US patent office at the same rules. By considering that the propensity to patent of the United States is higher in their home country we do not compare this indicator with the rest of the countries.¹⁶ The annual information on patents granted to each country in the United States was obtained from the database of the *United States Patent and Trademark Office* (USPTO). The search was carried out by taking the USPTO classes linked to pharmaceutical industry: those corresponding to drugs: 514 (*Medication and compounds for the treatment of biological and corporal infections*) and 424 (*Drugs, bioaffecting and body treating composition*) and those belonging to biotechnology: 435 (Chemistry: molecular and microbiology and 800 (Multicelular living organisms and unmodified parts thereof and related processes). The USPTO is consulted according to the volume of systematized information it has, this being linked to the importance that the United States has in technological competition.

The data for the pharmaceutical value added¹⁷ and the gross fixed investment of each country, in its national currency come from the Stan database of the OCDE for various years, with the exception of India. For this country the national Statistical Yearbook of that country was consulted. The pharmaceutical value added and gross fixed investment at current prices was deflated in 1990 prices and was converted to U.S. dollars by using the purchasing power parity (PPP) 1990 relative to USA. The population of each country was obtained from the Annual Population Statistics of the United Nations for various years. The national per capita GDP was calculated based on the GDP and the population of each country.

In order to analyze the pharmaceutical technological gaps and converging or diverging trends between countries we consider the average performance of three technological indicators in three different periods. The first one, is the level of pharmaceutical inventive capacity, which is calculated based on the number of pharmaceutical patents (classes 514, 424, 435 and 800) weighted by the size of each country, according to its population (patents per hundred thousand of inhabitants), and its export coefficient.¹⁸

¹⁶ In so far as patents are concerned, some studies of patenting among countries indicate that the different regulations make comparison difficult, so they propose consulting a common (foreign) market such as the USPTO (Soete, 1981). Other studies prefer to consult non-resident patents in the global market registered with the Intellectual Property Organization (WIPO), because in this organization the patent concessions of country x are tabulated for all countries except country x. This external patent level can be correlated with the country's level of exports (Fagerberg, 1987).

¹⁷ Value added represents the contribution of each industry to GDP.

¹⁸ The patents per hundred thousand inhabitants, has been identified as the inventive capacity of the country. The positive export coefficient could be linked to an innovating success performance.

The second indicator is the level of pharmaceutical innovation productivity; it was estimated based on the pharmaceutical patents (classes 514, 424, 435 and 800) per number of employees engaged in pharmaceutical industry of each country.

The third indicator is the pharmaceutical R&D effort. It was calculated by using pharmaceutical R&D expenditure as a percentage of the pharmaceutical value added.

Also, the relationship between R&D and patents was calculated. The relation of each indicator to the level of economic development (expressed in per capita GDP at 1990 prices), was estimated through correlation's Spearman's coefficient. The value of each interval was obtained by calculating the arithmetical average. During the periods selected, the Trade Related Aspects of Intellectual Property Rights (Trips) have been adopted in different years by the countries.

Nevertheless, the average performance of the three technological indicators only show the innovation dynamics differs and trends, but the overall countries technological gap related to the technological leader (United States) is displayed by estimating a coefficient of variation (standard deviation mean).

Afterwards we proceed to analyze the technological dynamics at the country and country panel level. Firstly, the impact that the ER&D has at the patent level in each country can be seen in plots of the log of patents versus log of ER&D (correlogram). Finally, to test the β -convergence, we have considered the Barro's model. The β -convergence is measured the by the innovation level (patents), as a function of the previous year's patents VA_{t-1}/L , the availability of knowledge (the previous year's patents), and the R&D efforts to innovate (the stock of ER&D) and with that the position that the pharmaceutical industry of each country is determined, according to its technological performance.

A serious limitation for the study is the size of the series available (25 observations for each country), which reduces the possibility of having a stable economic calculation. It would be better to have a sample of at least 60 data.

The results obtained from the proposed models present: i) the size of the sample (n)¹⁹; ii) the parameter's estimated value, and between parentheses the standard deviation (SD); iii) the value of the statistics: F, and iv) the self-correctional statistics: Durbin Watson (DW). The values of R^2 and R_a^2 are omitted because they are unreliable measurements. The Eviews package, which includes the routines necessary for the calculations, is included.

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¹⁹ A small sample (less than 60 observations) provides unstable calculations: the presence of autocorrelation and the t statistic are very small.

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