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Nanotechnology in Mexico: Key Findings Based on OECD Criteria

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Abstract

This analysis of Mexico's nanotechnology policies utilizes indicators developed by the Organization for Economic Co-operation and Development, which in 2008 conducted a pilot survey comparing the nanotechnology policies of 24 countries. In this paper, we apply the same questionnaire to the Mexican case, adding business information derived from the National Institute of Statistics and Geography survey on nanotechnologies, also an OECD instrument.

Keywords

Nanoscience Nanotechnology Mexico Research and Development Science and Technology

Introduction

The present survey is a Mexican replication of a 2008 Organization for Economic Co-operation and Development (OECD) pilot survey that compared nanotechnology-related public policies of 24 member countries. Additionally, the OECD directs its member countries to regularly carry out surveys on nanotechnology-related businesses, which Mexico did for the first time in 2011-12. In this paper, we apply the OECD pilot survey questionnaire to the Mexican case, augmenting the responses with the results of the recent Mexican nanotech business surveys.

Reviewing nanotechnology policy in Mexico is of broader importance as many developing countries are engaging in nanotechnology and facing similar challenges. In Latin America, for example, almost all governments have listed nanotechnology development as a priority (Foladori and Invernizzi 2013). Most countries in the region, however, did not create a specific public agenda or policy (except for Brazil and Argentina). In consequence, the analysis of the Mexican case ought to be of important relevance for academics and for decision and policy-makers. This, of course, is not exclusive of the region. In Africa there are several governments nurturing nanotechnology under the same context, and facing similar challenges when implementing specific agendas and programs (Demissie 2011).

We reach two main conclusions. On the one hand, although Mexico is far behind most of the surveyed countries with regards to public policy and financial support for nanotechnology, the number of businesses that incorporate nanotechnology is nonetheless significant. On the other hand, despite the fact that Mexico does not have a nanotechnology development plan, its participation in the OECD, in the ISO Technical Committee on nanotechnologies, and in the North American Free Trade Agreement (NAFTA) is resulting in nanotechnology regulations based on private international standards.

Methodology

A survey conducted in 2008 by the OECD Working Party on Nanotechnology (WPN) (WPN 2009) was taken as the basis for our research. The WPN is undertaking projects on:

> i) the opportunities and challenges for business investment in the development, application, and commercialization of nanotechnology and related policy needs, and ii) similarities and differences in national STI policy approaches and challenges for policy makers related to nanotechnology (WPN 2009: 25).

As part of the projects implemented, a questionnaire on nanotechnology was applied (WPN 2009).[1] This is a survey of 24 countries (21 members and 3 observers) to monitor the development of their Science, Technology and Innovation (S&T) nanotechnology policies. We applied the OECD survey instrument to the Mexican case, enabling us to analyze the Mexican government's efforts to promote nanotechnology development within the OECD framework. We also used the Module on Biotechnology and Nanotechnology from the Survey of Research and Technological Development and Activities (ESIDET, for its Spanish Acronym). This is an instrument developed by Mexico's National Institute of Statistics and Geography, and is based on the methodology described in the OECD's Frascati Manual (OECD 2002). This survey registers the number of businesses dedicated to nanotechnology Research and Development activities, including the pending on these activities by the businesses surveyed.[2] The analysis of this survey and Mexico's nanotechnology policies allows us to compare Mexico within the international context of OECD countries.

OECD S&T Policy

The OECD has 34 member countries, within which Mexico, Chile and Turkey are considered emerging economies. The OECD works with and includes statistical information from other countries that are not members, but that are considered as emerging, such as Brazil, China and India and developing economies in the Africa, Asia, Latin America and Caribbean regions (OECD 2014b). The OECD is funded by its member countries, with national contributions based on a formula that takes into account the size of each member country's economy. The largest contributor is the United States, which provides nearly 22% of the budget, followed by Japan. Unlike the World Bank or the International Monetary Fund, the OECD does not provide grants or make loans.

On May 18, 1994, Mexico became the 25th member of the OECD (OECD 1994). The OECD claims a number of benefits of membership, including the possibility of comparing public policies with the experience of best practices at the international level, strengthening public administration, and enabling various sectors of the country to make use of relevant information analysis. Taken together, membership in the OECD might be expected to contribute to a better understanding of at least some public policy issues in Mexico (OECD 2010a).

The OECD uses information on a wide range of topics to help governments foster prosperity and fight poverty through economic growth and financial stability. Among the policies to be strengthened to achieve comprehensive growth, OECD includes S&T. Because countries differ in their structural characteristics, such characteristics may in turn condition their R&D capabilities and S&T policies (Dutrénit and Puchet 2015). Structural differences include such things as degree of industrialization, internal market size, export structure (manufactured products, technological content, etc.), average age of the economically active population in relation to total population, education level, country size, and national resource endowments.

The OECD's approach to enhancing innovation in member countries is based on training people to innovate ("unleashing innovation"), creating and applying knowledge, applying innovation to address global and social challenges, and improving governance and measurement of innovation policies (OECD 2010b). Innovation is a key aspect of the OECD's approach, because its analysis of economic development for at least the last two decades shows that developed countries have reoriented their activities towards the services and manufacturing activities that are driven by high technology, where knowledge (OECD n/d) and innovation play a key role.

Following other international institutions like the World Bank and UNESCO, OECD calls these more advanced economies "knowledge-based economies" (OECD n/d).[3]

Although various criteria exist to define, via indicators, which are high-tech sectors, there appears to be universal agreement that such sectors all feature prominent investment in knowledge. According to the European Commission, for example, there are three basic approaches to identifying high-tech sectors, depending on whether one begins with:

- the sector itself, identifying industries and knowledge-intensive services, measured as a percentage of jobs or income with high content of knowledge in the total sectoral value
- products, distinguishing trade in high-tech products according to the R&D share of total sales value
- patents, identifying the various sub-class patents related to high-tech industries, and in some cases aggregating information into group patents by specific topics, as in the case of biotechnology (Eurostat 2014).

The United States employs similar criteria. The North American Industry Classification System (NAICS) is based on the degree to which employment is found in R&D activities (Hecker 2005). Although the classification criteria and indicators are always under review, the basic approach remains the same: identifying businesses and / or innovative and cutting-edge technology sectors. Thus there is a close connection between the concept of high-tech and innovation, and by default, competitiveness and development (NSF 1988; Eurostat 2014).[4] The World Bank ranks countries according to the percentage of high-tech contained in their export goods (i.e. computers, pharmaceuticals, industrial instruments, industrial machinery and aerospace products). In 2004, for example, 34% of Ireland's exports were high-tech products, 33% of South Korea's, 32% of the United States' and 21% of Mexico's[5] (World Bank 2013).[6] When a country is analyzed individually, however, use of these generic high-tech indicators can be misleading. Countries that assemble portions of high-tech finished products, as is the case of Mexico with electronics, appear as developed, when much of the value corresponding to the R&D may have been realized abroad and only assembled or put together at home. If the machinery, although sophisticated, were also imported, this country would not have merited an R&D classification, despite the fact that the maquiladora industries may be classified as high-tech. For example, in 2008, Singapore and South Korea occupied the sixth and seventh places, respectively, in the ranking of countries with high technology, but their success was due to the movement of products and parts (Eurostat 2014); the same applies to Mexico with its maquiladora industry.[7]

In policy terms, the problem is to select and implement adequate policies and priorities. These include not only the key issues and sectors in each case, but also the training of qualified staff, the creation of research networks, agencies that will drive the process, methods and amounts of funding and implementation, and plans and deadlines (Drilhon 1991; Gassler et al. 2004). OECD's innovation policies seek to promote competitiveness by building a business-centered innovation system, geared towards increasing public support for innovation (financial and otherwise), which would lead to private investment (OECD 2009). To guide such STI policies, governments must make considerable investments. Developed countries invest between 2 and 3 percent of their Gross Domestic Product (GDP) in R&D (World Bank 2012), but this is not the case for most developing countries, including Mexico, as we will see.[8]

Nanotechnology is considered a high-tech sector according to the major international institutions, and therefore, a priority for countries' S&T plans, along with biotechnology and information technology/communications (ICM n/d; Macilwain 1998; OEST 2004). Support for these sectors, through funding and public policies, therefore serves as an indicator of a country's impetus for the promotion of competitiveness and development, at least according to OECD criteria. Most public policies that endorse these technologies have the explicit intent of using their technological prowess to achieve an increase in the competitiveness of the country. "Competitiveness," in fact, became the banner of the entire policy package of nanotechnology; this is especially accurate in the case of Latin America (Foladori et al. 2012). Of course, there may be contrasting experiences, but in the case at hand, the support for these sectors serves as an indicator of a country's impetus for the promotion of competitiveness and development, at least according to OECD criteria.

Nanotechnology in Mexico in Light of OECD's S&T Public Policy Criteria

Mexico joined the OECD in 1994. Years later, an evaluation of the scientific-technological system by one of the institution's expert committees recommended several actions to create a technologically competitive industry in Mexico, including: the creation of an institution that controls all S&T, the development of a S&T policy linked to businesses demands, the search of external financing, and the restructuring of the National Council on Science and Technology (CONACYT [for its Spanish Acronym])

(OECD 1994). To accommodate the S&T policy recommendations made by OECD, Mexico requested $700 million from the World Bank in 1997 to finance scientific and technological research, link the university with businesses, restructure public research centers, and improve the technology of the private sector (World Bank 1998).

R&D activity spending is very low in Mexico. In 2012 it was second lowest of all OECD countries (0.43% of GDP), only slightly above Chile, which was the lowest (0.41% of GDP) (OECD 2014a). While most OECD countries spend an average of around 2% of their GDP on R&D (OECD 2010a, b), Mexico's average spending over the last 15 years has been less than 0.5% (Fig. 1).[9] In 2001, based on the OECD recommendations, Mexico called for raising its R&D investment to 1% of GDP by 2006 – a goal that has never been reached (OECD 2009). The closest Mexico has come to meeting that goal was 0.45% in 2010. To reverse this situation, OECD recommends that Mexico make a budgetary effort to support R&D investment, and introduce reforms aimed at ensuring greater spending efficiency. Examples of the latter would include greater reliance on direct governmental support rather than tax incentives, streamlining and restructuring the systems of direct support, and the expansion of programs aimed at improving the synergy between public and private R&D in high-priority areas such as health, energy, water management and food supply (OECD 2010a). However, the Mexican government has yet to address these OECD recommendations. Examples of the latter would include greater reliance on direct governmental support rather than tax incentives, streamlining and restructuring the systems of direct support, and the expansion of programs aimed at improving the synergy between public and private R&D in high-priority areas such as health, energy, water management and food supply (OECD 2010a). However, the Mexican government has not adjusted its policies in response to these recommendations. Figure 1 shows the evolution of R&D investment in the first decade of the century.[10]

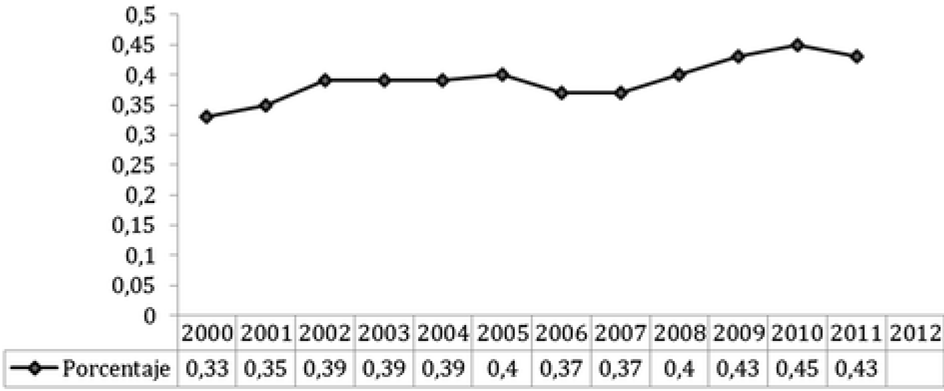

Fig. 1

Gross domestic expenditure on R&D as a percentage of GDP—México. Source: Our own calculations based on OECD. StatExtracts

In the OECD there are about 250 committees, working groups and expert groups.[11] Within the area of science, technology and industry, on September 14, 2006, the OECD established the Working Group on Manufactured Nanomaterials, a subdivision of the Chemistry Committee. The objective of this working group is to promote international cooperation on human health and on the environmental safety of manufactured nanomaterials among member countries and some other economies (according to the disclosure policy of the Chemical Products Committee) (OECD 2015a).

A year later, on March 26, 2007, the OECD created the Working Party on Nanotechnology (WPN), a subsidiary of the OECD Committee on Science and Technology Policy. The purpose of this group is to report on S&T policy developments with regard to the responsible development of nanotechnology (OECD 2015b). The WPN is also responsible for developing and implementing work programs that aim to promote international cooperation to facilitate research, responsible development and commercialization of nanotechnology in member countries and some other economies. The WPN interacts with other groups, such as WGMN, which analyzes the potential risks of nanoparticles and is of great importance for regulatory purposes (OECD 2012c).

In 2008 the WPN conducted a survey of 24 countries (21 members and 3 OECD Observer Countries) to oversee the development of their policies on Science, Technology and Innovation concerning nanotechnology (WPN 2009).[12] The survey focused on the following specific issues for nanotechnology (Table 1):

Table 1

Topics on nanotechnology OECD survey

1	National plan
2	Social participation in policy making
3	Relationship between private and public sector
4	Risk to health and the environment
5	International cooperation
6	Participation in international forums
7	Regulation
8	Direct financing
9	Rate of work
10	Support to private enterprise
11	Intellectual property

Source: Derived from WPN (2009)

These items pretend to deal with issues related to policy development. As OECD acknowledges, the lack of data on the development and commercialization of nanotechnology, including policy development, is a challenge that countries need to address. The survey conducted by OECD is an opening step towards addressing the lack of information about national policies (WPN 2009: 6).

Below we will discuss these issues, as they apply to the Mexican case, in the order indicated in the table.

1. The first item of interest in the OECD survey is whether the country has an initiative, national program or strategy for the development of nanotechnology. The OECD believes that a national program of long-term guidelines, financial support and S&T priorities is key for a sector - in this case nanotechnology - to develop in a sustained manner.

Of the total of 24 countries surveyed, 17 have a national plan or strategy, but 7 do not, even though among them there are some that have significant R&D in the area. The countries with a national plan include the following:

- The United States launched its National Nanotechnology Initiative in 2001. The leadership of the US is reflected in the funding it has allocated into the sector. For instance, the President's 2016 budget calls for $1.5 billion to be spent on the NNI, resulting in a cumulative total of $22 billion since its inception (National Nanotechnology Initiative 2015).
- Germany has monitored the development of nanotechnology since 1998 through its General Ministry of Education and Research (BMBF).[13] The BMBF promotes regional and national networks for competence in nanotechnology (Federal Ministry of Education and Research 2007).
- South Korea is another case of reference. The country adopted its National Nanotechnology Initiative in 2001 under the direction of the Nation Council for Science and Technology. The Council passed a Law for the Promotion of the Development of Nanotechnology in 2002, and has a strategy platform based on a 10-year development plan (StatNano 2015).

It is not only the highly developed countries that have created a national plan. South Africa launched the South African Nanotechnology Initiative in May 2002, aimed at solving social problems in the country (DS&T n/d: 9); and Brazil produced the first national strategy for nanotechnology in Latin America in 2005, under the scope of the Ministry of Science & Technology (MCT), subsequent to the funding for nanotechnology research networks as of 2001 (MCTI 2012).

Belgium, Canada, Denmark, Hungary, Poland, Sweden and Switzerland did not have, until 2008, a strategy, national initiative, or specific set of rules for nanotechnology; however, that did not stop any of them from having significant development in the field (WPN 2009). National projects are not critical for the development of nanotechnology. What matters is the articulation of diverse policies, rather than a group of separate, uncoordinated policies.

Mexico does not have a national strategy for development of nanotechnology, despite having considered its importance for economic development since 2001. Like most Latin American countries, Mexico described nanotechnology as a priority development area within its S&T plans (Foladori and Invernizzi 2013). Table 2 shows the reference to nanotechnology in Mexico's plans:

Table 2

Nanotechnology in Mexico's S&T plans

Plan	**Mention of nanotechnology**

Plan	Mention of nanotechnology
Special Program of Science and Technology 2001-2006 Volume I	The Special Program sees nanotechnology as a priority area for development in the field of advanced materials. “Information and communications - biotechnology - material - design and manufacturing processes - infrastructure and urban and rural development, including its social and economic aspects, are considered strategic areas of knowledge” (National Council of Science and Technology, 2002, p. 49). Places special emphasis on the potential for development of the energy sector and in relation to the Mexican Petroleum Institute. “Main lines of research [Mexican Petroleum Institute] ... Nanotechnology and its applications” (CONACYT 2002, 12).
Special Program of Science and Technology 2001-2006 Volume II	In this volume II of the Special Program of Science and Technology nanotechnologies are considered as a strategic area of advanced materials. There, the areas that would be of interest to its development are noted (catalysis, polymers, nanostructured materials, thin films, semiconductors, metallurgy, biomaterials, optical materials, advanced ceramics and simulation and modulation of materials and processes) and a brief overview is provided which includes, which research centers, how much human and material resources each of them possesses and what are the potential interactions with industry. “The formation of an ad hoc scientific committee is recommended, to promote and implement the National Program for Nanoscience with the characteristics mentioned in this document and to strongly support the national network of nanotechnology and other current efforts to this effect” (CONACYT 2001, p. 203). The need to develop a National Nanotechnology Program is also noted “National Program of the area on Advanced Materials. ... Another important element in promoting the theme is the recent creation of the National Nanotechnology Program, which seeks to combine the efforts of various national institutions working on the issue” [It was never created] (CONACYT 2001, 192).

Plan	Mention of nanotechnology
	And a network of researchers, “It is noteworthy that CONACYT is creating a network of Nanosciences, considering the attention to specific demands of businesses” (CONACYT 2001, 192).
Special Program of Science, Technology and Innovation 2008-2012	The 2008-2012 Program only refers to the priority of nanotechnologies “Other relevant issues of strong dynamics and focus are biotechnology, nanotechnology and materials” (CONACYT 2008b).
Special Program of Science, Technology and Innovation 2014-2018	The 2014-2018 program repeats the priority of nanotechnologies “Transversely, through existing instruments, special attention will be given to the following topics: Automation and Robotics, Biotechnology Development, Development of genomics, development of advanced materials, development of nanomaterials and nanotechnology, computer connectivity and development of information technology, communications and telecommunications, engineering to increase the value-added in industries, high-tech Manufacturing” (CONACYT 2014, 51).

Source: authors’ analysis

It can be seen that except for the enunciation of nanotechnology as a priority development area, there are no details in the 18 years covered by the plans, and that no entity developed any activity to implement concrete policies.

2. The second area of interest in the OECD survey has to do with social participation in S&T policies. Since the nineties, social participation has become a requirement of international institutions and some of the instruments to safeguard some degree of public participation. Absent a democratic approach, the adoption of new technologies could be jeopardized, as has been the case with such technologies as genetically modified organisms or nuclear energy.

Many of the surveyed countries have mechanisms to incorporate the participation of diverse social sectors. In the course of the first decade of this century dozens of forums, seminars, and multilateral working groups have been conducted in OECD countries (Observatory Nano 2015). These have allowed consumer groups, nongovernmental organizations (NGOs), and the general public to better understand nanotechnology through direct participation.[14]

The OECD has developed a guide for incorporating public participation in nanotechnology policy (OECD 2012a); many international agencies and institutions incorporate NGO representatives, trade unions and other figures of civil society in their working groups.

Mexico has not undertaken any public approach to the subject of nanotechnology, even though it does have an institutionalized mechanism to encourage public participation on virtually any S&T topic. Under guidance from the OECD, starting in 2002, it created the Consultative Forum on S&T, "an organ of expression and communication for users of the science, technology and innovation system, in order to promote dialogue with legislators and federal and state authorities strengthening collaborative bonds between the various actors" (FCCYT 2015a). But the Forum excludes organized civil sectors, since its Board is comprised of 21 representatives from research, technology and business (FCCYT 2015a, b). Furthermore, participation, according to the law that created the Consultative Forum, excludes organized sectors that are not directly involved in scientific inquiry:

> It will be composed of scientists, technologists, entrepreneurs and representatives of organizations and institutions of national, regional or local, public and private character, known for their permanent tasks in scientific research, technological development and innovation (Congreso de la Unión 2014: 22).

While individual citizens are invited to participate in a nationwide referendum on S&T that was launched in 2012, thus far nanotechnology has not been one of the topics put forth for discussion; moreover, NGOs and unions (as organizations) do not participate in this discussion.[15]

3. The third topic of interest in the OECD survey concerns the relationship between the private and public sectors, which differs widely between the countries surveyed. There are working groups for corporate engagement in the United Kingdom (The United Kingdom Nanotechnology Stakeholders Forum); industry-led activities, such as the initiative for the creation of nanotech businesses in Japan; technological forecasting activities and activities of technological assessment in Denmark, Finland (FinNano) and Ireland (NanoIreland); steering committees and advisory councils to address financing programs or strategies for the governance of nanotechnology in France, Germany, Russia and South Africa; links with innovation agencies and research centers in Hungary, Israel and Switzerland; workshops and forums in Australia, Austria, Canada, Czech

Republic, Finland, Germany, Portugal and the United States; and surveys and interviews in Korea (WPN 2009).

Nothing similar exists in Mexico regarding nanotechnology. The general approach has been to encourage businesses to engage with government and academia in S&T decisions, while subjecting R&D to business demands. This process shifts S&T orientation from a science push model, as had been common until perhaps the middle of the first decade of this century, to one of market pull,[16] which was clearly established by 2008 and has deepened ever since. The Science and Technology Act of 2002, corrected in subsequent years (most recently in 2014), facilitates the creation of spin-off companies from Public Research Centers (Congreso de la Unión 2014 Cap IX, Art. 55, VI).[17]

4. The fourth topic of interest in the OECD survey deals with the role given by public policies to ethical, legal and social issues (ELSI), especially with the health and environmental risks of nanotechnology. Most of the countries surveyed allocate part of their national budgets to research on exposure and the risks of nanomaterials. In Denmark, for example, the Danish Environmental Protection Agency is charged with developing nanotechnology policies that involve the public sector. In Portugal, a program concerned with "Environmental Monitoring and Food Quality and Safety" is undertaken as a routine part of nanotechnology R&D (IINL 2015). Finland's Environmental Administration, Ireland's Environmental Protection Agency, and the Netherlands National Institute for Public Health and Environmental Protection are important parts of the development and implementation of those countries' nanotechnology policies (WPN 2009).

In Mexico, none of the documents from CONACYT, which is the institution responsible for S&T policy, include anything about the exposure and risk of manufactured nanoparticles. However, both Mexico's participation in NAFTA and in the ISO committee have led to decisions on this subject, regardless of the absence of formal S&T policies, as will be discussed below.

5. The fifth topic of the OECD survey has to do with academic networks, collaboration agreements, and other forms of international nanotechnology ties. Again, this is one aspect with wide acceptance among the surveyed countries, and Mexico is no exception. CONACYT has specific nanotechnology cooperation agreements with Argentina (SRE CONACYT 2012), the European Union (CONACYT 2010), Brazil (CBM-Nano 2009), and the University of Manchester in the UK (CONACYT 2015a); there are cooperation agreements in place with other

countries that include nanotechnology as one of the subjects, such as with China (AMEXCID 2012), Japan and Singapore (SRE 2015a).[18]

6. The sixth topic of the OECD survey involves participation in international forums. There are several working groups in nanotechnology within international organizations, such as the World Health Organization or the SAICM (Strategic Approach for International Chemicals Management). Of these, Mexico has only participated in regional meetings of SAICM (Bejarano 2012; Foladori et al. 2013) and related meetings of the ICCM (International Conference on Chemicals Management (Foladori 2015). But judging by the results in regulatory matters to be discussed below, the recommendations of the SAICM and ICCM decisions have not been officially assumed in practice.

7. The seventh OECD theme includes questions about nanotechnology regulation. Mexico has been participating in the ISO nanotechnology committee, and has used the definitions of ISO to issue the Mexican standards. In 2007 the National Standardization Technical Committee on Nanotechnologies (CTNNN for its Spanish acronym) was created for the regulation of nanotechnology. This initiative is led by the Ministry of Economy's National Metrology Centre (CENAM), taking into account the recommendations of the OECD and ISO (Anzaldo 2014). In 2013, the CTNNN was constituted under the Federal Law on Metrology and Standardization and established its rules of operation, with powers to create Mexican standards for nanotechnology and actively participate in the work of the ISO TC 229 committee.

In October 2014 the Ministry of Economy, the Undersecretariat of Competitiveness and Regulation, and the General Standards Directorate issued declarations of validity for various standards for characterizing different nanomaterials.[19] These Mexican standards incorporate their ISO equivalents. It is known that these types of international institution standards, despite being voluntary, end up becoming the countries' laws. The World Trade Organization recognizes only the ISO international standards as valid, which makes these domestic standards quasi-legal (Bell and Marrapese 2011; Kica 2015).

Mexico's participation in NAFTA has led the negotiation with the United States as its main trading partner in nanotechnology. A High-Level Regulatory Council on Cooperation was created in 2010, which includes nanotechnologies as part of its work plan. As a result of work by a team appointed specifically for nanotechnology, and coordinated by the CENAM, the Ministry of Economy issued voluntary guidelines in December 2012, largely similar to the preliminary memorandum that the United States gave as a guideline (GTRN 2012; Anzaldo 2014; Foladori and Zayago-Lau 2014). This document, although voluntary, may go on to have significant weight in regulatory decisions by the Mexican government, particularly because it is a result of a negotiation agreement with the U.S. Department of Commerce, among other institutions of the U.S. government.

8. The eighth survey topic relates to the direct funding for nanotechnology. Many countries have contributed significant resources. In recent years, governments around the world have invested more than $10 billion annually on nanotechnology R&D (Cientifica 2011). The US has spent $22 billion since 2001, and has earmarked $1.5 billion for 2015 through its National Nanotechnology Initiative (National Nanotechnology Initiative 2015). China invested $1.3 billion (adjusted for purchasing power) for nanotechnology in 2011 (Cientifica 2011). The European Union, through the Programme Framework 7, has allocated some €896 million for 2007-2011, and nanotechnology also receives budgetary support through such areas as Information Technology and Communications and Energy and Biotechnology (European Commission 2013).

Mexico, meanwhile, has no record of specific expenditures in nanotechnology, although two specific instances of financing can be identified. The first is the creation of the National Network of Nanoscience and Nanotechnology in 2009, with a budget of approximately $700,000 for the duration of the project (five years), initially involving some 160 researchers. The second was the creation of two national nanotechnology laboratories in 2007 (CIMAV and IPICyT) worth approximately $1.8 million each (CONACYT 2008a). Many other resources directed specifically towards nanotechnology have been channeled through non-thematically specific S&T programs. Some authors suggest that between 2005 and 2010, Mexico allocated $60 million of public funds in nanotechnology (Takeuchi and Mora Ramos 2011).

Starting at the beginning of this century, Mexico has shifted most of its funding from basic R&D, to prioritize the participation of the private business sector, particularly that of large industry, through various specific funds directed towards applied research (Loyola-Díaz and Paredes-López 2009).[20] In addition, there have been several public funds for R&D aimed at partnerships between business and academia. There are funds for regional development, to support cluster and supply chains, small and medium industries, and large companies. There are also funds for intermediate agencies to support the linking of R&D and product marketing (Stezano 2009; Casalet 2012). Most programs of financial support for research are geared directly towards businesses or towards partnerships between academics and private businesses. But none of these research funds have been specifically directed towards nanotechnology. One may argue, however, that some nano programs and projects will benefit as long as they satisfy the requirements. The FCCyT (Foro Consultivo Científico y Tecnológico) published a catalog of programs that facilitate the linkage of R&D with the private sector. There are 40 programs that are part of the catalog. Although the FCCyT argues that any social or civil sector may participate, the reality is that 33 of them are aimed at the business sector and only eight to the social sector (FCCYT 2010: 17).

9. The ninth theme of the survey is on the classification of training programs for nanotechnology workers. OECD's documents sustain that, for example, Australia has educational and training programs in nanotechnology within the context of its "National Innovation System Review," Japan established the Super Executive Engineer Development Program for human resource training in nanotechnology, in addition to a summer school in the National Institute for Materials Science. Korea has nanotechnology programs for industrial work, as well as schools and colleges of advance technology for the training of engineers and skilled labor. Belgium launched a Masters of Nanoscience and Nanotechnology under the EU-Erasmus Mundus Programme. In Canada the Canadian Research Chairs implemented a winter course in nanotechnology. The Czech Republic, Denmark, Finland, France, Germany, Ireland, Israel, Norway, Portugal, Russia, Sweden, Switzerland, the United Kingdom and the United States have educational programs at the undergraduate and master's levels, courses and lectures on nanotechnology (WPN 2009).

Mexico has some 44 doctoral programs, 43 master's programs and 12 undergraduate programs in nanotechnology. The 87 graduate programs related to nanotechnology are distributed across 27 institutions. The graduate programs enroll 257 doctoral students and 216 masters-level students. However, the programs are designed via the individual initiative of the participating universities, not as part of a CONACYT program (CONACYT 2015b).[21]

Another important issue that has an impact on the manner in which nanotechnology is developed in Mexico is the mobility of the highly skilled scientific work force (basically turning brain drain into brain gain). To that matter, the OECD inquires about the inclusion of foreign experts. This topic is relevant to the OECD - and other international institutions – because as a result of globalization and the liberalization of the market, there is a growing competition internationally to attract a more competent (scientifically and technologically) skilled workforce. The OECD maintains that countries need to develop strategies if they hope to capture this workforce, regardless of nationality and where skilled workers may be located. Marmolejo (2009: 105) writes:

> One of the four scenarios for the future of higher education in the world, which the OECD has raised and that seems more feasible in developed countries, clearly points out that institutions of higher education will be competing globally to provide education and research using commercial parameters and, for them, they will aggressively be seeking to attract and retain academic talent wherever it can be found.

In the 1990s CONACYT developed a “Repatriation Program” that supported 1,321 Mexican academics and 934 foreign researchers between 1991 and 2002, some of whom are current nanotechnology researchers. More recently, a “Network of Talented Mexicans Abroad” was established in 2005. This program focuses on identifying relevant Mexican scientists working abroad, and especially those that besides academic activities have links with industry, in order to establish scientific and businesses relationships with national counterparts (SRE 2015b).

10. The tenth issue in the OECD survey has to do with government support for private enterprise, which in turn raises the question of the necessity for assessments of business-related needs. This is a difficult issue to address in any country, since most lack mandatory reporting of companies working with nanotechnology – the starting point for information-gathering.[22] There are also no studies of nanotechnology global value chains, so it is not known how the production of nanotechnology raw material is linked up with intermediate and end products, with manipulation and measurement instruments, and with production and marketing, all of which are key inputs that must be taken into account in any adequate study of business needs.[23] In Mexico there is no analysis of the evaluation of business needs in nanotechnology.

Another related issue is whether the orientation of S&T policy is directed to specific sectors or branches of the economy, as is the case, for example, with South Africa’s Nanotechnology Plan. Although in Mexico’s 2001-2006 Special Program of Science and Technology specific areas of development were identified, to the extent that there was no specific funding, monitoring, nor implementation of a national plan, there has not been any orientation that favors certain industries.

11. The last topic has to do with intellectual property. The World Intellectual Property Organization (WIPO) registered a total of 217 nanotechnology patents in Mexico between 1993 and 2014 where at least one of the inventors had a Mexican address (Robles-Belmont et al. 2015). On a previous estimate on patents registered by country, Mexico was second in nanotechnology patents (28 titles) in Latin America, after Brazil (89 titles), in the period 2000-2007. These two countries are followed by, in descending order and for Latin America, Argentina (12 patents), Chile (10 patents), Panama (9), Cuba (7), Puerto Rico and Uruguay (2 titles each), Honduras and Venezuela (with a patent each) (OEI 2009).

One element that might boost patenting is the modification of Mexico's Law on Science and Technology, which now allows researchers to take ownership of a substantial slice of licensing patents of public research centers. The law says:

> To promote the commercialization of the rights of intellectual and industrial property of the centers, government bodies will approve the guidelines that will allow granting academic staff who generated them up to 70% of the royalties generated (Congreso de la Unión 2014 Cap IX, Art 51).

In the near future we may be able to evaluate the outcomes and specific impacts. This, of course, will be a matter of further research.

Nanotechnologies on the Market

Another aspect of OECD's work on nanotechnology is the systematization of statistical information. For this purpose, the OECD began collecting surveys from companies working with nanotechnology to assess its market presence and issues related to investment and employment in the industry. In 2012 the OECD conducted a survey to determine the number of companies with nanotechnology R&D and production. The results are published in the "Nanotechnology Key Indicators" section of the OECD website. Mexico is in the eighth place of the survey, with 188 "nanotechnology companies," after Japan and Korea; the United States, Germany and France make up the top three countries in the survey (OECD 2014c). Data for Mexico was compiled from a survey conducted by the National Institute of Statistics and Geography (INEGI for its Spanish acronym). This survey was based on a sample of firms in the OECD database for the production sector, where the sample frame consist of companies with 20 or more employed persons, dedicated to industrial, commercial or services, for-profit or nonprofit (INEGI 2014).[24]

With regard to the number of companies that sell nanotechnology products, and compared to countries with a national strategy for nanotechnology, Mexico is just above South Africa, which has 10 nanotech companies. The rest of the countries are far ahead of Mexico. Korea, which is the closest, has more than twice as many companies as Mexico - 468. Of the countries that have no national strategy for nanotechnology, Mexico is a leader in number of companies, followed by Switzerland. Table 3 compares the situation in Mexico relative to other OECD countries in terms of the number of nanotechnology companies.

Table 3

Businesses with nanotechnology activity according to the OECD

Country	Nanotechnology business
United States	5,340
Germany	1,110
France	649
Brazil	522
Russia	486
Korea	468
Japan	197
México	188
Switzerland	141
Italy	136
Belgium	125
Irland	79
Norway	68
Czech Republic	64
Denmark	51
Poland	48

Country	Nanotechnology business
Canada	42
Portugal	31
Slovenia	15
South Africa	10
Slovakia	5

Source: Key Nanotechnology Indicators (OECD 2014c)

The OECD indicators also include the funding figures for nanotechnology R&D activities by these businesses. It is estimated that Mexico spent a total of $122.9 million dollars in 2011-2012 on these activities, which exceeds that of countries like Switzerland, Ireland and the Czech Republic among others (Fig. 2). If this estimate is correct, it would appear that in Mexico private R&D investment in nanotechnology far exceeds public investment, which as we noted above, could have been around $60 million between 2005 and 2010, and would also challenge the widespread notion that in Latin American countries, the private sector does not invest in R&D.

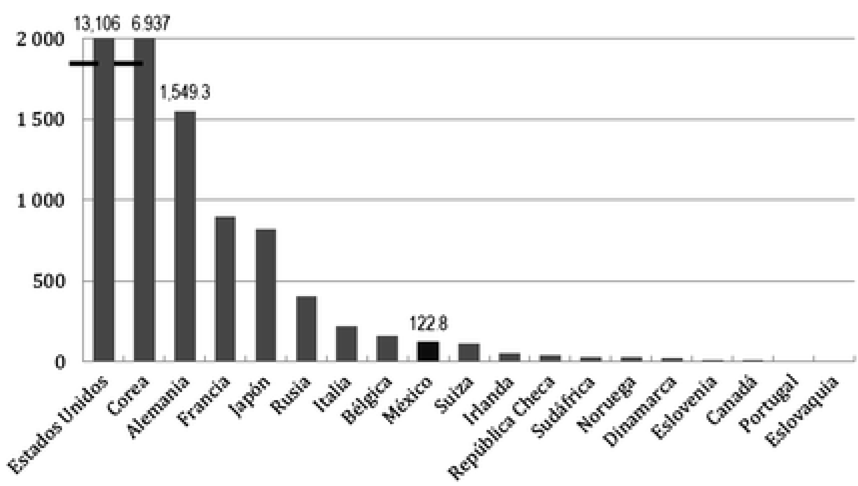

Fig. 2

Business Sector Expenditures on Nanotechnology R&D (millions of dollars). Sources: Key Nanotechnology Indicators (OECD 2014c)

If we consider that in Mexico the percentage of investment in S&T (0.4% of GDP) is far below that of many other countries, including most European countries and even South Africa, it turns out that the contributions made for nanotechnology in the Mexican case are not negligible, nor are the number of businesses in the industry.

Conclusions

In terms of specific nanotechnology-related public policies, Mexico has performed poorly, when compared with most of the 24 countries surveyed by the OECD. Despite having early on declared nanotechnologies as a priority area for development in its S&T plans, little was done in terms of implementation. Basically, a domestic R&D network was created, and two multi-user laboratories were launched. In terms of funding, Mexico also differs from most other countries surveyed, which have specific funding lines for nanotechnology. The various ways in which Mexico supports S&T remains unclear, and therefore is difficult to estimate. Mexico also lacks mechanisms for the promotion of R&D and the marketing of nanotechnology, despite the fact that its S&T policy privileges the business sector. As in half of the countries surveyed, Mexico has cooperation agreements in the field of nanotechnology with other countries. Yet at the same time Mexico actively participates in the ISO Technical Committee on nanotechnology, among the international organizations' working groups. One of the biggest gaps in the Mexican public policy on nanotechnology is the total absence of dealing with the issue of health and environmental risks, and the lack of mechanisms for public participation in the area, as is the case with most of the policies of the countries surveyed by the OECD.

Despite Mexico's small GDP percentage contribution to R&D (which has never exceeded 0.5%), and the absence of a nanotechnology development strategy, Mexico nonetheless ranks eighth among countries in terms of the number of nanotech companies. This places Mexico above several developed countries, as shown in Table 3. Mexico also has significant private sector funding, with an average of $650,000 for each of the 188 companies that we have identified. There is an asymmetry between the public support of nanotechnology, which has declined, and the significant nanotechnology business development. Such asymmetry may be the result of a market-driven environment (market pull); especially when most of the companies associated with nanotechnology in Mexico are transnational corporations (Záyago et al. 2012).

In regulatory terms Mexico walks the path of letting private standardization bodies regulate domestic law. In this sense the main influence comes from the commercial agreements arising from NAFTA and the country's participation in the ISO's Technical Committee, but it is also important that as a member of the OECD Mexico is under pressure to accept resolutions from the working groups of this institution, especially on nanomaterials.

Mexico's Science, Technology and Innovation lags that of other OECD countries. The ratio of R&D expenditures to GDP is one of the lowest among OECD countries, and most of the investment is performed by the public sector. Despite the macroeconomic stability over the past two decades in the country, the training of human resources for science and technology remains insufficient. Furthermore, the lack of opportunities to find an actual job discourages their additional development. This causes a vicious circle or a "technological trap" that affects the diffusion of knowledge and the innovative capacity within the economic sectors in which nanotechnology is applied. According to the OECD, the impacts of the changes in the S&T policy are positive but limited.

Footnotes

1

The questionnaire was sent by the WPN to the principal organizations involved in formulating and implementing STI policy related to nanotechnology (WPN 2009).

2

"The survey was designed to identify 15 different variables of the innovation process in production units of the country. Within those variables, nanotechnology was one of the topics in the survey" (INEGI 2014: 3).

3

"OECD economies are increasingly knowledge-based, with a shift of economic activity to services, and to high-tech and innovative activities … While manufacturing has declined in importance, its high-tech segment is very dynamic …" (OECD n/d, 3).

4

"Creating, exploiting and commercializing new technologies has become essential in the global race for competitiveness. High-technology or 'high-tech' sectors are key drivers of economic growth, productivity and social protection, and are generally a source of high value added and well-paid employment" (Eurostat 2014).

5

In the case of Mexico, the influence of maquiladora production and strong intra-firm trade between US companies demands a cautious analysis (Delgado Wise and Invernizzi 2002). The ESIDET survey, which will be discussed later, excludes export-oriented maquiladora businesses.

6

"... high-tech investment criterion is not an unequivocal measure of whether an industry should be classified as high tech" (Hecker 2005: 71).

7

Another difficulty relating high-tech industry with development is that the indicators include the entire military industry, which can hardly be identified with development, such as in the case of Israel and to a large extent that of the USA.

8

In 2012 R&D investment as a percentage of GDP was, for example, Israel 3.93; Finland 3.55; Germany 2.92; USA 2.79; France 2.26; Canada 1.73; UK 1.72 (World Bank 2012).

9

It is worth to note that the percentage of GDP is not the only way to measure R&D investment. There are other ways of sizing this, such as purchasing power parities (PPPs) & funding controlled for inflation. We are citing the most employed indicator as a way of comparison.

10

The budget in 2015 for CONACYT, which is the governing body in this field in Mexico, was 4.9% higher in real terms than that authorized the previous year (2014), according to the Ministry of Finance (SHCP 2013); but the fall in oil prices has led to a lowering of expectations and no increases are expected at this time.

11

Examples include economic policy, environment, development, public governance and territorial development, trade and agriculture, financial and business matters, tax policy and administration, science, technology and industry, employment and social issues, education, transportation and energy (OECD 2012b).

12

The surveyed countries were: Australia, Austria, Belgium, Canada, Denmark, United States, Finland, France, Holland, Hungary, Ireland, Israel, Japan, Norway, Poland, Portugal, United Kingdom, Czech Republic, Russia, South Africa, Sweden and Switzerland.

13

Bundesministerium für Bildung und Forschung (BMBF for its German acronym); and the next referenced acronyms in the text is for Brazil (PNN Programa Nacional de Nanotecnologia), under the Ministry of Science and Technology (MCT).

14

Some examples summarized by OECD include (WPN 2009): the Netherlands' risk observatory in 2007, Australia's Public Awareness and Engagement Programme, Belgium's festival in 2007, France's public debates, UK's citizens' juries and public dialogues.

15

"The Citizens Agenda for Science, Technology and Innovation is a nationwide consultation being done for the first time in Mexico, in which the population can choose between 10 challenges, which it considers must be faced with the participation of science and technology to achieve a better quality of life in the horizon of 2030" (FCCT 2015).

16

"Science push" means that science provides results that businesses should use, in contrast to the "market pull" model, which suggests that businesses determine what should be researched in order to meet their needs.

17

"VI. To authorize, in general, the program and criteria for the implementation of agreements and contracts for the provision of research services for specific research projects, technological development, innovation or technical services and to approve strategic partnerships and projects, agreements or contracts aimed at establishing technology-based businesses with or without input from the research center in its social capital" (Congreso de la Unión 2014 Cap IX, Art. 55, VI).

18

The agreements between universities are not considered in this section because they are private initiatives between the institutes and not related to national S&T policy.

19

The Mexican standards are: NMX-R-10867-SCFI-2014, NMX-R-10929-SCFI-2014, NMX-R-27687-SCFI-2014, NMX-R-80004-1-SCFI-2014, NMX-R-80004-3-SCFI-2014 (Ministry of the Interior 2014).

20

Between the 1990s and the second decade of this century, México has switched from a "science push" model towards one of "market pull."

21

Although these programs explicitly include the prefix "nano" in their title, further research is needed in order to distinguish the real emphasis of the programs and the ones that only fulfill publicity purposes.

22

Such records are just starting to be kept in France, Belgium, Denmark, and other countries.

23

See, for example, "California in the nano economy," carried out by Stacey Frederick, is an exception http://californiananoeconomy.org/.

24

The Biotechnology and Nanotechnology Module is from the Survey on Research and Technological Development and Activities (ESIDET for its Spanish acronym). "For the production sector, the sample frame consists of businesses with 20 or more employees, and for the higher education, nonprofit private and government sectors the sampling unit is the institution. The sampling frame for the productive sector consists of those businesses included in the 2009 Economic Census (CE 2009) without taking into account the maquiladora, higher education, government and non-profit sectors; also included are the businesses provided by the National Council on Science and Technology (CONACYT) and those which have been part of the same survey in at least 2 previous events occasions. It also includes the list of 703 businesses provided by CONACYT which have received some financial support for the realization of RTD (Research and

Technical Development)" (INEGI 2014: 7). It should be noted that export-oriented maquiladoras are not included in the INEGI survey. International recommendations issued by the Organization for Economic Cooperation and Development (OECD), expressed in the Frascati Manual, refer to four main areas of study: productive sector, government, higher education and private non-profit institutions (…) The productive sector includes businesses, organizations and institutions classified in mining, manufacturing, construction, electricity, services, transport and communications sectors, whose primary activity is the production of market goods and services (INEGI 2014: 3).

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