DETERMINANTS OF THE MATURING PROCESS OF THE MEXICAN RESEARCH OUTPUT: 1980-2009

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SUMMARY

This work analyzes the growth of Mexican research output and impact in the period 1980-2009. The general aim is to identify the policy issues that determined the consolidation of the scientific activity in Mexico during this period. The methodology employed is based on the use of tools such as the Web of Science, specifically the Science Citation Index and the Social Science Citation Index, in addition to selected indexing services from various Mexican institutions. The findings confirm that scientific growth came as the result of several changes associated with the number of active researchers in the National System of Researchers (SNI), fellowships for graduate studies, graduate programs certified by the National Council for Science and Technology (Conacyt) and implementation of the program of improvement of teachers in public universities, complemented with science policies performed efficiently by the Mexican government. The growth is independent of the stagnation of the federal spending in science and technology as percentage of the NGP. This conclusion is consistent with the thesis of other authors, that the growth of research in basic science is determined by a series of changes in the relevant scientific community.

Mexico has a still underdeveloped economy, second in Latin America after Brazil. With a population over 112 millions (INEGI, 2012), it has a large number of natural resources and, unfortunately, a large proportion, about 40%, of its population is classified within the extreme poverty limits (Casais-Padilla, 2009). A prevalent characteristic of underdeveloped countries like Mexico is the late arrival to a full research activity in science and technology. In particular, in the case of Mexico, the visibility of its research output in mainstream journals only became apparent in the decade of 1970. In recent years there has been an increase in the studies concerning the Mexican research activity from the bibliometric and science policy points of view. Most of the studies have focused on one given field (Collazo-Reyes *et al*., 2004; Sierra-Flores *et al*., 2009; Collazo-Reyes *et al*., 2010; Luna-Morales, 2012), one institution (Ramírez *et al*, 2002) and even on one specific topic like the Mexican involvement on the top-quark discovery. Recently, the early patterns of scientific production by Mexican researchers in mainstream journals or by the most productive Mexican scientists (González-Brambila and Veloso, 2007; Luna-Morales *et al*., 2008) have been analyzed. However, relatively little attention has been paid to the issues that could have influenced the growth of Mexican research output in recent times. In the present paper we will try to explore a critical issue concerning the current Mexican research production: how is it possible that, even though there has not been any increase in the federal investment in the activities of science and technology (González-Amador, 2009b), the research output has kept a steady growth since the late 1980's?

Research production by Mexican scientists had a slow start in the first half of the 20th century. The number of papers published in mainstream journals during this period barely reached 300 articles (Collazo-Reyes *et al*, 2009). The accumulated number of published papers had reached the 8000 mark by the late 70's, a figure equivalent to the number of articles published annually in mainstream journals in recent years by Mexican researchers (Collazo-Reyes *et al*., 2011). A detailed analysis of Mexican research production reveals a deep-seated connection between scientific performance and various extra-curricular factors such as: social, political, cultural and economic events. For example, early interest in training Mexican

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students abroad in scientific disciplines was halted in the period 1910-1935 due to the sudden outbreak of the Mexican Revolution (Trabulse, 2003). However, a few papers were produced during this time by researchers associated to various public-health institutes and laboratories located in the industrial sector; the subject matter of this research was related mainly to public health, infectious diseases, clinical and general medicine, as well as industrial chemistry.

The outlook for Mexican science underwent a real change due (Monteón-González, 2006) to the establishment in 1935 of the National Council of Higher Education and Scientific Research (CNESIC by its initials in Spanish). The institutionalization and professionalization of the scientific activity in Mexico received a new impulse with the creation of various research institutes within the National University: Astronomy, Biology and Geology (1929); Physics and Geography (1938); Mathematics (1942); and the Schools of Sciences and Chemistry (1941). In the decades of 1960 and 1970, other research institutions were created that further contributed to the maturing process of the research performance by Mexican scientists: the National Polytechnic Institute (IPN), the Center for Research and Advanced Studies (Cinvestav) and the *Colegio de México* (ColMex). All these institutions are located in Mexico City, but some research groups were created also in public and private universities in other parts of the country.

The Mexican research output increased steady during this period, due in part to a solid national economy. The most important event in this period was the foundation of the National Council for Science and Technology (Conacyt) in 1970. But, unfortunately, fluctuations in the national economy began to jeopardize the evolution of research activity in the late 70's.

In the present paper the determinants of the performance of research production and citation by Mexican scientists in the period 1980-2009 are explored. It was found that the Mexican research output has scaled-up in several steps as a result of a variety of policy issues during this period: the advent in 1984 of the National System of Researchers (SNI); the first International Monetary Fund (IMF) grant dedicated exclusively to support new research projects (1990), a magnanimous system of fellowships for graduate studies implemented by Conacyt (1994), a new hiring scheme for young researchers in public universities (SEP, 2006) and, finally, a certification process for all graduate programs in science and technology, implemented also by Conacyt (Rojas, 2004).

Crane (1972) pointed out that the growth of research carried out in basic science is the product of a series of changes in the respective science community that involve usually an increase of material and economic resources, as well as the creation of new research groups and access to specialized data bases. This thesis has been also endorsed more recently by Autant-Bernard *et al*. (2006) and V Mangematin and K Errabi (2010). In the particular case of Mexico, we find that both research and citation outputs were determined by various changes in the academic sector: number of active researchers, graduate programs in science and technology and the associated fellowships granted by Conacyt. A similar conclusion has been reached in recent studies of the Brazilian scientific production (Glanzel *et al*, 2006; Frazao-Helene and Leta-Ribeiro, 2011). It was found that the evolution of the Brazilian scientific production was determined mainly by some input parameters (number of permanent researchers and graduate fellowships) rather than by growth rates of research investments.

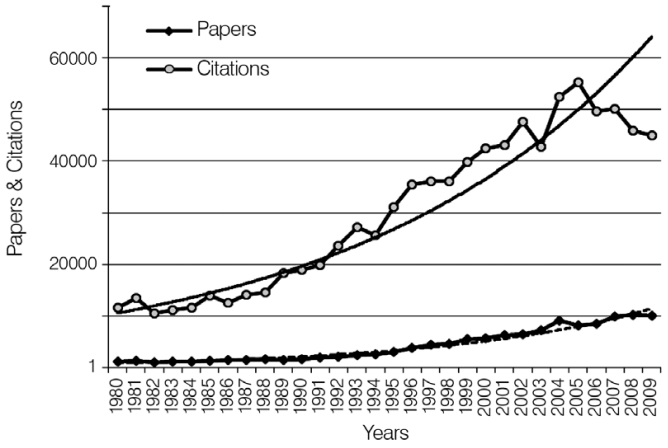

Figure 1. Papers and citations by annual series for Mexican researchers, 1980-2009.

This work leans heavily on bibliometric analysis, as a means to analyze the qualitative and quantitative aspects of science (production and impact). The study of the scientific literature allows to determine the relation between the scientific development and the implementation of science policies in Mexico (Pérez y Torres-Vega, 1998). The baselines of analysis are the publications and citations included in the Web of Science as well as in selected Mexican indexing services.

Materials and Methods

Mexican research output published in mainstream journals in the period of interest was recovered through a search by address 'Mexico (not New Mexico)' in the Web of Science (WoS) data base. The search was limited to the Science Citation Index Expanded (SCIE) and the Social Science Citation Index (SSCI) for the periods 1980-2009 and 1997-2009, respectively. In a first search 143,600 entries were obtained, but the baseline was then reduced to 126,776 entries after it was verified that all the cases correspond to researchers working in a Mexican institution. The respective number of citations for this set of articles was searched in the same data base but for an extended period: 1980-2010 for SCIE and 1997-2010 for SSCI.

The evolution in the number of researchers in the SNI was taken from the records of the *Foro Consultivo Cientifico y Tecnologico* (FCCyT, 2011) and the *Atlas de la Ciencia Mexicana* (Pérez-Angón, 2010). Conacyt's annual reports were consulted for numerical data on the number of fellowships granted annually to graduate students and the number of Graduate Programs certified by Conacyt in its *Programa Nacional de Posgrados de Calidad* (PNPC; PNPC; Pérez-Angón, 2010). The statistical information on the grants allocated by the Ministry of Public Education (SEP) in its *Programa de Mejoramiento del Profesorado de las Instituciones de Educación Superior* (PROMEP) was obtained directly from its official web page (SEP, 2006).

The growth patterns of production, citations, PNPC (graduate programs and fellowships) were compared using time series analysis, correlations and adjustments to different growth tendencies. These indicators were subjected to bivariant analysis to determine the degree of correlation.

Results

Figure 1 presents the evolution of the annual numbers of publications and citations for the en-

TABLE I
PARAMETERS OBTAINED FOR THE EXPONENTIAL FITS USED IN THE PERIOD (1980-2009)

Variables	N_O	*K*	R^2 (Exp.)	Periods
Papers	79	0,08	0,96	1980-2009
Citations	99	0,06	0,93	1980-2009
Fellowships - Conacyt	133	0,07	0,95	1980-2009
Researchers - SNI	188	0,07	0,88	1984-2009
PNPC (Graduate Programs)	109	0,07	0,86	1991-2009

tire Mexican scientific community from 1980 to 2009. As can be appreciated, there has been a steady increase in both research output and impact of Mexican researchers in this period. Both, publications and citations, follow a similar growth, but the number of citations shows fluctuations in the recent years due to the fact that recent publications will take more time to accumulate a reasonable number of citations. The parameters obtained in an exponential fit to this data are shown in Table I. The exponential function given in Table I was used to observed the respective parameters obtained in these fits according to the exponential function $N(t)= N_0 10kt$, where N_0 is the number of articles or citations in 1980, k is the respective annual rate of growth and t is time in years. Finally, R^2 is the value of the respective regression number. The fit to the number of articles is better than the fit to the number of citations, even though the regression numbers obtained indicate that both fits are good ones and close to 0.90. This behavior corresponds to the second stage expected in the logistic growth of scientific knowledge pointed out by Price (Crane, 1972).

The thesis that we would like to explore in the present study is that this growth arose as the result of several changes associated with the number of active researchers as well as of science policy initiatives implemented by the Mexican government. Each of these issues are considered in chronological order (Table I).

The correlation between articles published in the period 1980 and 2004 and the respective citations generated by them is shown in Figure 2. It was decided not to include the number of citations registered in recent years (2005-2009) in order to avoid the low number of citations that all articles receive in the first years following publication. It can be seen that in the 1980's the number of articles and citations is very low, followed by a steady increase in both articles and citations. Lineal and exponential fits to the data are included in this figure. The best fit is for the lineal case, with a high regression value of 0.937, which implies that there is a very good correlation between production and impact of the Mexican research output in this period.

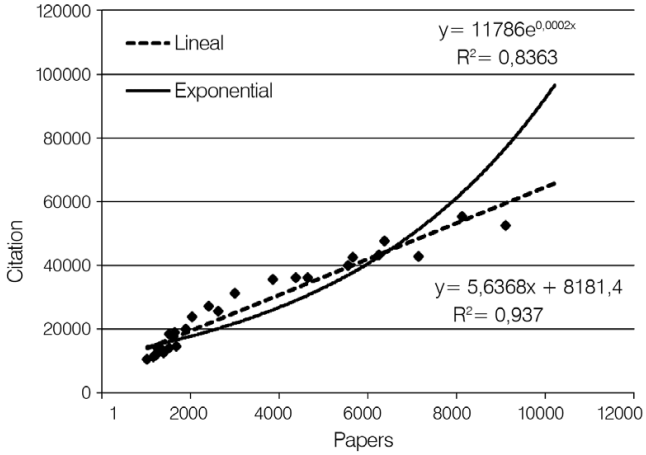

Figure 2. Correlation between papers and citations, 1980-2004.

The National System of Researchers (SNI)

The National System of Researchers (SNI) was created in 1984 in order to provide a pecuniary compensation, as a salary complement, tothe most productive researchers when the Mexican economy was in crisis in the 80's. These complements represent currently about 30% of the income of the researchers in this program. In this respect, the increase in the number of researchers in SNI is a natural factor to consider in the evolution of research output of Mexican scientists. Accordingly, there are minimal values in both production and impact around 1983-1986 (Figure 1). Figure 3 depicts the evolution of the number of researchers since the year of the creation of SNI (FCCyT, 2011). Also included in this figure are the evolution of the number of fellowships granted by Conacyt and the number of graduate programs certified also by Conacyt in the PNPC program (Hernández-Guzmán, 2010). Just as it was the case in the number of articles and citations (Figure 1), the number of fellowships and PNPC programs show a slow growth in the 1980's, followed by an impressive increase in all items. Therefore, it is easy to associate the growth in production and impact shown in Figures 1 and 2 with the steady increase in the number of member of researcher in the SNI, as they had been identified as the most productive researchers in Mexico (González-Brambila and Veloso, 2007).

In order to find out if there is a close correlation between the increase in the number of researchers in the SNI and the observed growth in articles and citations shown in Figures 1 and 2, the respective data was plotted in Figure 4. It can be seen that there are close correlations and the respective regression values are given by $R^2= 0.840$ for citations and $R^2= 0.902$ for papers. In order to avoid the low accumulation of citations in recent years, the respective data for 2008 and 2009 has been excluded in this analysis.

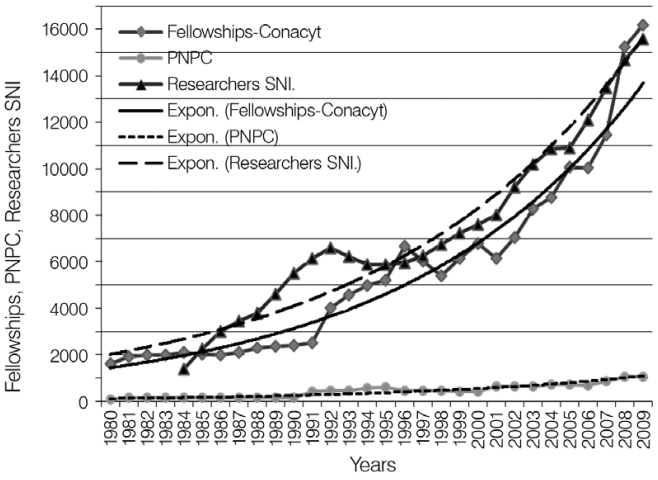

Figure 3. Growth dynamics for the number of fellowships-Conacyt, Graduate Programs.

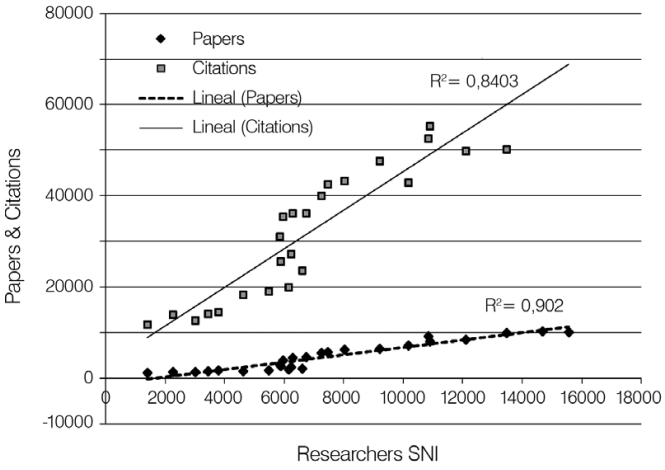

Figure 4. Researchers SNI *vs* papers and citations, 1984-2004.

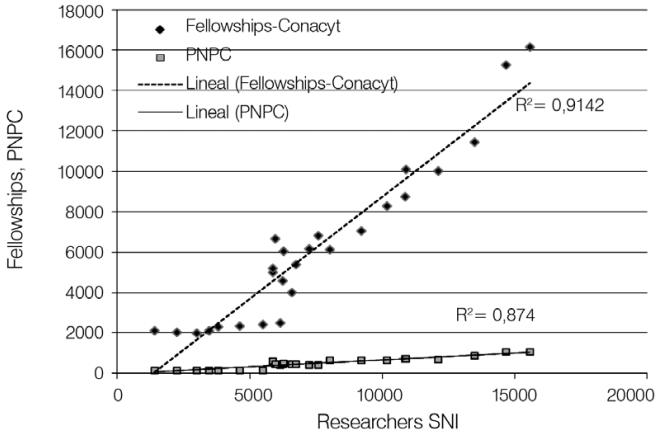

Figure 5**.** Researchers SNI *vs* Fellowships-Conacyt and PNPC (Graduate Programs), 1980-2009.

Fellowships and Graduate Programs (PNPC)

From its very beginning in 1970, Conacyt has implemented a fellowship program for graduate studies in Mexico and abroad. This program did not grant a really ambitious number of fellowships until the early 80's. In figure 3 is presented the evolution of the number of fellowships in the period 1980-2009, and graduate programs included in the PNPC of 1991-2009, as well as the number of researchers in the SNI in the period 1984-2009. The number of fellowships granted by Conacyt doubled in 1992 and 1996, and the increase is notable in these years. This behavior may be a consequence of the increase in the number of graduate programs certified by Conacyt, which shows also an exponential increase after 1990: in the early 80's there were only 160 graduate programs in the PNPC, but they have became about 1000 in recent years. Again, in Figure 3 the growth in the number of fellowships granted by Conacyt was fitted by an exponential function and the respective parameters obtained are shown in Table I. It can be seen that the regression number shows a very good fit. However, the regression numbers obtained for the PNPC fit were not as high as those obtained for the number of researcher in SNI and the number of fellowships granted.

In Figure 5 the number of fellowships and graduate programs is plotted *vs* the number of researchers in SNI and the regression numbers come out asare R^2= 0.9142 and R^2= 0.8740, respectively. In the latter case, it can be seen that there is not a good correlation between the increases of the number of researchers and the number of graduate programs. We believe that this is natural outcome, since the certification process of these programs usually is slower than the increase in the number of researchers incorporated to new graduate programs.

PROMEP Programs

The Ministry of Public Education (SEP) introduced a special program to stimulate an increase in the number of active researchers in public universities located outside the metropolitan area of Mexico City. New hirings in these institutions were restricted to active researchers that were able to qualify as members of SNI. The result was rather positive and as a consequence there has been a steady increase in the contribution of these universities to total national research output since the early 90's, when the program was implemented. In fact, the PROMEP initiative has been identified as being instrumental in the decentralization process of the Mexican scientific activity (Pérez-Angón,

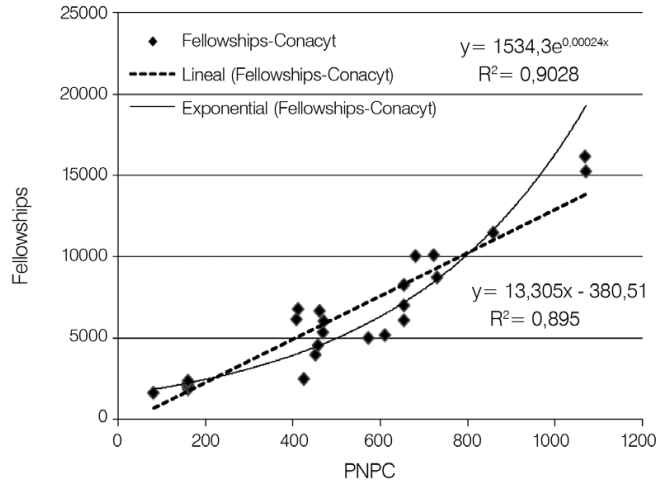

Figure 6. Relationship between graduate programs and Fellowships-Conacyt, 1980-2009.

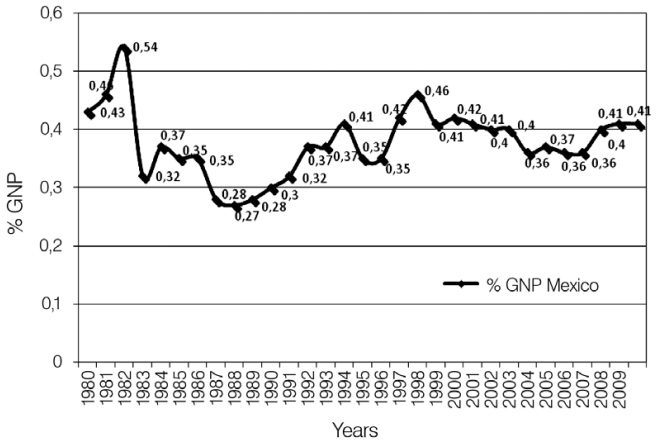

Figure 7. Distribution by annual series of the percentage of the GNP assigned to science and technology, 1980-2009. Sources: FCCYT (2010), (Pérez-Angón, 2010)..

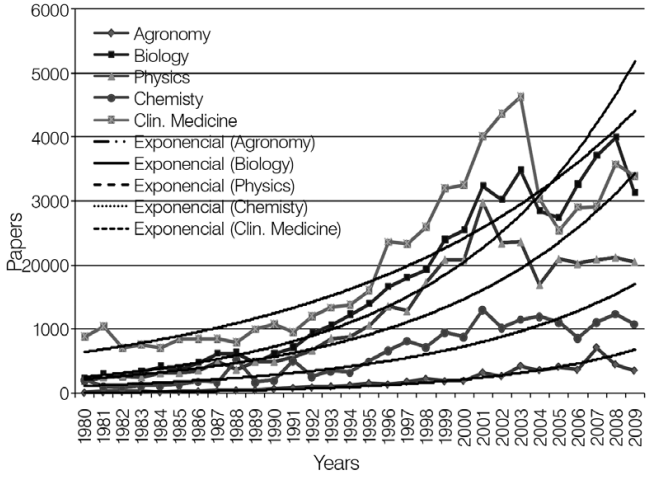

Figure 8. Annual growth by scientific disciplines. Part 1, 1980-2009.

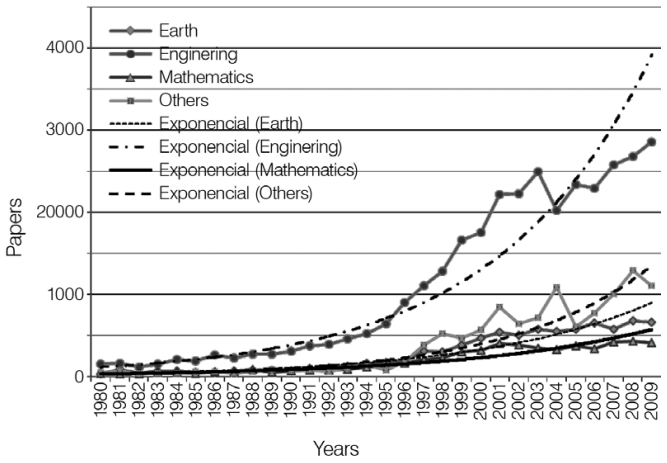

Figure 9. Annual growth by scientific disciplines. Part 2, 1980-2009.

2010). The effect of this program can be appreciated in Figure 3 as a steady increase in the total number of SNI members, since the public universities and research centers usually hire new members of their faculties if they fulfill the requisites imposed by SNI. In turn, these new researchers help to consolidate graduate programs and the number of fellowships. In this way, the excellent correlations obtained in Figure 5 between the SNI members and the number of fellowships and PNPC programs can be understood. In both cases, good lineal fits for these correlations were obtained. On the other hand, in Figure 6 can be found the correlation obtained between the number of fellowships and the number of programs certified by PNPC. It can be seen that the best fit is given by an exponential function with a regression value of 0.902. In order to explore the possibility that the increase in the number of fellowships is delayed somewhat with respect the number of new graduate programs included in PNPC, a delay of one year was introduced between the data for fellowships and programs in PNPC. However, the respective fits do not improve the results shown in Figure 6, in both cases for either the lineal or exponential parameterizations. There is one way to understand the lack of time correlation between fellowships and certified programs in PNPC: Conacyt usually recognizes new graduate programs a few years after they have started to operate and, thus, when they are included in the PNPC they already have a reasonable number of students enrolled and sometimes even some students have graduated.

TABLE II
PARAMETERS OBTAINED FOR THE EXPONENTIAL FITS BY DISCIPLINES

Disciplines	N_o	K	R^2 (Exponential)
Agronomy	16	0,12	0,95
Biology	240	0,10	0,95
Physics	206	0,09	0,91
Chemistry	102	0,09	0,85
Others	22	0,13	0,89
Earth	31	0,11	0,93
Engineering	99	0,12	0,96
Mathematics	27	0,10	0,93
Clinical Medicine	600	0,06	0,83

Percentage of the GNP in S&T

The spending of the Federal Government in science and technology in Mexico has been a matter of continuous debate (González-Amador, 2009a). The evolution of the percentage of the Gross National Product (GNP) in S&T activities is shown in Figure 7. An increase in this percentage can be noted only in the period 1988-1994, when Mexico received special grants for S&T activities from the International Monetary Fund and the World Bank (Conacyt, 2005; González-Amador, 2009b). In this respect, we did not find a positive relation between this funding and the growth of research production and impact by Mexican scientists.

Research output by discipline

In order to appreciate the evolution of each discipline, the data on the number of articles published in the period 1980-2009 was separated into two groups: biology, physics, chemistry, medicine and agronomy in Figure 8, while mathematics, engineering, geosciences, social sciences and humanities are in Figure 9. In Table II the parameters obtained for the best fits for each discipline are shown. All of them have similar regression numbers except for medicine, which has had a slower growth during this period, while engineering shows the quickest increase. It should be noticed that all disciplines show a local minimum in 2004. We do not have en evident explanation for this behavior.

The general pattern observed in all research areas is associated with a similar increase in the respective number of researchers in SNI for each research area. In particular, in areas such as social sciences, humanities and engineering the number of researchers has increased considerably in recent years (Pérez-Angón, 2010; CONACYT, 2009ab). Increases in the numbers of international publications (SCI and SSCI) are substantial in all areas, especially in earth sciences, physics, engineering, chemistry, medicine and social sciences (Veloso, González-Brambila *et al*, 2006). We did not include in these figures the data for the humanities, since our baseline only included articles in SCI and SSCI.

Discussion and Conclusions

The main determinants of the maturing process of Mexican research output and impact in the period 1980-2009 have been analyzed in the present paper. Quantitative evidence is presented that supports the hypothesis that Mexican scientific activity in this period under consideration did go through a maturing process in terms of growth in

the number of articles published in mainstream journals, the respective number of citations, as well as the number of active researchers and certified graduate programs. Our analysis also supports the hypothesis formulated by Crane (1972) that enduring growth in research output is intimately connected to the changes experienced by the respective community in the same period. However, this analysis has shown that there is a policy issue that is not correlated with this growth: the stagnation observed in the investment of the Mexican government in science and technology activities. We believe that the current percentage of GNP dedicated to S&T, which is about 0.40%, is so low that it may jeopardize the observed growth in Mexican research production and impact. A similar conclusion was obtained in recent studies of the Brazilian scientific production: the powerful growth of science in Brazil parallels striking structural changes (Glanzel *et al*., 2006; Frazao-Helene and Leta-Ribeiro, 2011) rather than increases of investment in research activities. However, the results presented in this paper support the conclusion that the steady increase in the Mexican research production observed in the last 20 years (Figure 1) can be explained by the efficient investment of a few federal programs such as SNI, PNPC, PROMEP and the number of fellowships granted by Conacyt.

The lack of continuity in the investment in research by part of the Mexican Government has been criticized by several authors (Tshipamba and Rubio, 2007). On the other hand, there are some authors (Casas-Guerrero, 2004) that consider that public policies implemented by Conacyt are in the right direction, even though only some research areas have profited from them. The latter conclusion is not fully supported by the analysis presented in this paper, since we have shown that most of the research areas reflect a continuous growth in production in mainstream journals (Figures 8 and 9). It was found that the fastest growing areas are biology, physics, medicine, and engineering, which in turn also correspond to some of the areas with a high increase in the number of SNI members in the period studied.

The present analysis is consistent with the results obtained by Mexican science in some international rankings published recently. For example, the Ministry of Science, Technology and Innovation of Argentina (MCITP, 2007) places Mexico's performance in research growth in 10th position among 20 other nations for the period 1997-2007. A similar conclusion was obtained by the National Science Foundation (NSF, 2010), which placed Mexico's science among the top 30 countries with the highest production, with an average annual increase of 6.7%, and 0.6% as the national percentage of the global production. UNESCO's Science Report 2010 indicates that Mexican scientific production has been doubled in the period 2002-2008 (UNESCO, 2010). This pattern has been also noticed in a recent study of the production and citation performance of Latin American countries: Brazil and Mexico registered the largest growth in articles and citations in the period 1991-2003 (Glanzel *et al*, 2006).

We conclude that the growth in production and impact in the Mexican science has been driven by an efficient use of the public support. The main factors studied in our analysis that have determined the growth of the Mexican research output in the cycle 1980-2009 are:

- A steady increase in the number of active researchers that are members of the National System of Researchers (SNI).

- Conacyt has certified a large number of graduate programs that in turn has induced a steady increase in the number of fellowships granted by Conacyt.

- The decentralization process of the Mexican science, which has consolidated a large number of active research groups in the public universities outside Mexico City, as well as in the research centers supported by Conacyt (Luna-Morales, 2010).

- The successful performance of the *Programa de Mejoramiento del Profesorado* (PROMEP) applied in public universities, which allowed to increase the number of Ph.D. researchers, as well as the opening of full-time contracts.

- The expenditure by the Mexican Government in S&T activities had only a small visible effect on the growth of research output in the period 1990-1998, when Mexico received special grants from the World Bank and the International Monetary Fund to be applied specifically to S&T activities.

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LOS DETERMINANTES EN EL PROCESO DE MADURACIÓN DE LA PRODUCCIÓN CIENTÍFICA MEXICANA: 1980-2009

María Elena Luna-Morales

RESUMEN

Este trabajo analiza el crecimiento de la producción de investigación en México y su impacto de 1980 a 2009. El objetivo general es identificar las medidas de política que determinaron la consolidación de la actividad científica en México durante este período. La metodología se basa en el uso de herramientas como el Web of Science, en concreto el Science Citation Index y Social Science Citation Index, además de los servicios de indización seleccionados de diversas instituciones mexicanas. Los hallazgos confirman que el crecimiento fue el resultado de varios cambios relacionados con el número de investigadores activos, las becas de posgrado, la mejora los posgrados nacionales de posgrado, y la aplicación del programa de mejoramiento del profesorado en las universidades públicas; en complemento con políticas científicas desarrolladas de manera eficiente por el gobierno mexicano, y es independiente del estancamiento de su inversión en actividades de ciencia y tecnología como porcentaje del PIB. Esta conclusión es coherente con la tesis otros autores, que el crecimiento de la investigación en ciencia básica está determinada por una serie de cambios en la comunidad científica pertinente.

OS DETERMINANTES NO PROCESSO DE MATURAÇÃO DA PRODUÇÃO CIENTÍFICA MEXICANA: 1980-2009

María Elena Luna-Morales

RESUMO

Este trabalho analisa o crescimento da produção de investigação no México e seu impacto de 1980 a 2009. O objetivo geral é identificar as medidas políticas que determinaram a consolidação da atividade científica no México durante este período. A metodologia é baseada no uso de ferramentas como a Web of Science, em concreto o Science Citation Index e Social Science Citation Index, além dos serviços de indexação selecionados de diversas instituições mexicanas. Os achados confirmam que o crescimento foi o resultado de várias mudanças relacionadas com o número de investigadores ativos, as bolsas de estudo para pós-graduação, a melhora dos cursos nacionais de pós-graduação, e a aplicação do programa de melhoramento do professorado nas universidades públicas; complementado com políticas científicas desenvolvidas de maneira eficiente pelo governo mexicano, e é independente da estagnação de seu investimento, em atividades de ciência e tecnologia, atrelado ao PIB. Esta conclusão é coerente com a tese de outros autores, de que o crescimento da investigação em ciência básica está determinado por uma série de mudanças na comunidade científica pertinente.