Women's participation in inventive activities in Mexico, 1980-2015: a study of the challenges they face

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Abstract

This article analyzes the challenges faced by women scientists in Mexico to participate in innovation activities during 1980-2015. Specifically, this article seeks to: *i)* describe the evolution and nature of inventive activity with female participation; *ii)* identify which factors influence the propensity of women to be inventors; and *iii)* contribute policy proposals to foster women's equitable inclusion in the knowledge and innovation economy. Findings from the empirical study suggest that the following factors promote women's propensity to become inventors: stock of technological knowledge, inventor team size, company or institutional patents, technological category, and presence of foreign inventors.

Keywords: Mexican women inventors; propensity to innovate factors; Mexican USPTO patents; knowledge economy.

1. INTRODUCTION

Currently, women make up half of the world's population. Despite this, gender inequality[1]1 is still present in economic and social arenas, and conditions are exacerbated by the poverty and underdevelopment that characterize developing countries (Jayachandran, 2015). However, even developed countries report gender gaps. Some studies have focused on analyzing gender inequality and economic growth (Cuberes and Teignier, 2014) and others on the division of labor within the home (Treas and Tai, 2016). Labor differentials associated with families and societal cultural patterns have also been studied (Bishy and Alkadry, 2017; Korpi *et al.,* 2013). A significant finding has been that education plays a positive role in overcoming gender disparities originating in traditional societies and cultures (Korpi *et al.,* 2013). Education is also found to have a positive impact on salary gaps (Livanos and Nunez, 2010). This shows that women achieving access to higher education, science and technology plays a crucial role in closing the gender gap, as indeed it does for all members of society.

Historically, women were thought of as the weaker sex and believed to have limited intellectual abilities when compared to men (see Schiebinger, 1991). Historians have widely ignored women's involvement in and contributions to scientific and technological developments, or indeed deliberately obfuscated them with male figureheads (Eynde, 1994). The impact of gender inequality throughout history has been to marginalize, limit and, occasionally, overlook women's creative potential. Male culture has been reluctant to recognize women's intellectual attributes (with some honorable exceptions).

Despite women being excluded from the development of science and technology (Schiebinger, 1991), they have made important contributions in these fields from antiquity onwards. For example, in the Middle Ages convents were considered a refuge by some women, places where they could continue their studies and develop their creativity. Universities were founded in the 13th century and women were still being excluded from formal education in the early 20th Century. Often, the contributions made by women were ignored, or appropriated by their fathers or husbands, but in some exceptional cases credit was given to the woman in question (see Eynde; Guil, 2016).

As women were admitted to study science-related subjects at universities during the 20th Century, their significant contributions to universal knowledge gained visibility (Martínez *et al.,* UNESCO, 2016). Marie Curie (a physicist and chemist) said that the "way of progress is neither swift nor easy" (Currie, 2001). As an established researcher she once said that a scientist believes in ideas, not people. Despite being constantly disparaged, Madame Curie's valuable contributions to radiology gained her two Nobel Prizes (1903 and 1911). The first was shared with her husband Pierre Curie and Henri Becquerel; the second was awarded to her alone. Rosalind Franklin, an English chemist, and x-ray crystallographer made significant contributions to understanding DNA's structure. The importance of her findings is known, despite her colleagues' (Watson and Crick) reticence to recognize them. Franklin believed that science and daily life could not, nor should not, be separated.

The battle fought by some women to overcome patriarchal barriers to contribute to scientific and technological discoveries has existed throughout history and continues to this day, as has their exclusion from these fields and education (Eynde, 1994; Khan, 2015).

In a knowledge economy, it is indispensable to include women extensively in formal education systems, science, and technology and consequently in labor markets and with higher salaries. Once differentials in access, generation, treatment, and control of areas of knowledge have been overcome, women will have greater opportunities to fulfill their intellectual potential (Milli *et al.,* 2016). This presupposes a collaborative working process between men and women, enriching knowledge, and the economic and social growth in countries, especially those with greater underdevelopment.

The Millennium Development Goals (MDG)[2] called for the elimination of disparities in primary and secondary education by 2005, and from all levels of education by 2015. Despite substantial improvements, gender inequality subsists globally, and has intensified in some areas. Due to this, the Sustainable Development Objectives (SDO) (UN, 2015) lay particular emphasis on gender equality, among other objectives, and aim to eradicate poverty, protect the planet, and ensure peace and prosperity by 2030.

Once gender parity is in place and women are empowered within the knowledge economy, they will have equal access to education and scientific knowledge. Within this context, international organizations such as the United Nations Educational, Scientific and Cultural Organization (United Nations Educational, Scientific and Cultural Organization, [UNESCO] 2016, promote gender equality in science, technology, and innovation among its members, implementing new programs, such as STEM and Gender Advancement (SAGA).

Gender disaggregated data on further education, scientific research activity, and innovation is currently available. Figures show that gender equality in first degree graduates in 2018 was higher than ever (53% women (47% men). Master's degree graduates also showed an increase in parity (55% women: 45% men). However, 56% of PHD graduates were men, as opposed to 44% women.

Disparities vary according to regions and countries. The largest gender gap can be seen in graduates gaining employment as researchers; men represent 71% versus women, 29%. The highest differentials of women working as researchers were found in countries and regions of the African subcontinent, East Asia, and the Pacific. However, when looking at employed researchers, countries in Central Asia and Latin America, have achieved gender equality (UNESCO, 2018).

Higher numbers of women studying science and technology at degree level and going on to work in these fields is seen as a potential source of economic growth, productivity, and well-being for society (The European Commission, 2008; Hunt *et al.,* 2012; Kahler, 2011; Huyer, 2015). On average, women account for 29% of all researchers in the world with the highest percentage recorded in Thailand, in 2015 (56.1%) (UNESCO, 2016).

Women inventors are therefore becoming increasingly relevant. However, literature on this subject is limited, particularly when focusing on factors influencing their choices. The research presented in this article contributes to the existing literature by examining the evolution, nature and factors that explain women's propensity to innovate in Mexico.

Equally, this paper sets out to give visibility to the challenges faced by female inventors when overcoming the inequality present in the knowledge economy and who will doubtlessly contribute to Mexico's economic growth. Specifically, the goals are these: *i)* to define the evolution and type of activity undertaken by women in the field of invention, *ii)* to identify factors that influence women to become inventors and *iii)* to contribute with policy proposals focused on increasing women's participation, thus reducing gender disparity in the knowledge economy.

The key questions in this research paper are: how have women evolved in the field of innovation and invention in Mexico? What factors of the nature of invention influence the propensity of women to invent? Based on empirical findings, what policy proposals can encourage growth in women's inventive activity?

The hypothesis used is that the low participation of women in inventive activities tends to increase gradually. Some of the variables of an inventive nature influencing a woman's tendency to be an inventor are the stock of technological knowledge: the research team's size, ownership of patents granted, the patent's technological field, the mobility of the inventors and the value of the patent.

This article has five sections, including the introduction. The second section presents specialized literature on the subject. The third outlines policies put into place to decrease gender disparity in education, science, and technology with regards to the MDG. The fourth section identifies the evolution and defines the nature of gender inventive activity in Mexico, using an empirical model. The results are analyzed, and policy proposals put forward. The fifth section is dedicated to conclusions.

2. A BRIEF REVIEW OF LITERATURE ON FEMALE INVENTORS

Several gender studies on inventive activity recount the social impact of inventions made by women throughout history, especially during the industrial age (Blashfield, 1996; Braun, 2007; Whittington and Smith-Doerr, 2008; Karnes and Bean, 1995). Others highlight female inventors in a variety of countries and regions, differentiating technological fields and sectors (Martínez *et al.,* 2016). Patented inventions that had female participation in areas relating to new technological paradigms such as Information and Communications Technology (ICT), were also analyzed (Ashcraft and Breitzman, 2007; Kahler, 2011). Studies have also focused on the enormous gender gap in inventive activity, patent ownership and their commercialization (Ejermo and Jung, 2014; Frietsch *et al.,*2009; Hunt *et al.,* 2012; Kahler, 2011; Whittington and Smith-Doerr, 2008). Many of these studies look at industrialized nations; very few studies focus on emerging and developing countries such as Mexico (Guzmán and Orozco, 2011) and Latin America (Morales and Sifontes, 2014). Another area of interest is identifying the technological sectors in which women participate, and the causes for low numbers of female inventors in Brazil (Maldonado and Guzmán, 2015; Sifontes and Morales, 2020).

Documents and patents show that women's participation in research and development, and invention is limited. The question remains, why haven't women participated actively in these sectors?

When looking at technology, women have contributed to innovations that have had a substantial impact on an industrial scale and on successful businesses. Some of these are- the mechanical dishwasher (Josephine Cochran, 1886); windscreen wipers (Mary Anderson, 1903); the telephone switching system (Erna Schneider, 1954); antibiotics and antifungals (Rachel Fuller-Brown and Elizabeth Lee Hazen, 1957); and petrol refining (Edith Flanigen, 1956). In 2006, the Global Women Inventors and Innovators Network, (GWIIN), began giving recognition and awards to Mexican female scientists and inventors.[3]

Female inventors form part of research teams that create patented products or processes. Despite not all inventions being patented, patent documents provide information that is classified, consistent and long-term, which permits inventors to be identified, even though their gender is not specified. Recent studies have concentrated on identifying female inventors' participation using the database belonging to the World Organization of Intellectual Property (WIPO), (Martínez *et al*., 2016).

Women's contribution to invention can be seen in the sphere of technological knowledge, with probable precedents of findings recorded in scientific publications. Effectively, this type of development can occur on the frontiers of basic science. This would mean that scientific contributions feed the emergence of new technology, without women necessarily participating in later phases of development. There is, therefore, a difference to be marked between female scientists and female inventors.

This article aims to contribute to the assessment of women's involvement in the thought economy, and inventive activities. Their participation, alongside that of men, strengthens innovation capabilities in Mexico and supports economic growth and social well-being.

3. IS THERE A MOVE TOWARDS GENDER EQUALITY IN EDUCATION, SCIENCE AND TECHNOLOGICAL KNOWLEDGE?

Despite advances in access to education, science, and technology for women in developing countries over past decades, the lag in comparison to countries with higher per capita income continues. Gender gaps are associated to other indicators such as health, labor, and salary, that contribute to creating inequality. Following this line of thought, could women who become part of the knowledge economy improve their standard of living compared to men's?

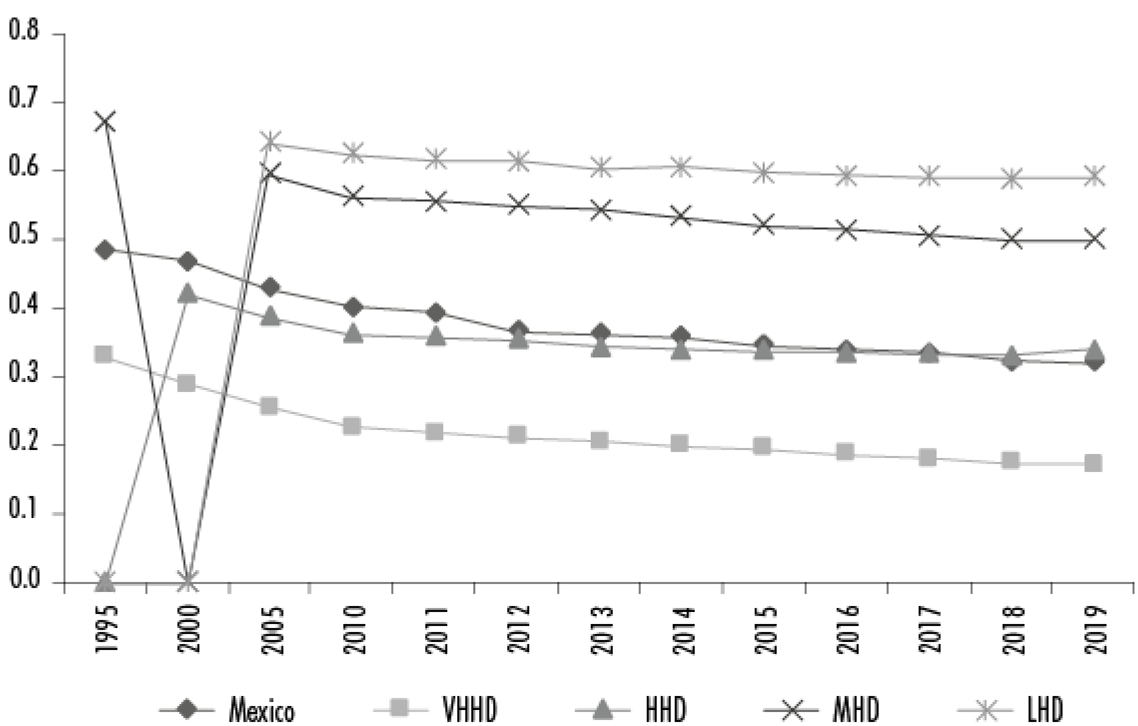
To overcome the gender inequality present in access to knowledge, disaggregated data is needed to evaluate the issue and put the necessary policies into practice. To this end, some national and international institutions collect relevant data. The United Nations Development Program (UNDP, 2020) calculates the Gender Inequality Index (GII), which includes 166 countries, divided into four groups. The first includes nations with very high human development (VHHD); the second, high human development (HHD); the third, medium human development (MHD), and the last, low human development (LHD).

This gender-based index highlights disadvantages in three areas: *i)* reproductive health, *ii)* empowerment and *iii)* the labor market. The index oscillates between 0 and 1, with 1 showing greater inequality between men and women, and 0 reflecting equality.

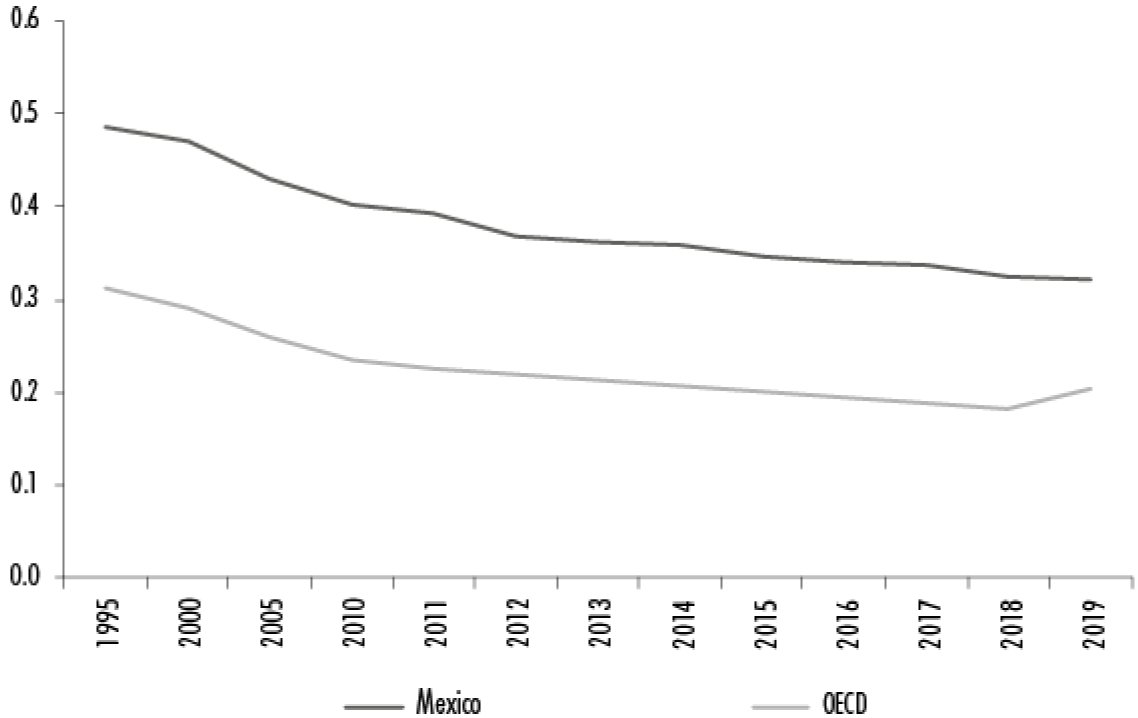
According to UNDP,[4] the GII in Mexico went from 0.469 in 2000, when the GII was first implemented, to 0.332 in 2019, showing that gender inequality is clearly ongoing (see figures 1a and 1b). The Social Development Objectives (SDO) (2015) advocate for gender equality to contribute to peaceful, prosperous, and sustainable societies. On comparison with other groups of countries classified by development, one can see the tendency of HHD nations to converge with the GII. However, there is still a gap between LHD and VHHD (see figure 1a). Countries that are members of The Organization for Economic Co-operation and Development (OECD) have VHHD, including Mexico that logs above average inequality (see figure 1b).

Figure 1. Mexico's Gender Inequality Index

a) As compared to countries grouped by their development level.



b) In comparison to OECD countries*

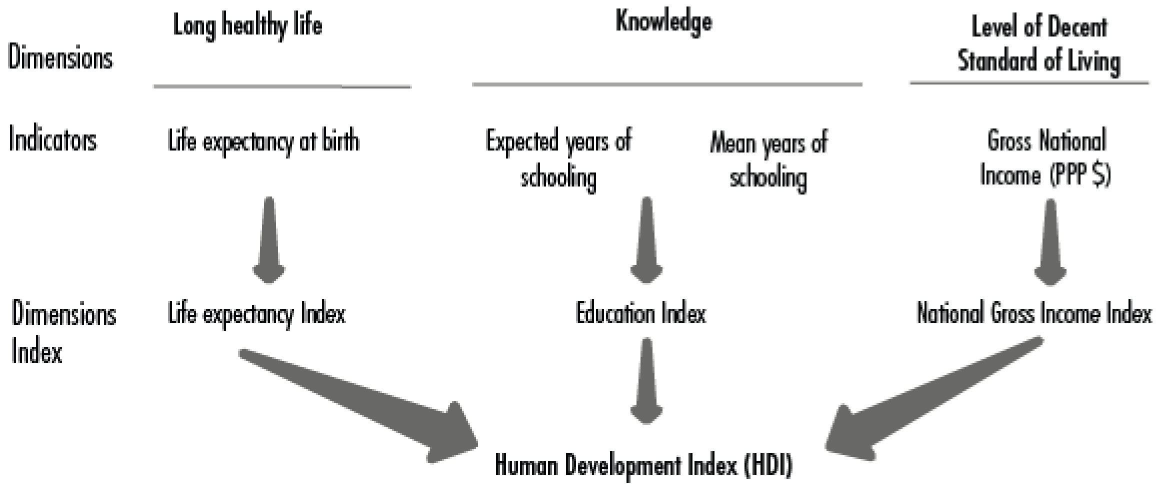


*Note: *closer to 1=greater inequality; closer to 0= less inequality.*
Source: UNDP 2020. Human Development Report, 2019.
http://hdr.undp.org/en/indicators/68606United

The GII is significant as it identifies the gap in human development between men and women, which makes it a useful tool for developing policies to reduce the gender gap.

The Human Development Index (HDI) is comprised of three categories: *i)* long and healthy life; *ii)* being knowledgeable and *iii)* and having a decent standard of living. The first consists of life expectancy at birth and the index of life expectation. The education index is calculated with expected years of schooling, and average of school years attended. The third is calculated using gross national income per capita at purchasing power parity, creating the Gross National Income Index (see figure 2).

Figure 2. Human Development Index (HDI)



Source: UNDP 2020. Human Development Report, 2019. http://hdr.undp.org/en/indicators/68606

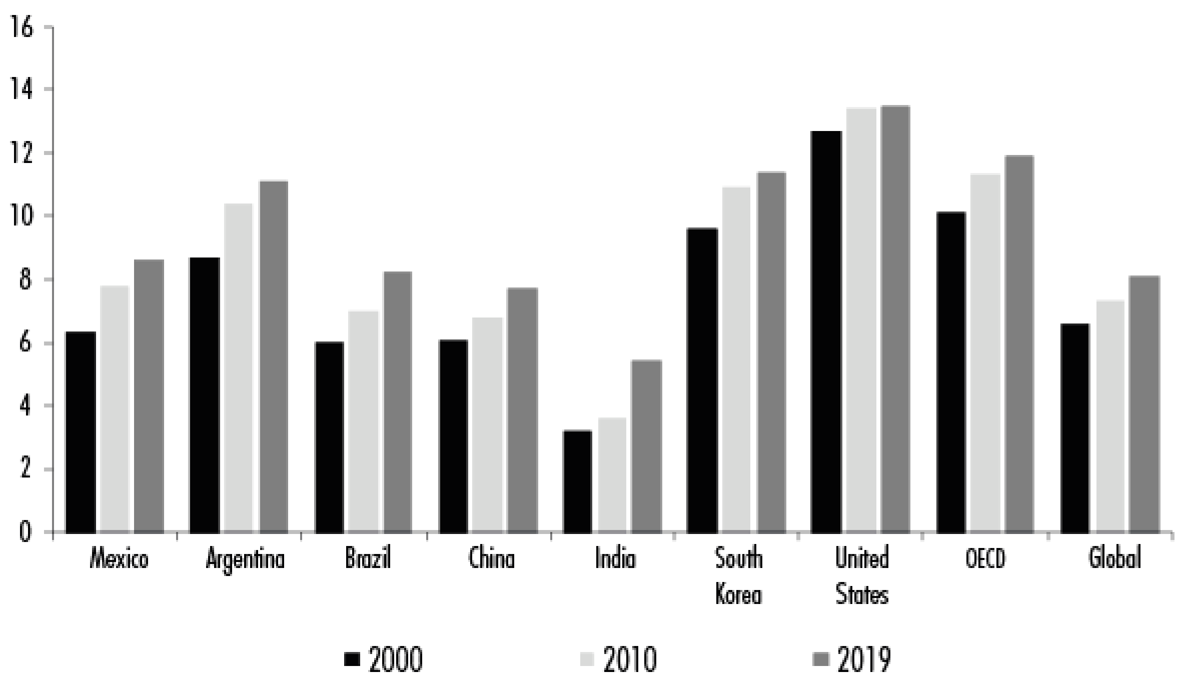
In Mexico, female life expectancy is higher than that of males, at birth. In 1990, life expectancy was estimated to be 73.8 years for women and 68 for men. By 2000, the indicator increased to 77 for women and 76.3 years of age for men. Nineteen years later there was only minimal improvement:77.9 years for women and 77.7 for men. On comparing Mexico's gender indicator of 77.9 years with the average of 82.9 years for OECD member countries, one can see a significant difference. The OECD showed an increase of two years and nine months in life expectancy for women (UNESCO, 2020), whilst women in Mexico only achieved a nine-month increase.

When looking at the education dimension, two indicators comprise the gender parity education index *i)* expected years of schooling (EYS) and *ii)* mean years of schooling (MYS). The first refers to the number of school years expected to be completed from the moment a child starts school, if enrollment patterns continue throughout their life. The second is the number of years of education completed by the population, until the age of 25 or more, taking consecutive years of each level into account. It is predicted that in all countries the EYS will be higher and tend towards gender parity.

There are many reasons why children, young people, and adults of both sexes, see their studies cut short, particularly in countries that have lower economic and social development. Thus, the MYE reports the actual level of schooling reached by the population. Consequently, they report the skill-related differentials for countries, including those that are vocational and technical. These are indispensable for obtaining employment, decent jobs, and for the entrepreneurial spirit of the population.

Mexican female students achieved a substantial advance in the mean years of schooling, increasing from 6.3 years to 8.6 from the year 2000 to 2019. This is very close to male students MYS (8.9) but far from expected completed years (15). Comparing the mean years of schooling of male and female Mexican students with other nations, one can see that the gender inequality gap has not been overcome, although women have a greater educational lag in India, Brazil, and China. However, Mexico's EYS HAS a lag in comparison to OECD member countries (Argentina, South Korea, and United States) where women have more than 11 years of schooling (see figure 3).

Figure 3. Average school years completed the female population in Mexico, as compared to selected countries 2000-2019

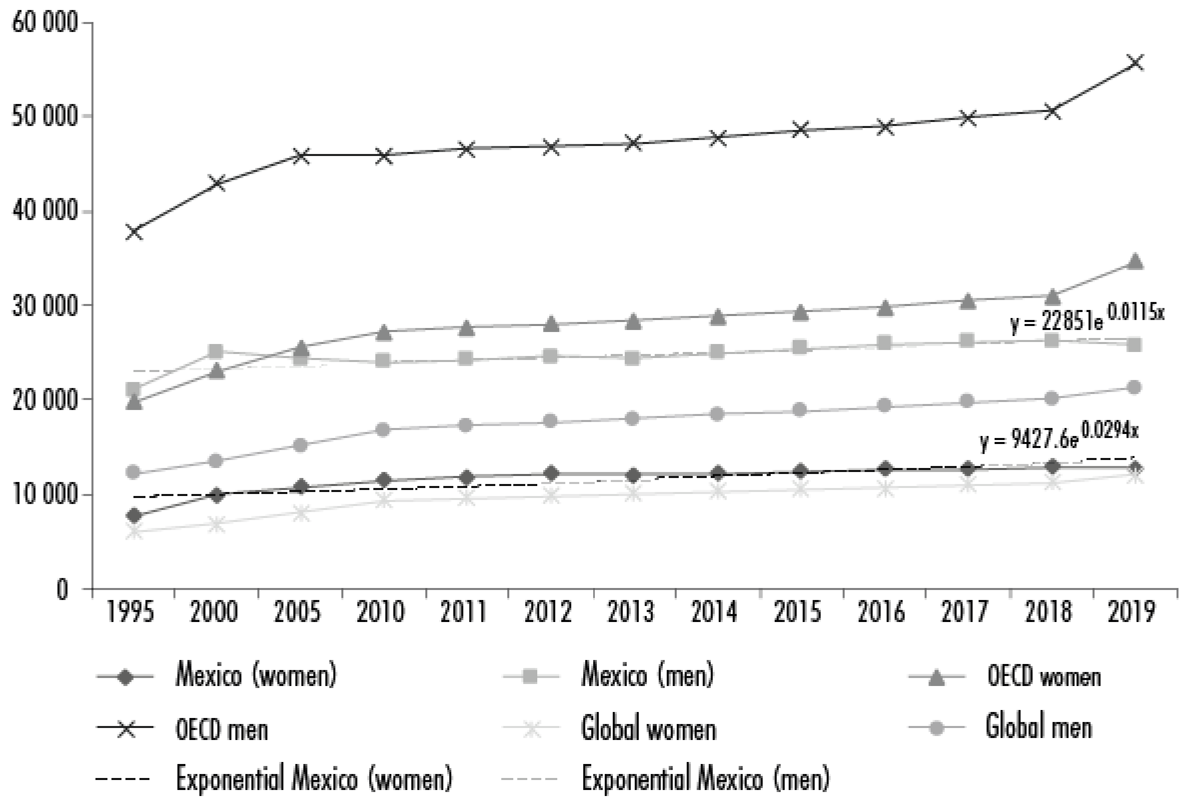


Source: UNDP 2020. Human Development Report, 2019. http://hdr.undp.org/en/indicators/68606

Lastly, the dimension of the level of a decent standard of living takes the gross national income per capita, by gender. This indicator shows the huge gender inequities with regards to income both comparing countries and within a country. Mexican women's income was estimated to be almost two fifths of that of their male counterparts in 2000 and reached almost half in 2019. It is important to note that men's salaries increased by a meagre 0.16% of average yearly growth, compared to 1.29% for women.

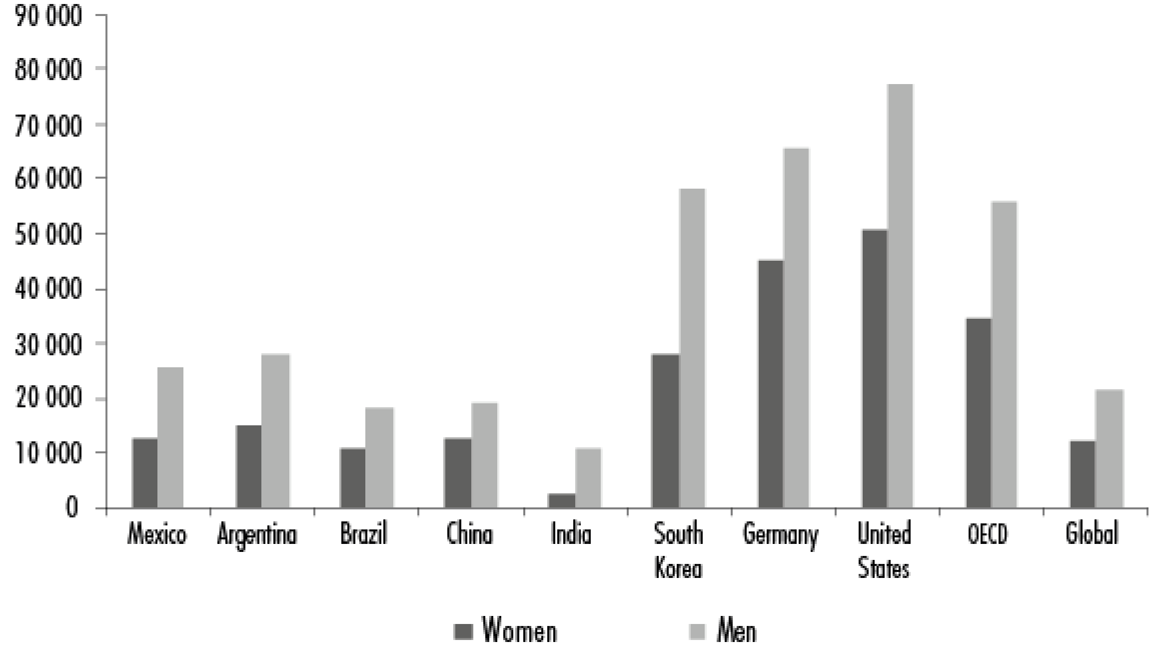
Likewise, the average income for women in OECD countries was 52.3% of that of men in 2000 and increased to 62.1% in 2019. This means an average annual increase of 3.0%., which is higher than men's, of 2.6%. The global growth pattern of salaries was also higher than Mexico's (3.65% for women and 3% for men) (See figures 4a and 4b)

Figure 4a. The evolution of the gender gap of gross national income per capita, 1995-2019 (Dls PPP for 2017)



Source UNDP 2020. Human Development Report, 2019.
http://hdr.undp.org/en/indicators/68606

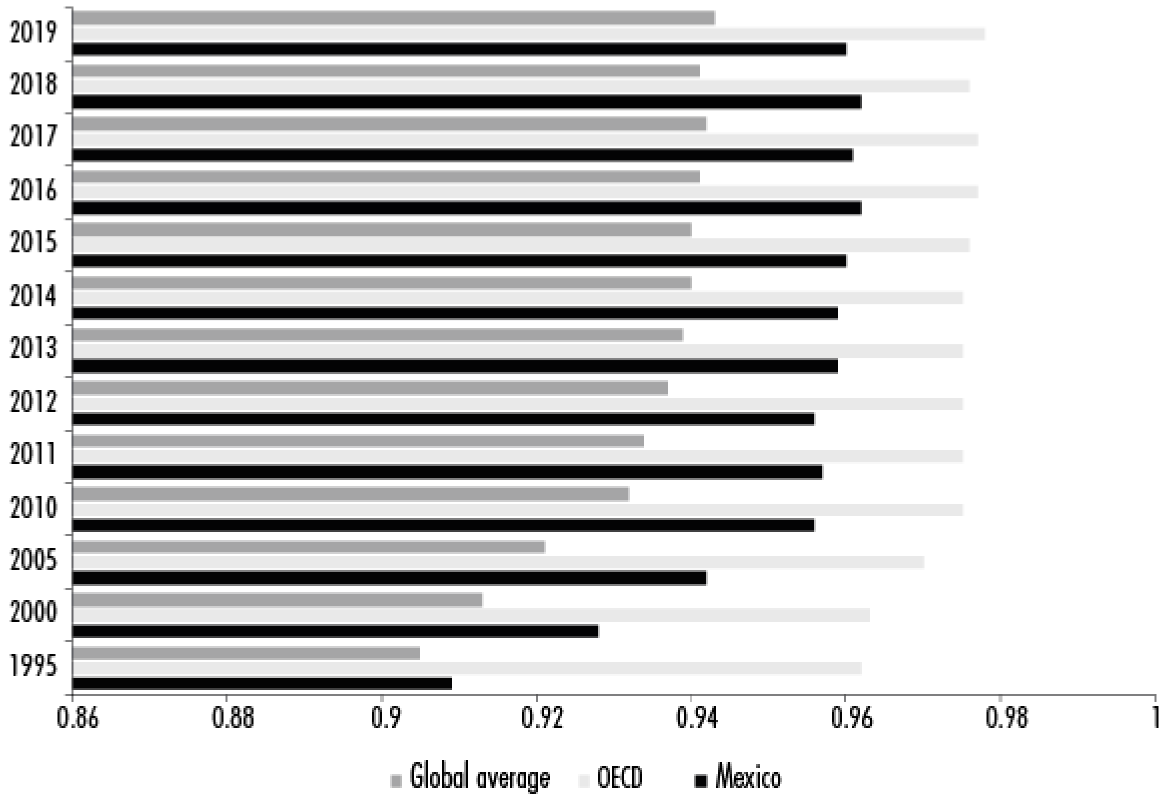
Figure 4b. Gender Differential of Gross National Income per capita by country, 2019 (Dls PPP of 2017)



Source UNDP 2020. Human Development Report, 2019.
http://hdr.undp.org/en/indicators/68606

The Mexican GII, which only includes women, is higher than that of the aggregate global total, not including Mexico and only including women). As LHD and MHD countries are numerous and gender disparities are higher, the global GII level is lower. However, Mexico is below the OECD average. It went from having a GII of 0.928 in 2000 to 0.960 in 2019 (see figure 5).

Figure 5. Gender Development Index: Mexico compared to the OECD and the global average



Source: UNDP 2020. Human Development Report, 2019. http://hdr.undp.org/en/indicators/68606

Overall, one can see that although gender inequality with regards to life expectancy, years attending school and income has decreased in Mexico, it has not happened at the speed seen in other OECD and emerging countries. The following is an analysis of women's access to higher education and scientific disciplines, leading to an increased understanding of their participation in the field of innovation.

Specialization in gender human capital. What scientific disciplines are women choosing in higher education?

Considering the gender inequalities present in the knowledge economy expressed by *i)* the integration of women in tertiary education (bachelor's degree, masters, and doctorate) and *ii)* the scientific fields of science and technology in engineering and math (STEM) that lead to graduation and probable participation in research, with the potential of contributing to new ideas in science and technology, changes are analyzed based on the commitments acquired under the MDG and SDO.

The gender gap among graduates by scientific field has different dimensions; it is greater in engineering, manufacturing, and construction sciences as well as in technological engineering and mathematics. The lag in women being included in these scientific fields did not improve in 2017. In contrast, a higher percentage of male postgraduates was observed in information technology and communication sciences, agriculture, forestry, fishing, and veterinary sciences (see table 1).

Table 1. Mexico: Number of tertiary education graduates by program of scientific field, 2014-2017 (%)

Years	*Programs*	*Female*	*Male*
2014	Agriculture, forestry, fishing, and veterinary studies	36.3	63.7
2017		36.8	63.2
2014	Science, technology, engineering, and mathematics	31.2	68.8
2017		30.6	69.4
2014	Engineering, manufacturing, and construction	27.9	72.1
2017		28.5	71.5
2014	Natural sciences, mathematics, and statistics	52.6	47.4
2017		51.1	48.9
2014	Health and well-being	66.3	33.7
2017		68.2	31.8
2014	Information and communication technology	58.4	41.6
2017		58.0	42.0
2014	Arts and humanities	58.4	41.6
2017		58.0	42.0
2014	Business, administration, and law	56.2	43.8
2017		55.1	44.9
2014	Social science, journalism, and information	68.9	31.1
2017		70.4	29.6
2014	Education	66.3	33.7
2017		68.2	31.8
2014	Services	28.7	71.3
2017		50.0	50.0

Source: UNESCO, 2018.

When looking at women's tertiary education and their gradual inclusion into scientific disciplines- unattainable in the past- it is helpful to look at their inclusion in research activities. In an environment of adequate knowledge governance, the joint effort that entrepreneurs, public and private institutions put into Research and Development (R+D), would increase the dynamic roads to innovation by including women.

Over 40% of women comprise the research community in nine of eleven countries, and the number increases to 50% in the European Union. There was a substantial improvement in their numbers in Life and Health Sciences between 1996-2000 and 2011to 2015, but there is still meagre participation of women in physics, as shown by the Elsevier Research Intelligence (2017).[5]

With regards to Mexico, the proportion of women participating in research improved in 2011-2015 in comparison to 1996-2000 (see table 2). Overall, the number of male researchers had a higher increase (39 thousand more) than female researchers (26.3 thousand) which meant that women went from holding 8.1 thousand research posts to 34.4 thousand. However, compared to other countries this is a marginal improvement due to stagnant expenditure in R+D with respect to Gross Domestic Product (GDP) (0.4% on average).[6]

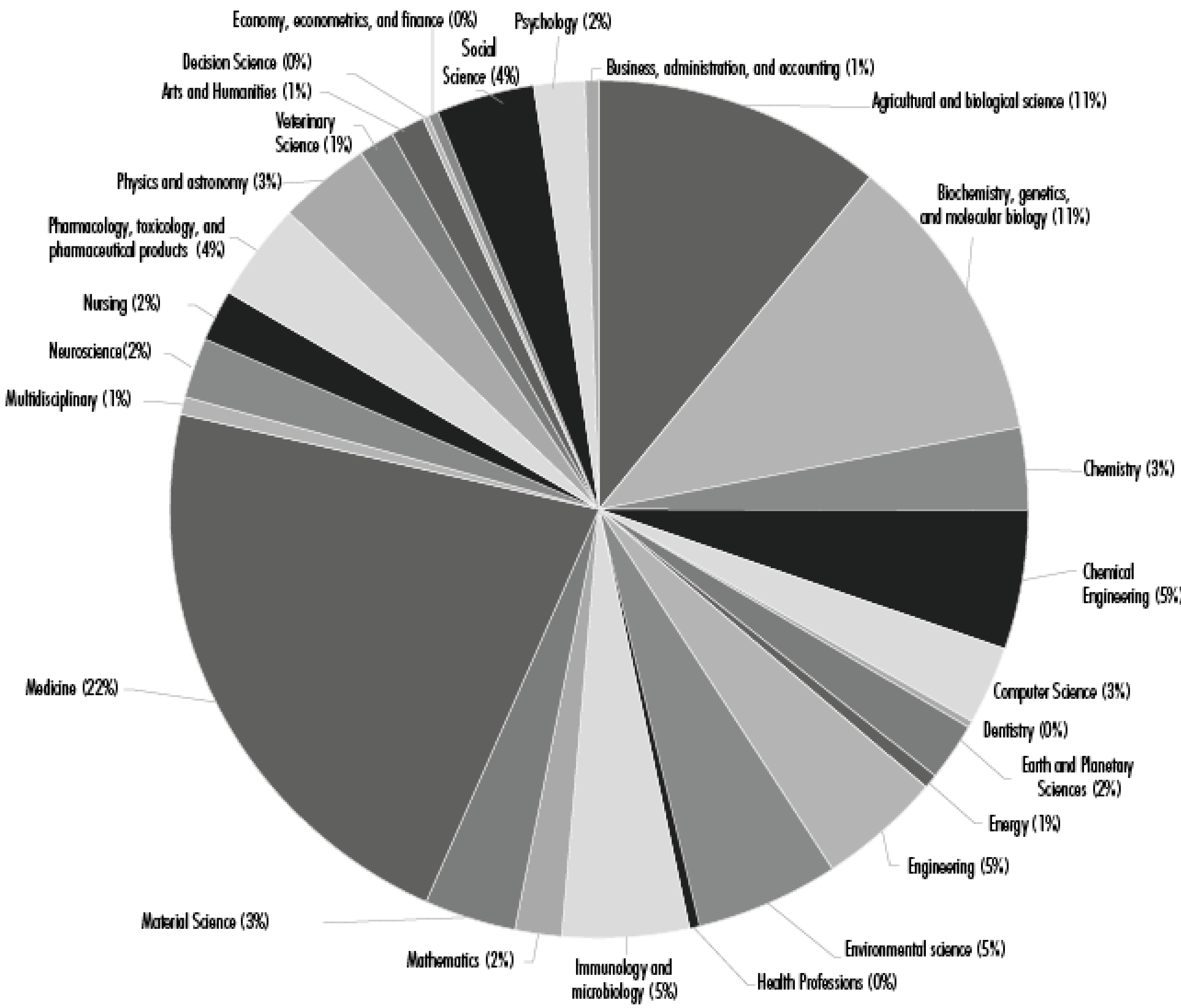
Table 2. The number of Mexican researchers by gender and scientific field 1996-2000 compared to 2011-2015 (Mexico)

Scientific field	*Period*	*Female*	*Male*
Agricultural and biological sciences	1996-2000	1 652	3 014
	2011-2015	8 578	13 067
Arts and Humanities	1996-2000	50	70
	2011-2015	1 010	1 406
Biochemistry, genetics, and molecular biology	1996-2000	1 877	2 287
	2011-2015	8 690	11 305
Business, administration, and accounting	1996-2000	15	60
	2011-2015	413	869
Chemistry	1996-2000	328	962
	2011-2015	2 451	4 454
Chemical Engineering	1996-2000	821	1 497
	2011-2015	4 111	6 690
Computer Science	1996-2000	146	800
	2011-2015	2 333	7 833
Decision Science	1996-2000	10	78
	2011-2015	168	557
Dentistry	1996-2000	34	76
	2011-2015	199	272
Earth and Planet Sciences	1996-2000	4 468	8 763
	2011-2015	1 722	3 902
Economy, econometrics, and finance	1996-2000	36	119
	2011-2015	306	771
Energy	1996-2000	145	1 037
	2011-2015	423	2 453
Engineering	1996-2001	423	2 453
	2011-2015	3 638	11 806

Scientific field	*Period*	*Female*	*Male*

Looking at researchers by scientific field, one can see greater diversification and integration of women in traditionally male fields between 2011 and 2015 (see figure 6) with 22% of researchers working in medicine. Other important areas are agricultural, biological, and biochemical sciences (11%), genetic biology and molecular biology (11%) and to a lesser degree immunology and microbiology (5%). Overall, women account for 8% of researchers in chemistry and chemical engineering, whilst the other fields have a marginal percentage. It is important that female researchers are scientifically diverse, given the current trends of cognitive convergence of scientific fields to study the complexity of the various phenomena facing humanity.

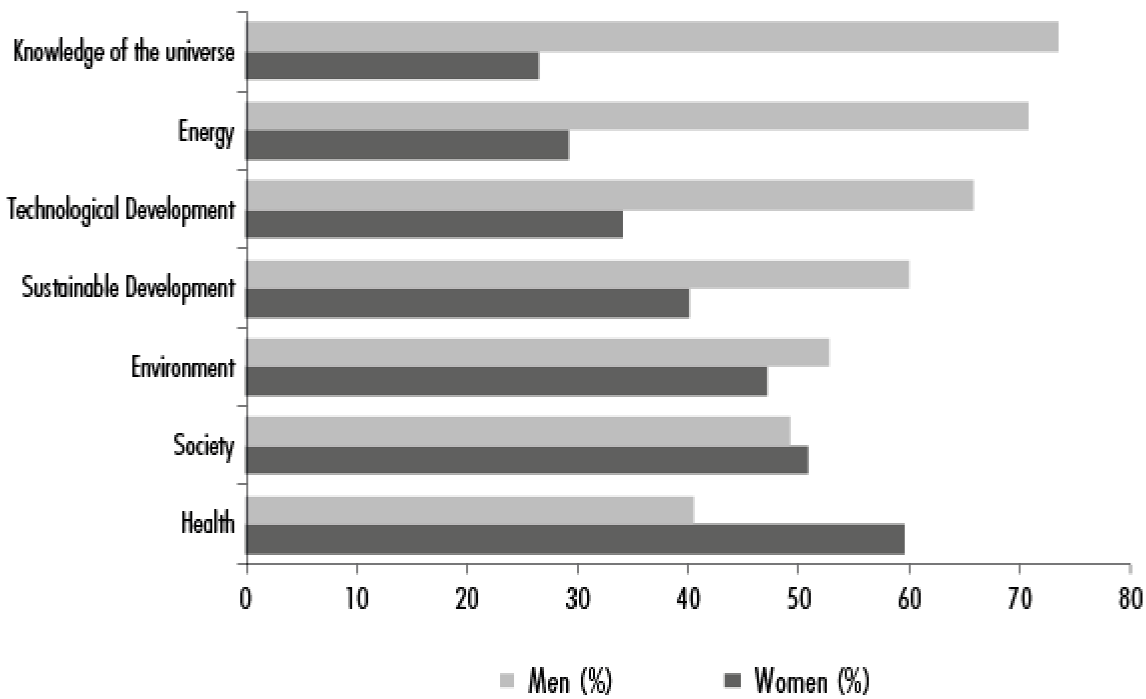
Figure 6. Distribution of female Mexican researchers in different scientific fields, 2017%



Source: *based on table 2*

The participation differentials of women in science disciplines can be seen in the research projects financed by the National Council for Science and Technology (CONACYT). Between 2014 and 2017, the differentials were higher in projects relating to knowledge of the universe, energy, technological development, and sustainable development. However, women had a higher participation percentage in health. Environment and society showed a tendency to be at parity.

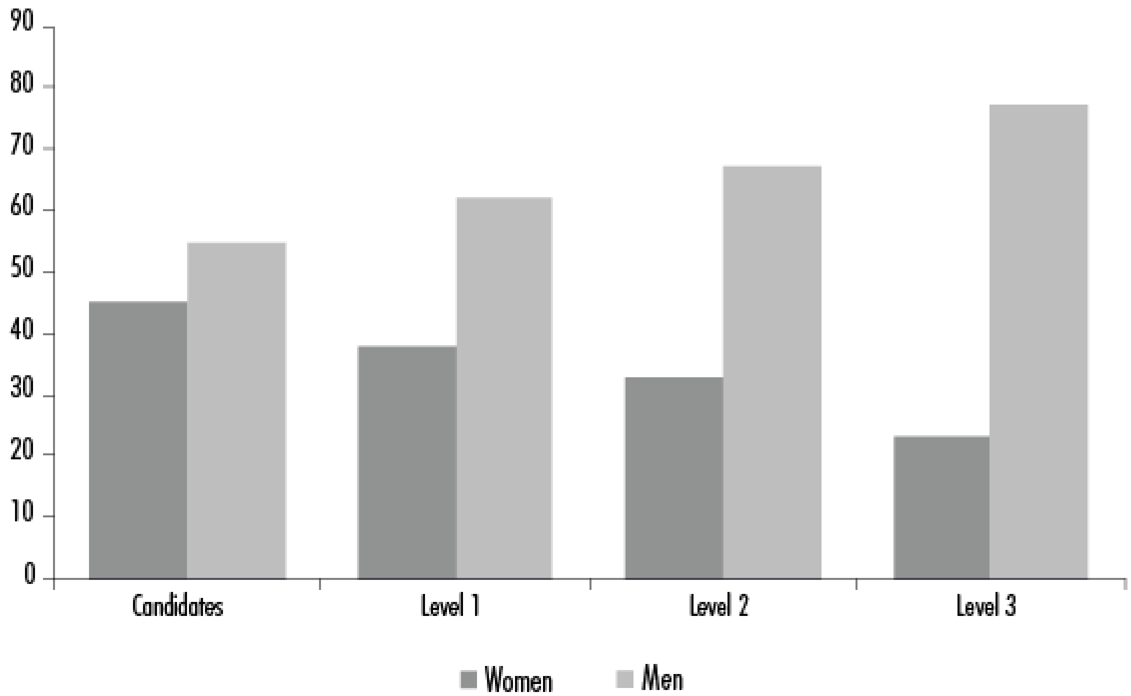
Figure 7. Participation of men and women in scientific research projects 2014-2017 (%)



Source: National Women's Institute (INMUJERES) (2018), based on CONACYT.

Using statistics from the National System of Researchers (SNI) under CONACYT (2020), one can see significant gender gaps at each level. This is most evident in level 3, with 23% of female researchers to 77% male researchers. Progress for women at this level is still marginal compared to 2015 (21.2%), and this is true of all levels. Younger generations at candidate level tend to lessen the differential (see figure 8).

Figure 8. Number of female and male researchers from the SNI register, CONACYT, 2020 (%)



Source: basic statistics from CONACYT, 2020.

These stylized facts reveal the significant policy challenges faced in overcoming gender inequality in the Mexican thought economy. This highlights the importance of studying which factors contribute to women developing their potential in innovation.

4. FACTORS THAT AFFECT WOMEN'S PROPENSITY TO INVENT

This section looks at the evolution and nature of women's inventive activity and proposes a model to test the hypothesis of the factors that affect their inventive tendencies.

The data comes from 1193 patents granted by the United States Patent and Trademark Office (USPTO) to Mexican title holders from 1980 to 2015. We chose to use this database as it granted access to all the information on the patent document and thus to the creation of a microeconometric model. Only patents that had at least one female inventor were selected from the total, which was 218 patents, or 18.27% of the total. The information taken from each patent allowed us to create the variables that influence the propensity for innovation.

The evolution and nature of the Mexican women's patented inventions

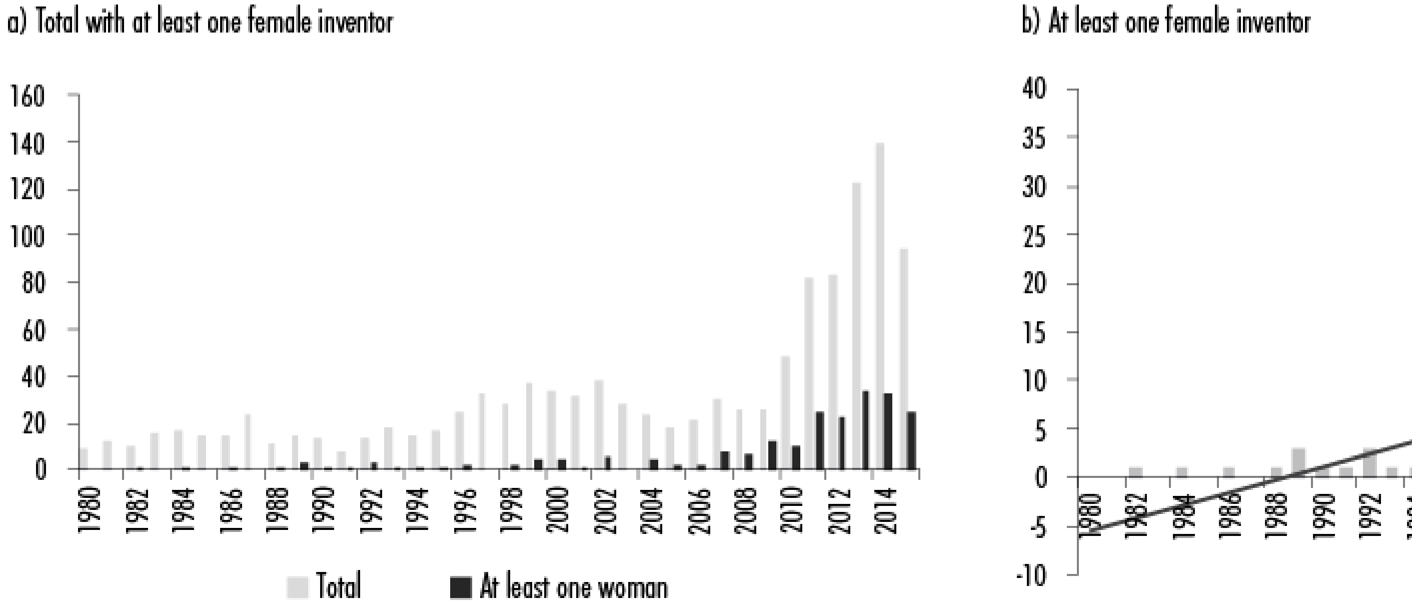
Women's inventions were practically inexistent in the 1980s and 1990s. It is not until 2007 that the number of patents began to increase, because of there being at least one female member on research teams. Of the 542 patents granted from 1980 to 2006, only 42 included female researchers. However, the inventive activity of 108 women was registered in 176 of 651 patents, from 2007 to 2015 (see figure 9).

Despite an increase of female participation in the development of new products and processes, gender inequality in Mexico persists in activities related to innovation.

A characteristic of the 108 women who contributed to Mexican-owned new technology that received patents from USPTO, was that they were inventors listed on three or more patents. The American inventor, Mary Therese Jernigan is notable; she registered inventive activity on eight patents belonging to Petromex. S.A de C.V in San Pedro Garcia, Nuevo Leon and can be considered a prolific inventor in the field of chemistry. Another three women inventors are noted on six patents, in medications and other medical products, chemistry and others (agriculture, food, leisure articles, clothes, textiles and household furniture). The presence of foreign female researchers is associated with innovative leadership.

44% of patents that have a female inventor presence belong to businesses, 54% to institutes-universities, 2% to individuals and co-ownership is minimal. The businesses that own the highest number of patents with female participation can be found in a variety of categories. The highest is the category 'others' which includes food and beverage companies such as *Sabritas,* and *Tequila Don Julio*. In mechanics and chemistry, the *Petromex* group, *Hylsa* and *Dynasol Elastómeros* are listed. Institutions and universities include the Mexican Petroleum Institute, the National Autonomous University of Mexico (UNAM), the Autonomous Metropolitan University (UAM), and The Center for Research and Advanced Studies of the National Polytechnic Institute, CINVESTAV (see table 4).

Figure 9. Mexico: the total number of patents granted with at least one female inventor, 1980-2015



Source: USPTO DATABASE, 1980-2015

Table 3. Female Inventors with the greatest participation in patents granted to Mexico by USPTO from 1980-2015

Female Inventor	*Number of patents*	*Classification Category*
Jernigan; Mary Therese	8	Chemistry
Colin; Maria Alejandra Noble	6	Other
Morrow; Ardythe L.	6	Medication and medical products
Vazquez Gastell; Alma Rosa	6	Chemistry; other
Hartford; Jennifer	5	Other
Torres Sanchez; Fabiola Maria Teresa	5	Other
Noble Colin; Maria Alejandra	4	Other
Azuara; Lena R.	3	Chemistry
De Lourdes Garcia Aleman; Maria	3	Others; medication and medical products
Garcia; Carolina Gonzalez	3	Others

Source: USPTO DATABASE, 1980-2015.

Table 4. Companies, institutes, and universities with the highest number of patents with at least one female inventor, 1982-2015

Company	*Number of Patents*
Sabritas. S. de R.L. de C.V.	28
Grupo Petrotemex. S.A. de C.V.	16
Mexichem Amanco S.A. de C.V.	7
Hylsa, S.A. de C.V.	6
Dynasol Elastomeros, S.A. de C.V.	5
Tequila Don Julio S.A. de C.V.	5
Institutes /Universities	*Number of Patents*
The Mexican Institute of Petroleum	30
The National Autonomous University of Mexico	17
The Autonomous Metropolitan University	7
The Center for Research and Advanced Studies of the National Polytechnic Institute	4

Source: USPTO DATABASE, 1980-2015.

When looking at the size of research teams, 72% had between two to five male/female inventors, 11% had only one female inventor, and 17% had on average more than six male/female inventors. The teams had an average of 3.9 researchers, including at least one woman. In the categories pertaining to electrical and electronical technology, computing and communication, and mechanics, the teams had between one to three members; in other categories the average was four and in chemistry five. Thus, teams are quite small in comparison to those in industrialized and some emerging nations (see table 5).

Table 5. Variables of the nature of innovation by technological category (Mexico)

Patent's technological category		*Frequency*	*Percentage*
	Chemistry	16	26
	Computing and communication	2	3
	Medication and medical products	19	31
	Electrical and electronics	2	3
	Mechanics	1	2
	Other	21	34
	Total	61	100
Knowledge stock		*Frequency*	*Percentage*
	Chemistry	1 449	51
	Computing and communication	17	1
	Medication and medical products	226	8
	Electrical and electronics	66	2
	Mechanics	7	0
	Other	1 100	38
	Total	2 865	100
Patent value		*Frequency*	*Percentage*
	Chemistry	90	34
	Computing and communication	0	0
	Medication and medical products	49	18
	Electrical and electronics	2	1
	Mechanics	0	0
	Other	126	47
	Total	267	100
Patent claims		*Frequency*	*Percentage*
	Chemistry	462	38
	Computing and communication	34	3
	Medication and medical products	344	28
Patent claims		*Frequency*	*Percentage*
	[illegible]	[illegible]	[illegible]

Another characteristic of these research teams is that there are 7.5% foreign inventors listed on patents, the remaining 92.5% are Mexican nationals. [7]

The estimate of female participation, (the number of female inventors/total number of inventors) shows that close to two thirds of the patents registered 10 and 40% for gender inclusion; almost one fifth registered between 50 and 75% and only 13% had women present.

When looking at patents that are classified as electrics or electronics, female participation was logged at 100% - these are individual patents. With regards to computing and communication, three quarters are women. In other fields grouped in categories there is a higher participation of women than men, whilst chemistry had gender parity.

The highest number of backward patent citations (*BwPatCit*),[8] is in chemistry (51%), followed by the category of others (38%). The average of forward patent citations (*FwPatCit*),[9], which gives an indication of patent value, is much lower at only 2.7% per patent. These were listed in the top three categories: others, chemistry, and medication and medical products. Lastly, we can see that the highest numbers of women registered in technology and patent claims[10] are in medication and medical products, chemistry, and others.

Specification of the econometric model

The propensity of women to be inventors (*WmPropInv*) refers to the number of female inventors registered on a patent in relation to the number of patents that have at least one woman listed, of the total granted by USPTO. This study's scope is solely patents of Mexican ownership.

We propose the following econometric model with the aim of proving the hypothesis that *WmPropInv* is associated to variables that characterize innovation, specified in the equation below:

$WmPropInv_i = \dot{A} = SizeRT, AssigPat, TechField, TechInnScope, MobInv, ValuePat$

Where: $WmPropInv_i$ = the propensity of women to be inventors.

That is to say, the number of women inventors on the patent/ the number of patents with at least one female inventor listed, of the total number of patents granted by USPTO to Mexican owners.

Where:

i = for each female inventor

$\dot{A}$ = Prior technological knowledge stock. The number of backward patent citations –*BwPatCit*– are used as a proxy variable.

SizeRT = The size of the inventor team.

AssigPat = Patent Ownership

Where: 1 = Signatory; 2= Institution; 3= Individual; 4= Co-patents among signatories; 5 = Co-patents signatory-institution.

TechField = The patent's technological category.

Where: 1 = Chemistry; 2= Computing and communication; 3= Medication and medical products; 4= Electrics and electronics; 5= Mechanics and 6= Others

TechInvScope = The scope of each patent's invention; the number of claims made is used as a variable proxy.

MobInv = Inventors' international mobility; or the presence of foreign inventors as a dummy variable.

Where 0 = inventors of the same nationality; 1= foreign inventors.

ValuePat = The patent's value; the number of future claims made was used -*FwPatCit*- as a variable proxy.

Analysis of Results

The results show that the hypotheses are partially confirmed. The statistically significant variables are: $\dot{A}$, *SizeRT*, *AssigPat*, *TechField* and *MobInv.* However, *ValuePat* was not significant and was not included in the *TechInvScope* to avoid multicollinearity.

The model estimates presented in table 6 were satisfactory with a relatively high R^2 (0.67), and coefficients that, seen together, are statistically significant (test F *pvalue* = 0.000). Potential heteroscedasticity was avoided by calculating with robust standard errors. Diagnostic tests were also satisfactory in relation to multicollinearity (VIF=6.73), the correct specification (Reset test *pvalue* = 0.0002) and error normality (Shapiro-Wilk *pvalue* test = 0.00136).

Table 6. Mexico: factors that impact on the propensity of women to be inventors

Propensity of women inventors to innovate	*Coefficient*	*Elasticity*
$\dot{A}$	0.00004**	0.012
SizeRT	0.020***	0.49
AssigPat		
Institution	0.020***	0.002
Company	0.081***	0.008
Individual		
TechField		
Computing and Communication	-0.004	
Medication and medical products	-0.007	
Electrics and electronics	-0.035	
Mechanics	0.039**	0.07
Others	-0.031	
MobInv	0.140***	0.05
ValuePat	-0.00039	
constant	0.046	
	0.236	
N	61	
R^2	0.67	
F	6.89	

Notes: $p < 0.01$ ***; $p < 0.05$**; $p < 0.010$*.
Source: calculated by authors.

The prior technological knowledge stock was statistically significant with an elasticity of 0.012. This means that, if the backward citations increase by 10%, the propensity of women to innovate increases by 0.12%. Following the Griliches (1990) tradition, several authors have used backward citations – *BwPatCit* – to study knowledge flow. In this study, ($\dot{A}$) is an inventor's stock of prior technological knowledge needed to develop an invention.[11] The fact that $\dot{A}$ has a positive impact on the propensity to invent teaches us something about the externalities of technological knowledge. Accordingly, patent disclosure should be taken advantage of with increasing R+D efforts. In other words, expanding the knowledge boundaries in a given scientific field required by the patents. This can be achieved by growing the research team, investing in fully equipped research laboratories that would contribute to the propensity of women becoming inventors. Spending at least 1% of the GDP on R+D is a challenge that has not yet been met.

The coefficient associated with team size is positive. According to elasticity estimates, when the research team increases by 10%, the propensity to invent increases by 4.9%. According to Bianco and Venezia (2019), a larger research team has a greater, more diverse knowledge pool, which will yield better results in innovation. Therefore, it is relevant that research teams should be larger, allowing gender collaboration.

Ownership of patents by institutions and companies has a positive influence on the propensity to innovate (.02% and.08% respectively). Thus, the links between business and institutions are key in understanding women's participation in scientific research, and possibly, in discovering new products and processes that could be put into production. According to Murray (2004) the local network of academic laboratories, made up of students and advisors, that inventors establish throughout their lives can be a potential antecedent for businesses. However, Martínez *et al.* (2016), did not analyze the causal effects of ownership on the propensity to innovate in their study on women inventors from 182 patents registered as PCT (Patent Cooperation Treaty).[12] They only note that, on average, 48% correspond to women working in the academic sector, with a smaller presence in the business sector (28%). These results coincide with prior studies (Whittington and Smith-Doerr, 2008). China, Brazil, and Spain have the highest percentage number of PCT patent applications with female inventors from academic sectors (about two thirds). In Mexico, 69% of female patent applicants are in the academic sector and 26% in the business sector (Martínez *et al.* (2016). Mexico has few entrepreneurs and technological dependence dominates in all sectors, as opposed to industrial and emerging countries such as India and Brazil.

Female inventors' participation in patents from various technological categories has been examined in several studies and highlights the differences among countries (Martínez *et* *al.* (2016). Mechanics was statistically significant for women's propensity to invent; however, this did not occur in medication and medical equipment. In contrast, other studies corroborate the advance of women in life sciences, innovation, and commercialization, which is the case in Mexico (Guzmán and Orozco, 2011) and other emerging nations such as Brazil (Maldonado and Guzmán, 2015), as well as industrialized nations (Cook and Kongcharoen, 2010).

Very few studies analyze the characteristics of the innovation factors that affect the propensity of women to become inventors, especially using the microeconomic model that takes each inventor into account. Hunt *et al.* (2012), found that it is indispensable to increase the numbers of women working in physics and engineering to close the gender gap in patenting. This could increase the GDP to 2.7%, if patents are considered an explanatory variable of long-term economic growth among countries (Guzmán *et al.,*2018).

The positive effect of researcher mobility in innovation is highlighted in economic literature. The coefficient associated to the presence of foreign researchers in a patent team, as a proxy variable for international mobility, is statistically positive. By increasing the participation of foreigners by 10% the propensity of women to invent increases by 0.05%. This strengthens Bianco and Venezia's (2019) finding that increasing the presence of foreign inventors results in a higher number of patent claims and increases their technological value. In effect, greater work experience accrued by inventors seems to influence their capacity to create novel products that generate higher recognition. Moreover, these authors' findings are consistent with the contributions of previous authors, who highlight that openness and experience have a positive impact on teams' innovation skills.

Lastly, the patent's value and the scope of invention of each patent was not corroborated in the propensity of women to invent. Mexico has few patents and little innovation, both at a national and international level, and the non-significance of *ValuePat* would appear to be related to this. In other words, the number of citations received for Mexican patents is not relevant; the patents have few claims, especially when the innovations are incremental. The other side of the coin is the low percentage of public and private R+D, relative to the GDP. The weak innovation capabilities of companies and institutions highlights the need to increase the number of women on research teams in institutions, and even in businesses.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

In over 20 years since the MDG and five years since the SDO were proposed, there has been substantial improvement regarding gender inequality and, particularly, women's access to education, science, and technology. However, there is still a lot of ground to cover in less-developed countries. Policies encouraged by UNESCO and other international institutions, in collaboration with several countries seem to have an increasingly positive impact on the number of women graduating from tertiary education in medical and health sciences, although numbers in science, engineering and technology are lower. In this context, Mexico is making progress in lessening gender disparity in education, with differences according to specialisms. However, there are still challenges left regarding gender parity and the knowledge economy.

This study's findings confirmed that women's propensity to become inventors is increasing. It also corroborated that A*, SizeRT, AssigPat, TechField* and *MobInv* are factors that characterize, and have a positive impact on innovation activity. Based on the elasticity of each significant variable, policy proposals to encourage the inclusion of women in innovation activities are suggested below.

First, increasing the size of research teams, associated to the inclusion of women, is crucial. This presupposes an increase in R+D spending, which will encourage research of the technological knowledge stock previously codified in patents. Incentivizing female participation in institutions and businesses, with the aim of increasing their propensity to become inventors is also recommended. Highlighting Mexican patents in mechanics, we suggest including women, thus reducing gender inequality, showcasing women's creative ability, and empowering this sector's development and innovation capabilities. Although it is true that there are women working on CONACYT's research projects with a focus on health, the inclusion of women in fields that require advanced knowledge such as medication and medical products, information technology and communication, electrics, and electronics, should be reinforced. The more women involved in science and technological research projects, the greater the parity percentage achieved in the various levels of the National System of Researchers, (SNI). Finally, the presence of foreign researchers in inventor teams, favors women's propensity to become inventors.

Mexico needs the creative potential of women working alongside men, developing new technological products and processes required by industry, institutions, and society itself. This is the path to overcoming gender inequality in the knowledge economy, sustainability, and social well-being.

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[1] Gender equality is conceived as being parity in political, economic, social, educational rights etc., between men and women. It appeals to the legal statute and the principal of non-discrimination based on sexual differences. Both genders must have access to the same life opportunities (Zamudio *et al.,* 2014).

[2] Faced with the enormity of the inequality present in the world, members of the United Nations subscribed to the MDG in 2000, with the aim of fighting poverty in its many facets.

[3] Maria del Socorro Flores Gónzalez was awarded the MEWII prize in 2006 for her work on diagnosing invasive amebiasis

[4] PNUD is the acronym in Spanish for the United Nations Development Program

[5] The countries studied are: United States, United Kingdom, Canada, Australia, France, Brazil, Japan, Denmark, Portugal, Mexico, Chile, and the average of 28 from the European Union.

[6] Mexico designated 1% of the GDP to military spending (INEGI 2015).

[7] This information was included in the econometric model as an approximation of the international mobility variable.

[8] Backward citations are patents that are referenced in a patent application. This information is very useful as it facilitates identifying the source of coded technological knowledge used in the development of new processes and patented products.

[9] Forward citations are those citations made by patents at a later date. The more patents that cite a patent indicates its value the innovation’s importance.

[10] Claims are the number of new aspects in a patent. Thus, in literature this variable is defined as the scope of an invention.

[11] Even though the intellectual property offices, and not the inventors are on the citation, the examiners are. Sometimes, inventors are aware of the progress made by other national and international agents by attending conferences, or through interactions with colleagues working in science and technology, but they do not have the exact patent information.

[12] According to the World Intellectual Property Organization WIPO, applicants can protect their invention globally in many countries, when they apply for an international patent.