Propensity toward industry-science links across Mexico's technological sectors: An analysis of patents, 1980-2013

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■ **Abstract:** Links between universities and firms (U-F) have been developed in a process in which universities have transformed the arena in which they carry out their missions and firms have internalized the need for cooperation in order to strengthen their R&D, with the idea of developing new products and processes in the context of the innovation economy. The aim of this paper is to analyze the factors affecting knowledge links among industry and scientific fields across Mexico's technological sectors. According to our estimations, using a negative binomial model based on 959 USPTO Mexican patents granted from 1980 to 2013, and using the scientific references cited in the patents as a dependent variable, we found that a greater propensity toward industry and science links is positively associated with the international mobility of inventors, previous technological knowledge, technological knowledge diffusion, science-intensive technological sectors, and larger inventor team size, but negatively associated with technological collaboration.

■ **Keywords:** Industry-science links, patents, factors of propensity toward industry-science links, Mexico.

■ **JEL Classification:** O14, O31, O33.

■ **Resumen:** Los vínculos entre las universidades y las empresas (UF) se han desarrollado en un proceso en el que las universidades han transformado el escenario en el que llevan a cabo sus misiones y las empresas han interiorizado la necesidad de cooperación a fin de fortalecer sus actividades de I + D, con la idea de desarrollar nuevos productos y procesos en el contexto de la economía de la innovación. El objetivo de este trabajo es analizar los factores que influyen en los vínculos de conocimiento entre los campos de la industria y científicos en todos los sectores tecnológicos de México. De acuerdo con nuestras estimaciones, utilizando un modelo

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binomial negativa sobre la base de 959 patentes USPTO mexicanos otorgados desde 1980 hasta 2013, y el uso de las referencias científicas citadas en las patentes como una variable dependiente, se encontró que una mayor propensión a los vínculos entre la industria y la ciencia se asocian positivamente con la movilidad internacional de los inventores, los conocimientos tecnológicos previos, la difusión del conocimiento tecnológico, los sectores tecnológicos intensivos en los equipos de inventores de mayor tamaño, pero asociados negativamente con la colaboración tecnológica.

■ **Palabras clave:** Vínculos industria-ciencia, patentes, factores de la propensión a los vínculos industria-ciencia enlaces UF, México.

■ **Clasificación JEL:** O14, O31, O33.

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■ *Introduction*

In the current knowledge economy, universities plays an essential role, given their role as the main source of new scientific and technological knowledge (Agrawal, 2001). Given this new paradigm, the communicating vessels between science and technology are key elements for knowledge generation in fields such as biotechnology, nanotechnology and information and communication technologies (Freeman, 1974;1982; Brooks, 1994; Gibbons *et al*., 1994; Foray, 2000; Brechi & Catalini, 2008).

In this process of technological progress, the connection between firms and universities is essential in guaranteeing interaction that contributes to boosting knowledge creation, its flow and the use thereof (Freeman, 1987; Nelson, 1993; Metcalfe, 1995). In this context, the relationship developed between firms and universities in each country is in keeping with its own specific innovation system (Mowery and Sampat, 2004). Under this set of initiatives, technology transfer from universities to firms becomes a strategic matter of public policy (Rahm, 1994: 267). Therefore, in each country there are different experiences that produce diverse results in terms of knowledge generation and innovation.[4] Nevertheless, the 1980 adoption by the US Congress of the *Bayh-Dole Act*, designed to stimulate technological research transfer and collaborations between universities and industry, has had a great influence on policies in other countries, especially in relation to intellectual property, technological transfer and R&D collaborations (Mowery and Sampat, 2004). Indeed, the *Bayh-Dole Act* has become an important point of reference for public policy reforms associated with academic research undertaken in industrialized countries, and it is beginning to be just as important in the 'emerging' economies.

4 During the 1970s, the designers of industrial policies referred to research collaborations between universities and companies in the United States and Europe. Some would say that in the case of Japan, such a relationship was one of the key factors in the country's rapid technological development.

Although industrialized countries, including the United States, have a history leading up to the link between universities and enterprise, particularly experiences at universities that patent and transfer technology, a broad debate regarding the relevancy of the Bayh Dole Act and its consequences, especially for universities and their professors and researchers, was initiated when the law was first introduced. Some of the concerns outlined by the academic community and specialists in the field include: differences in educational systems; whether it is necessary to promote a patents policy oriented toward encouraging greater research and technological transfer collaboration, and the potential risks associated with such policy changes (Mowery and Sampat, 2004).

Another problem at the core of the debate around the *Bayh-Dole Act* is in regard to university financing. Institutions require increasing amounts of ongoing economic funds for research, yet access to publicly financed budgets is sometimes limited.[5] These aspects are especially sensitive matters in developing countries, which are characterized by their technological and economic backwardness, and where economic resources for universities are usually less than abundant. In this sense, links between universities and companies not only acquire special relevance in relation to the financial aspect, but also the interaction established in the generation and spillover of technological knowledge. The capacities of university researchers in creating new ideas will not only depend on their own efforts in R&D, but also on feedback from industry. In the managerial environment, the absorptive capacities, or connectivity (collaboration agreements, among others), are the other side of the coin in the university-company link.

Our investigation proposes that university-firm (U-F) links are incipient and weak in Mexico. This is due, on the one hand, to reduced technological competition and innovation in locally-based firms, but also to the limited institutional environment with regard to intellectual property and the level of technological transference in Mexican universities. Although Mexico possesses the necessary scientific and technological capabilities, there is a lack of funding necessary for promoting cooperative projects between universities and firms. As a consequence, only a reduced number of links occurs in an individual and informal manner.

We aim to establish the factors affecting the knowledge links between industry and scientific fields across Mexico's technological sectors. By using the scientific references cited in the patents as the proxy dependent variable of industry and science links (Branstetter, 2003a, 2003b; Gittelman & Kogut, 2003; Nomaler & Verspagen, 2007), we established our hypothesis that a greater propensity of patent to cite an academic science reference is positively associated with technological collaboration, previous technological knowledge, science-intensive technological sectors, international mobility of inventors, diffusion of inventions and larger inventor team size.

The following section contains a review of specialized literature on this topic. The third section aims to characterize the institutional policies associated with intellectual property and technology transference in Mexico. And the section that follows proposes

5 Thus, in the United States, as in other countries, there is a growing competitive atmosphere among academic institutions in search of new sources of financing. In this process, some universities acquire a managerial profile (Mowery and Sampat, 2004).

a binomial model, and we verify our hypothesis concerning the factors explaining the propensity toward links among industry and scientific sectors. We analyze the results in order to propose some policy recommendations, and lastly, we offer our most important conclusions.

■ *Background*

First, we look at the ways in which links between universities and firms have evolved, from a historical viewpoint. Next, we shift our attention to the experiences of different countries and industries, highlighting the collaboration between the academic and industrial worlds. And lastly, we outline the issues and findings of empirical studies in relation to knowledge flows and spillovers between these two agents.

University-firm links as a historical process

Links have been developed between universities and firms (U-F) as a result of a process in which universities have transformed the arena in which they carry out their missions and firms have internalized the need for cooperation in order to strengthen their R&D, with the idea of developing new products and processes in the context of the innovation economy.

Initially, universities were created for the purpose of preserving and disseminating knowledge, and in that context, only professionals were educated. The first revolution around the role of universities can be traced back to the end of the 19th century, and it consisted of adding research to the mission of teaching (Storr, 1952; Metzger, 1955; Veysey, 1965; Jencks & Reisman, 1967).[6] This process has been accompanied by organizational changes within institutions and, in turn, has led to substantial changes in the mission of universities (Etzkowitz *et al.*, 2000; Etzkowitz, 2003).

In the second revolution, the transition toward an entrepreneurial type university can be explained in a context in which a university's internal development, and its contact with external parties interested in bonding with the academic world, are interconnected (Etzkowitz, 2003).[7] The external influences are related to emerging innovation based on the knowledge economy (Etzkowitz *et al.*, 2000; David & Foray, 1995; Dickson, 1988; Gibbons, et. al., 1994; Foray, 2006). Thus, each university has been guiding itself toward an incubation process in relation to interested firms through the participation of graduates in close contact with university research groups (Shane & Stuart, 2002).[8] Likewise, programs that linked scientific disciplines with technological ones were encouraged (Terman Paper, 1943, quoted in Etzkowtiz, 2003). Thus, organizational changes in the academic world responded to the industrial-research model.

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6 John Hopkins University and the University of Chicago are forerunners in these changes. Basically, transformation took place through the incorporation of professors' assistants (generally recently-graduated students) who worked with professors in their new function of researching (Olesson & Voss, 1987, quoted in Etzkowitz, 2003).

7 Antecedents can be found in the Massachusetts Institute of Technology (MIT) in 1862.

8 An example of this policy's great influence was the creation of the Silicon Valley cluster. (Branstetter (2003) and Branstetter & Ogura (2005) analyze the impact of university researchers in California's industry in 2003, through their patent citation analysis.

The incorporation of a third mission implied new organizational changes that consider aspects regarding intellectual property as well as the commercialization of technology. The pioneering model used by Stanford University spread throughout other US universities (Etzkowitz, 2003; Shane, 2002), as well as to those in other industrialized countries, and was then introduced in some developing countries.[9] The most relevant features in the managerial-university model integrate elements characteristic of the research-focused model (the organization of research groups and the creation of basic research with commercial potential), but they also include the transition from a research to a entrepreneurial (with the development of organizational mechanisms to mobilize marketable research through institutional limitations) and, finally, to what it is clearly considered a university-firm model (with the integration of academic and non-academic organizational elements) (Etzkowitz, 2003). The relevance of technological transfer offices (TTOs) in universities has gradually increased, and they have become the primary university/firm link. The transition toward an entrepreneurial -type university has given rise to an important debate between those who question this kind of model and those who defend it.

Academy-industry collaboration: the experience of countries and industries

In an economic perspective of university-industry relationships, three models proposed by different authors can be identified: i) the "Triangle" model (Sábato, 1975; Sábato & Mackenzie, 1982; Etzkowitz & Leydesdorff, 1997); ii) the approach of the National Innovation Systems (NIS) (Nelson, 1993; Lundvall, 1988, 1992); and iii) the triple-helix model (Etzkowitz & Leydesdorff, 1997; Etzkowitz, 1998, 2002). Each proposal attributes a different level of importance to institutions throughout the innovation process. The first model recognizes greater influence on the part of the State. In the NIS model, the company acts as the main engine for innovation. And in the triple-helix model, universities contribute to innovation in a decisive way, especially with regard to the relevance acquired at the time through the knowledge economy.

A review of the literature has been carried out by asking the following questions: What are the individual, institutional and environmental factors influencing patent activity at universities? What are the main factors affecting joint coollaboration in the area of research? How do enterprises and universities communicate their research collaboration? What are the most important factors affecting the performance of joint university-enterprise research? IPR and TT are two of the main focuses in this type of study.

Regarding the behavior of university (faculty) patenting, there is some empirical evidence of patent generation associated with scientific publications, the evolution of the academic incentive system toward new environmental needs, the commercial orientation of scientific research and the spreading of the patent culture among

[9] The entrepreneurial (managerial) function of universities has been introduced in several universities in Western European countries –United Kingdom, Germany and Italy– as well as some Eastern European countries. Likewise, there is evidence of the same in Japan and Brazil (Meyer-Krahmer & Schmoch, 1998; Etzkowitz *et al*., 2003). In Germany, a strong university-industry collaboration is identified in the mature technologies –chemistry and mechanical engineering (Meyer-Krahmer & Schmoch, 1998).

academic researchers (Azoulay *et al*., 2006, Göktepe, 2008). Particulary, the Bayh Dole Act seems to have a positive influence on patents granted to US universities, in comparison to what can be observed in European countries. Even though European countries possess a strong scientific base, they have not been able to transfer research findings into new viable commercial technologies –the european paradox- (Brechi, *et al*. 2006; Göktepe, 2008).

University-firm collaboration can be found within a managerial strategy oriented toward complementing technological effort, thus increasing the possibility for technological advances, aimed at boosting innovation development and contributing to the improvement of a firm's technological performance. However, in this type of technological collaboration, universities also develop scientific and technological capabilities when they expand their research environment. Especially in developing countries, characterized by high costs associated with innovation, the lack of technological capabilities and human capital, a reduced level of R&D investment, and weak productivity in terms of patents, we find that coollaboration between universities and firms can still act as a catalyst for technological progress as long as there is a suitable regulatory framework. In the case of firms, especially those in developing countries, technological transfer frequently constitutes an alternative to technological learning, thus providing quicker industrial-productivity improvement (Basant & Fikkert, 1996). Nevertheless, as technological capabilities develop, the U-F link should become more interactive.

A firm's ability to convert university research into its own profits, identified by Cohen and Levinthal (1990) as absorption capabilities, are linked to its R&D spending. However, these capabilities will only be effective if there is connectivity with universities (Cockburn & Henderson, 1998). Connectivity is crucial, especially when a firm uses its abilities to make connections and develop collaborations with universities and other public-sector scientists and then make a profit from it, while at the same time, contributing to public sector development in relation to science (Zucker et. al, 2002). This expresses the degree of interaction between a firm's scientists and its external counterparts, particularly other firms, universities and research institutions (Lim, 2009). The internal R&D mechanism helps promote connectivity, which in turn, generates absorption capabilities.

Some studies are focused on analyzing whether companies have gained any knowledge absorption abilities through contact with universities or research centers, taking into account variables such as R&D intensity (Blumenthal *et al*., 1986; Campbell & Blumenthal, 2000; Blumenthal, 2003; Vedovello, 1998), the academic level of a firm's employees (Lund, 2004), spatial closeness, company size, coded knowledge and tacit knowledge. With or without R&D, firms and universities can establish links (formal, informal or resource-related), but firms that use R&D have a higher tendency toward stronger links or collaborations (Vedovello, 1998). Moreover, it is an essential factor in facilitating feedback between universities and firms (Bodas *et al*., 2008). Technological proximity is recognized as an essential variable in technological transfer because it favors direct contact with TTOs, but its importance diminishes in the case of smaller firms (Arundel & Geuna, 2001). Therefore, a firm's size has an effect on university-firm collaboration. Social connectivity and the trustworthiness of university research centers (UCR) to provide technological transfer and intellectual property policies, as well as a firm's technological capabilities, on the whole, facilitate technological transfer (Santoro & Bierly, 2006).

The impact of universities on manufacturing and service industries, as a guide to innovation, is analyzed through the sale of innovative products and the tendency to analyze patents (Lööf & Bromstrom, 2006). But the nature of how universities and their researchers can impact an industry's innovation (faculty quality, level of R&D activities, number of researchers, research groups and geographical proximity between universities and firms) are also taken into account (Mansfield, 1995) .

Also analyzed is how a firm's size and the universities' researchers and academic potential can affect the channels used for technological transfer (Fukugawa, 2005).

Regarding geographically-localized knowledge spillover, published works analyze the effects of transaction costs incurred through the direct interaction established between the creator and the receiver of tacit knowledge (Agrawall, 2001). Knowledge intakes are generally identified as R&D and patented products, but some studies attempt to link them to geographical location (Jaffe, 1989; Jaffe Trajtenberg & Henderson, 1993). "Local funds for university research" are a consumable associated with the product, and "local industry´s added value" and the variations in this relationship are examined through geographical location at a state level (Audretsch & Feldman, 1996). Some researchers use patent citations as the basis for their analysis of university-enterprise spillover in relation to technological knowledge and geographical location (Jaffe *et al*., 1993; Jaffe & Trajtenberg, 2002), while others use analysis of academic publications citations in patents (Guitelman & Kogut, 2003; Branstetter, 2003, 2004; Branstetter & Ogura, 2005; Brechi *et al*., 2006; Nomaler & Verspagen, 2007).

The stylized facts show increasing feedback between scientific and technological knowledge, and this becomes essential in explaining the university-industry knowledge transfer. The co-invention and co-authorsip by individuals from both communities may give us some evidence of this connection occurring in academic social networks (Brechi *et al*, 2006).[10] In this sense, the study of links between patents and scientific publications is useful in establishing the ways in which the academic scientists' community and the industrial researchers' community are connected, and therefore in attempting to measure knowledge flows between science and industry. The high quality of scientific papers (frequently cited in other publications) is captured in order to develop new technologies. In this way the publications cited by patents become a proxy of knowledge flows from science to technology (Brechi *et al*., 2006)

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10 "They are researchers that do publish scientific articles and patent new inventions, thereby participating into both communities. Social network analysis reveals that such individuals are characterized by a higher degree centrality, i.e. they tend to collaborate on average with a significantly larger number of other inventors and authors, than do simple inventors and authors, and by a higher centrality, i.e. they play a crucial function of knowledge brokers in the network that makes them more in-between than simple inventors and authors, and ensures a rapid diffusion of knowledge and ideas from one domain to the other." Brechi *et al*., 2006: 107.

Finally, some literature refers to the channels through which knowledge is transferred to industry, and points out that there are other means of economic significance in addition to patents, namely: publications, consultations, informal meetings, joint ventures, research contracts and the interchange of personnel (Cohen *et al*., 1998; Cohen *et al*., 2000; Shane, 2002).

In recent years, firm-university collaboration has increased considerably in some industrialized countries, but interaction patterns in the different technological fields are somewhat uneven.[11] Therefore, studies carried out on U-F links refer more to industrialized countries, and to a lesser extent, consider the experience of developing countries (Yusulf & Nabeshima, 2007). In the case of emerging countries there is an increasing effort to build an institutional framework that allows scientific and technological flows between universities and firms.[12] The need for this type of relationship acquires significant importance given the enormous funding needs of universities and research institutes for developing scientific and technological knowledge. Both could benefit from collaboration by expanding their research capabilities, technological potential and external financing (Wang & Shapira, 2012), and even by building market niches within the context of international competition.

In the case of Mexico, we can observe some recent interest in studying the incipient bonding processes between universities and firms. Casas, De Gortari and Luna (2000) analyze the dimensions of interactions between firms and universities, underlining the role of universities in relation to scientific competencies for knowledge production, and the two patterns of university-industry collaboration. The first is an indirect pattern through professional consultancy, and the second pattern occurs in research-scientific activities aimed at contributing to industry's technological needs in a national system of innovation approach. There are some empirical qualitative studies that attempt to account for the interaction between universities and industry (Cabrero *et al*., 2011; Stezano, 2013; Dutrénit, 1996; among others), including the role of government (Casas & Luna, 1997), and also universities' incipient efforts in the regional scope (Luna, 2001; Casas, De Gortari & Santos, 2000; Alvarado-Borrego, 2009). Another topic studied is focused on the best channels through which institutions and industry are interacting and how they perceive their benefits (De Fuentes & Dutrenit, 2012). And others have focused their studies on characterizing universities' inventive activity and technological transference (Calderon, 2014).

Few studies have focused their analysis on the role of university patents in an entreprenerial scope. Calderon (2014) analyzes the factors affecting patent generation in universities. Her empirical findings point to team size and researcher quality (as some

[11] One of the most studied countries is the United States. Other industrialized countries have also been analyzed: United Kingdom, Japan, the Netherlands, Northern European countries, Switzerland, Spain and Canada, among others. The United Kingdom is characterized by greater diversification in U-F interaction types, while the United States seems to prioritize licensing and joint R&D (Vedovello, 1998; Hughes, 2006). The biopharmaceutical sector is one field in which there is important evidence on collaboration between universities and firms (Fabrizio, 2006; Fukagawa, 2005; Zucker, Darby & Brewer, 1998). In this sector the intensive basic research levels of firms seem to be associated with an increased use of academic knowledge. The financing of universities by firms is essentially focused on research, and to a lesser extent, on consultancy services.

[12] Such is the case of China (Wu, 2007), India (Basant & Chandra, 2007) and Singapore (Wong, 2007).

of the elements characterizing universites) as determinant factors. Calderon (2013) also concentrates her analysis on the case of the National Autonomous University of Mexico (UNAM), to establish whether patents generated at the UNAM are the result of researchers' own inciative or are guided by an institutional effort through a technological transference office. The patent culture among UNAM researchers has been a unique process in which there was no institutional framework and the priority for researchers was to publish new scientific findings instead of exploring industrial utility potential. The relationship between researchers and firms has developed primarily through consultancy activities, but within a passive entrepeneurial environment. Cervantes (2012) attempts to delve deeper into the role of specific characteristics of individual academic researchers on patent activity and the impact of relationships with firms. This author first evaluates whether patents by academic researchers complement their scientific training, and secondly, explores whether patents, as a channel for exchanging knowledge, positively or negatively reinforce links with the entrepreneurial sector.

Nevertheless, even if the analysis of patents associated with other institutional and individual factors has been used to investigate university-firm links, the wealth of information offered by patent microdata has not yet been sufficiently explored. By considering that Mexico has not been characterized by innovative activity and therefore patents applied for and granted are relatively few, when compared with other emerging or developed countries, there is a tendency to underestimate patents as a source of analysis. Despite reduced growth in patents, they are an important source for characterizing the nature of innovation in Mexico and predicting some policy implications. In that sense, we reclaim Schmokler's (1962) pioneer contribution of patent analysis, followed by Griliches (1984), Jaffe, Trajtenberg, Henderson (1993), Trajtenberg (2002); Hall, Jaffe & Trajtenberg (2001) and many other academics who have expanded patent analysis to study a number of theoretical and empirical problems. In particular, we take into account those contributions that have pointed out the citation of scientific papers in patents as an indicator of technological knowledge flows between academic and entrepreneurial sectors (Guitelman & Kogut, 2003; Branstetter, 2003, 2004; Branstetter & Ogura, 2005; Brechi *et al*., 2006; Nomaler & Verspagen, 2007; among others). No evidence in this regard is available in the case of Mexico and thus our research is aimed at contributing to identifying the factors affecting the relationships between academic and industry sectors, using the citation of scientific papers in patents.

■ *Mexico's universities: institutional policies concerning intellectual property and technology transfer*

In this section we will identify the main changes concerning intellectual property and technology transfer policies in Mexico during the the last decades.

Institutional environment

The adoption of institutional policies regarding intellectual property and technological transfer in the fields of science and technology in Mexico is relatively recent. In the context of the industrialized exports-based model, Mexico has carried out structural and institutional reforms since the mid-1980s (Aspe, 1993; Lustig, 1994). The new regulatory framework includes aspects regarding foreign investment, technology, intellectual property and innovation associated with the demands imposed by the new international competition based on technological competence and the knowledge economy. The adoption of Trade Related to Intellectual Property Rights (TRIPs) in 1991, just prior to the signing of the North American Free Trade Agreement (NAFTA), is among the most outstanding of the events (Aboites & Soria, 1999). With the adoption of TRIPs, Mexico acquired the international commitment of adopting a strong patents system, and in general terms, has harmonized intellectual property rights with those specified by countries belonging to the World Trade Organization (WTO).[13]

New laws on intellectual property marked a limit to the imitative technological strategy followed by Mexico during the industrialization imports substitution (ISI) period. The protection of industrial and intellectual property provided foreign firms with a safe institutional context, as well as positive marketing expectations, especially after the signing of the NAFTA. However, these legal changes forced Mexico to think about the need for agreeing to a new scientific and technological policy that would allow the country to stimulate the development of technological capabilities, productive associations and the creation of funds to finance programs of technological development and innovation (Cruces, 2008).

Several studies have coincided in highlighting the fact that the low-standard performance of Mexico's local innovation levels constitutes one of its main limitations in terms of its global-competitiveness level (Conacyt, 1995; OECD, 1997; World Bank, 1994, quoted in Vite-León, 2005). Mexico's national innovation system has been characterized as weak and disjointed, which implies the absence, in different environments, of communicating vessels that facilitate the construction of innovation strategies, economic growth and competitiveness (Aboites & Cimoli, 2002). Therefore, the average industrial activity is noted as moderate, the patent system is known for its inconsistent international performance,[14] and economic growth is generally low, as is its per-capita GDP.[15]

Given the relative speed with which structural reform and the respective changes in economic regulation have been adopted (since the mid-1980s), programs for fomenting links between universities and companies supported by public financing were unfortunately scarce and limited over the same period (Casas & Luna, 1997). This fact has great relevance because, in spite of the enormous technological opportunities

13 In particular, the pharmaceutical industry has registered remarkable changes with regard to intellectual property and regulation (Guzmán & Viniegra, 2005; Guzmán, 2014).

14 According to Aboites and Cimoli (2002), divergent patent systems are characterized by their low local innovation activity, in turn, related to limited spending in R&D, human resources with low training and low-level participation of the private sector, weak bonds among companies and institutes, and exports with low technological content. The minimal innovation is essentially located in mature technology sectors such as the mechanics and some areas of the chemical industry. Additionally, the diffusion rate (penetration in the USPTO) has been very low during the last three decades, in spite of patent reforms.

15 These national-innovation-system deficiencies are also expressed with regard to the pharmaceutical sector (Guzmán, 2014).

associated with NAFTA, national companies have not created the correct conditions that will allow them to take advantage of them and thus have been unable to develop the desired technological and absorption capabilities. Foreign technological transfer, knowledge networking, and firms' absorption capabilities, among other aspects, were limited, or sometimes nonexistent. Even though human resources training in the higher education system was increased from the start of the 1990s (Kent, 2003),[16] no fluid channels between knowledge generation institutions and local companies were encouraged.

With such a diagnosis, recommendations on economic policy from specialists and international development organizations pointed to strengthening direct collaborations between national universities and local industry.[17] Additionally, the challenges of the new policy were to promote cooperation between companies, outsourcing contracts and technological incubation programs (Cruces, 2008). Policies directed at increased integration between academic and productive sectors, since the end of the 1990s, were essentially aimed at eliminating the barriers that hampered collaboration -as in the case of intellectual property-, fomenting incentives and overcoming bureaucratic structures in universities and firms (World Bank, 2003).

We distinguish two main focuses in recent institutional reform, designed to encourage technological scientific development and its link with the productive sector. The first is aimed at improving quality accessibility to higher education, and the second at articulating a scientific and technological policy that contributed to increasing technological capacities and fomenting innovation, thus strengthening links between universities and firms.

University reform included changes in structures and functions, and the promotion of relations associated with formal and direct collaboration with companies and government (Luna, 2001).[18] The development of potential research capacities has been considered crucial in the strategy to encourage university-firm collaboration networks, and it also influences their form. In this respect, public financing, although certainly higher, began to decrease marginally and the private sector began to finance research projects. Regional differences were also reflected in financing, because in addition to federal funds, there was also local state funding (Luna, 2001).

The second stage corresponds to the design of scientific and technological policies aimed at regulating and fostering scientific and technological research, along with innovation in the group of universities and research institutes, as well as to promote university-industry collaboration. The approval, in 2002, of the Science and Technology Law and the Organic Law of the National Council of Science and Technology

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16 R. Kent, "The changing role of the state in Mexican higher education: from the crisis of ineffectual populism to development regulation," a paper presented at the *Consortium of higher education researchers*, 16th Annual Conference-, Porto, Portugal, 4-6 September 2003, quoted in Vite-León, 2005.

17 Casas & Luna, 1997; Conacyt, 1995; Conacyt, 2001; OCDE, 1997; World Bank, 1994, 2000, 2003, quoted in Vite-León, 2005.

18 In this context, incentive programs were designed to foment linking with the productive sector of CONA-CYT, and regional programs linking with the National Association of Universities and Institutes of the States (ANUIES). Likewise, university policies have taken into account the needs and requirements of businessmen with regard to human resources training.

(CONACYT), as well as the Special Program of Science and Technology 2001-2006 (known as PECYT, its Spanish acronym) are among the most significant changes.[19]

The Science and Technology Law provided the formation of a General Council of Scientific Research and Technological Development, presided over by the Mexican president, and with abilities to: i) form national policies for scientific progress and technological innovation supporting national development; ii) approve special programs for science and technology; and iii) define priorities and approaches for federal public expenditure allocation to science and technology.

Preliminary Principles of the Support provided to Scientific and Technological Activity (Ch. III, Art. 12) included: joint participation of the academy and the technological and productive sectors in the decision-making process regarding science and technology; the convergence of private and public, national and international contributions to promote development and human resources training and the creation of tax incentives (among others) so as to encourage investments aimed at innovation and technological development.

For its part, PECYT[20] defined governmental policy goals as follows: i) to establish a State policy for Science and Technology;[21] ii) to increase the country's scientific and technological capabilities; and iii) to encourage competitiveness between companies, guided by a regulatory framework.

Therefore, efforts by the involved institutions had to focus on increasing spending on R&D to 1% of the GDP by 2006, the distribution being 60% public sector and 40% private funding. This aim was never achieved because, according to INEGI data, expenditure on R&D as a percentage of GDP never surpassed 0.4% in 2007. However, some legislative advances were registered such as the Income-Tax-Law Reform regarding tax incentives and the creation of an Advisory and Technological Forum made up of respected members of the Mexican scientific, technological and academic community.[22]

Institutional reforms in universities, and in science and technology policies (CONACYT), had a positive effect on perceptions toward industry, and consequently a new context for fomenting university-firm links took shape. Nevertheless, evidence suggests that these links depend on several local factors, public policies and each university's own regulatory framework (Vite-León, 2005).[23]

As we have seen, Mexican universities have only recently begun to engage in IPR and TT, encouraged by governmental policies on science and technology (see Ley de Ciencia y Tecnología, 2002, amended in 2011 and 2014). This seems also to have a positive effect on collaboration efforts between universities and firms. Although science and technology and higher education reforms have provided some incentives to

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19 See: Foro Consultivo Científico y Tecnológico. (2005).

20 http://siicyt.gob.mx/siicyt/docs/acerca_pecyt%202001-2006.pdf.

21 CONACYT was created in the mid-1970s.

22 http://www.conacyt.gob.mx/aps.

23 In this study, the determinants of university-industry collaboration are analyzed in four Mexican states: Puebla, Nuevo León, Guanajuato and Jalisco, all characterized by significant industrial and commercial activity.

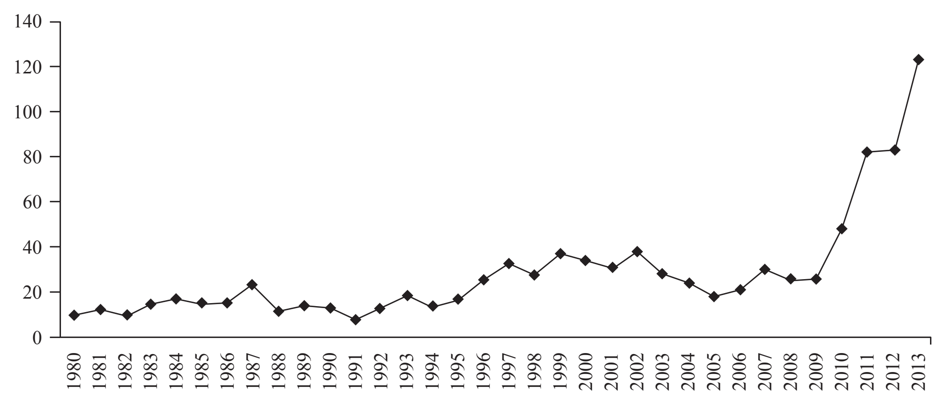
researchers in the field of innovation, these institutional efforts have still not spurred on the research and entrepreneurial culture. Indeed, among the scientific community, some myths regarding the relevance of collaboration with industry still remain. Some even consider this collaboration to be a type of university privatization. Other researchers are not worried about patenting because the incentives for research productivity are focused primarily on the production of scientific articles.

■ *Propensity of factors of university-firm links*

In order to analyze the factors affecting knowledge links among the industry and scientific fields across Mexican technological sectors, first of all, we propose a Poisson model,[24] therefore a negative binomial model.

Data sources
Our search is based on 959 patents granted to Mexican holders by the USPTO from 1980 to 2013. The USPTO patent data provides information on the patent application and grant dates, invention abstract, holder or holders name(s), whole inventor's name and nationality, claims, USPTO technological class or classes assigned, PCT application, backward patent citation, forward patent citation and academic references (articles and books).

Figure 1
Mexican patents granted by USPTO, 1980-2014
(patent's number by year)

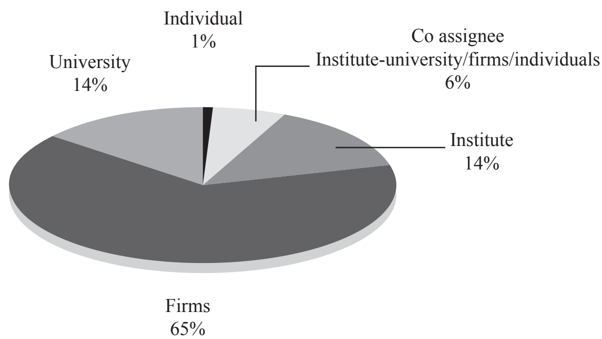


Source: USPTO patent database.

24 The Poisson regression model is a non-linear model in which the λ parameter of the Poisson process depends on a set of explanatory variables. Thus, the aim is to explain the number of times that an event of interest to individual i occurs (i=1,…,N) within a unitary amplitude interval, as a function of a set of explanatory variables *Xi=xi*: for the model supposes that the dependent variable is distributed in accordance with a Poisson-type distribution function.

According to the assignee specified, two-thirds of Mexican patents registered by USPTO from 1980 to 2013 were granted to firms, 28% to universities-institutes, and 6% had co-assignees, either institute-university/firms or institute-individuals. The portion of patents granted to individuals is marginal.

Figure 2
Distribution of USPTO Mexican patents granted by assignee, 1980-2013 (%)



Source: USPTO patent database.

Among the holders of Mexican patents, especially worth mentioning are firms associated with technologies classified as mechanical or chemical. An example of the first case is *Hylsa*, an iron and steel producer firm, characterized by its innovative trajectory since the 1940s. The firm developed technological capabilities through different learning stages from transferring technology to innovating the iron process of direct reduction (*HYL*) and commercializing its technology in Mexico and in several other countries (Guzmán, 2002). The interaction between *Hylsa* and universities has been essential in reinforcing its R&D and innovation activities. *Hylsa* is the leader among Mexican patents granted by USPTO, with 66 patents accumulated between 1980 and 2013. The foundation of the *Instituto Tecnológico y de Estudios Superiores de Monterrey* was seen by the ALFA Group (to which *Hylsa* belonged) as necessary for training professionals for their firms, but *Hylsa* and the other firms in this industrial corporation, such as *Vitro*, were linked with the Universidad Autónoma de Nuevo León an ongoing basis in order to share their research.[25] In the chemical sector, *Grupo Petrotexmex* is particularly associated with petroleum activities. Also in the chemical sector are *Vidrio Plano* and *Vitro*.

Among institutes/universities, the *Instituto Mexicano del Petróleo* (IMP) is the one with the most patents, followed by the *Instituto Politécnico Nacional* and *Universidad Nacional Autónoma de México*. In the case of the IMP, it is one of the institutions characterized by its interaction with the industrial sector through *Pemex*. Although

[25] Unfortunately, this firm has been recently sold to an Argentine firm.

this institute was created specifically to conduct R&D activities, the state company did not make the necessary technological efforts to bring innovative dynamics into its activities. Because of this weakness in Pemex capabilities, the IMP did not expand its efforts to further develop technologies by interacting with firms as well international research networks.

Table 1
Ranking of the bigger patenting Mexican holders, 1980-2013
(Patents granted by USPTO)

Patent holders	Patent's number
Hylsa, S.A. de C.V.	66
Grupo Petrotexmex, S.A. de C.V.	42
Sabritas, S. de R.L. de C.V.	30
Vitro Tec Fideicomiso	29
Instituto México del Petróleo (IMP)	24
Servicios Condumex S.A. de C.V.	22
Instituto Politécnico Nacional (IPN)	22
Vidrio Plano, S.A. de C.V.	21
Universidad Nacional Autónoma de México (UNAM)	19
Instituto Mexicano de Investigaciones Siderúrgicas	9
Instituto Potosino de Investigación Científica y Tecnológica, A.C.	6
Instituto Tecnológico y de Estudios Superiores de Monterrey	6
Universidad Autónoma Metropolitana	5
Barrera; Roberto González	5

Source: USPTO patent database.

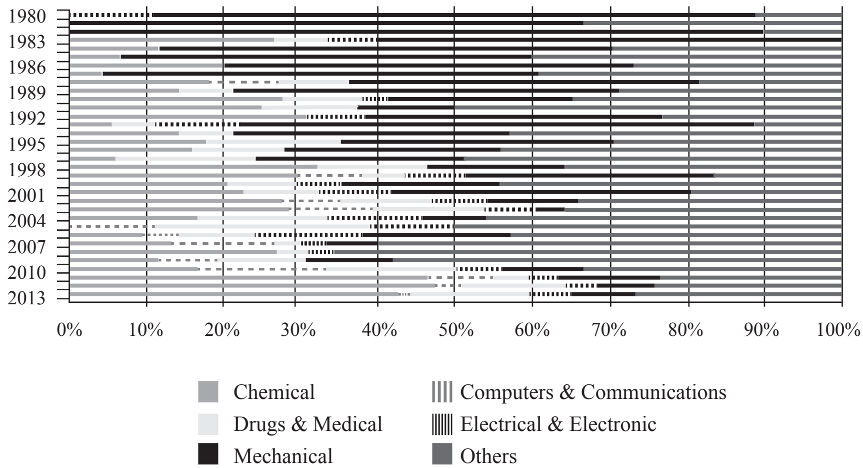
If we look at Mexican patents granted by USPTO according to technological category, we can see that mechanical and chemical sectors, together with a group of technological subcategories identified as labor or resource intensive[26] were those with reduced inventive activity. The technological categories characterized by scientific knowledge intensity, such as drugs and medical (the category that includes biotechnology), computers and communication, and electrical and electronic, are less represented among the USTPO patents granted to Mexican holders.

Poisson and negative binomial models of factors affecting the links between industry and science

By means of a Poisson model we attempt to prove whether or not the higher propensity of industry and science links in Mexico is associated with the following variables: collaboration between firms and institutions (co-patents), international mobility of inventors (presence of foreign inventors), science-intensive technological sectors,

[26] As agriculture, husbandry, food, amusement devices, apparel & textile, earth working & wells, furniture, house fixtures, heating, pipe & joints, receptacles, miscellaneous.

Figure 3
Mexican patents granted by USPTO by technological categories, 1980-2013



Source: Own elaboration.

previous knowledge stock (backward citation patent), diffusion and importance of inventions (forward citation patent) and inventor team size.

Using a Poisson-type model as a base, we have plotted the following equation:

LinkInd-Sc$_{Mx}$ = *f* (*Cooptec, Mov_In, TechSec, BwCit, FwCit, SizeInvT, SizeInvT-1, SizeInvT_2-5, SizeInvT_6*)

Where the dependent variable:

LinkInd-Sc$_{Mx}$ = denotes links between the industry sector and the academic or scientific sector. We use the number of scientific articles cited (SC) in the Mexican patents granted by USPTO as a proxy variable of academic knowledge used by patents to build the new invention (Brechi *et al*., 2006).

And the independent variables and their hypotheses are:

Variable	Variable description	The following is expected:
CoopTec	Technological collaboration. The co-patent assignee is used as a proxy variable and it is expressed as a dummy variable, where 1 means that there is technological collaboration and, 0 when it doesn't	The shared property of a patent between firms and institutes/universities presumes a previous collaborative agreement in which efforts in R&D are also shared (Henderson, Jaffe & Trajtenberg, 2002; Messeni, 2009). When *CoopTec* is 1, the propensity toward links between industrial and academic sectors is higher.

Variable	Variable description	The following is expected:
MobIn	International inventor's mobility. This is a dummy variable where 0 means only the presence of inventors of the same nationality as the patent, and 1 indicates the presence of foreign inventors.	By considering that the inventor's mobility favors the spillover of codified and tacit knowledge (Feldman, 1999), we state that if this occurs, the propensity for scientific articles to be cited by a patent is higher.
TechSector	Technological sector axed to scientific intensity. This is a dummy variable where 1 means the patent is classified in at least one of the scientific intensity sectors, and 0 means it is not.	By considering the classification developed by Jaffe & Trajtenberg (2002), we expect that the higher propensity for scientific articles to be cited by a patent occurs in the science-intensive sectors such as chemical, computers & communication, drugs & medical, electric & electronic. (Bransteter, 2003; Branstetter & Ogura, 2005; Brechi et al., 2006)
BwPatCit	Previous accumulated knowledge. This variable specifies the number of patent citations made in a patent to previous patents. We use *backward patent citation* as a proxy numeric variable.	The larger the BwpatCit, the higher propensity for scientific articles to be cited by a patent. Since the patent is taking into account previous technological knowledge, research needs the support of advances in academic knowledge to improve or develop new ideas.
FwPatCit	Technological knowledge diffusion. This variable specifies the number of patent citations made in successive patents. We use *forward patent citation* as a proxy numeric variable.	The larger the FwPatCit, the higher propensity for scientific articles to be cited by a patent. As the diffusion of new patents spreads and new knowledge achieves importance, the propensity to search for scientific sources increases. (Bransteter, 2003; Brasntetter & Ogura, 2005; Brechi et al., 2006)
SizeInvT	*Inventor team size*. This variable specifies the number of inventors for each patent involved in the generation of new technological knowledge.	The larger the inventors team, the higher propensity for scientific articles to be cited by a patent. Since the research team is larger, there is the possibility of an increase in networking and inter-discipline interactions, and therefore the propensity toward consulting academic sources increases. (Sing & Fleming, 2010).
InvT_1	*Single inventor team*. The patent has only one inventor. This variable specifies the number of patents with a single inventor.	There is lower incidence of citation of scientific articles when a patent has a single inventor, than when there is a team of inventors. Singh & Fleming, 2010
InvT_2-5	A team with 2 to 5 inventors. This variable specifies the number of patents with a team of 2-5 inventors.	When the inventor team is of this size, the incidence of citation of scientific articles increases more than in the case of a single-inventor team, but less than a larger inventor team. (Brechi et al., 2006; Singh & Fleming, 2010).
InvT_≥6	A team of 6 or more inventors. This variable specifies the number of patents with a team of 6 or more inventors.	In the case of an inventor team of this size, the incidence of citation of scientific articles is the highest.

The Poisson model is intended to be a distribution function in which the average and variance are equal (equidispertion). Nevertheless, this characteristic is not always accomplished, and consequently the data adjustment is not reliable. In addition, heteroscedasticity is intrinsic, given that the nature of the data is not linear, and thus, the error variance is not constant. Therefore, we propose a second model, specifically a negative binomial model, in order to improve the estimation quality.

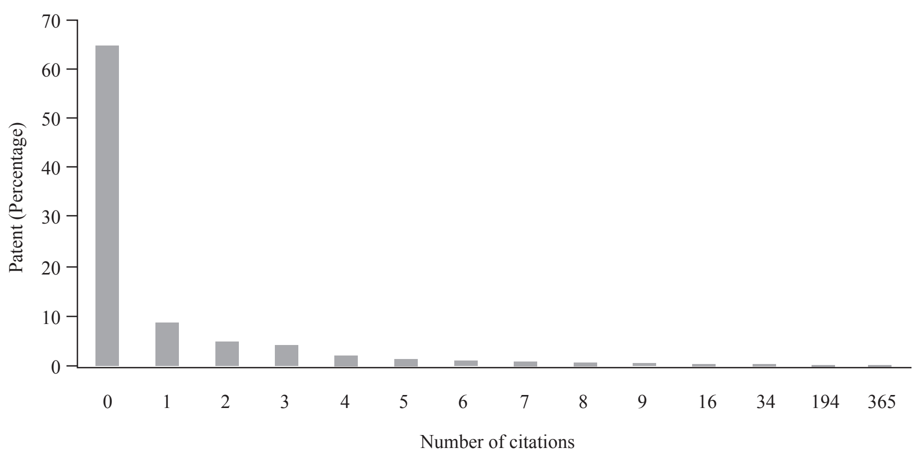
Through the negative binomial model, we add a randomness variable in parameter λ:

$$\lambda_i^* = \exp(x_i\beta + \varepsilon_i) = \lambda_i \exp(\varepsilon_i)$$

Statistical evidence

According to USPTO patents granted to Mexican holders, we have 959 observations for each numeric variable. The distribution of the dependent variable, the relationship of the industry sector with the academic or scientific sector (LinkInd-Scf),[27] has a mean of 5.8 and a standard deviation of 24.2, with a minimum value of 0 and a maximum value of 365. This suggests that observations are distributed toward the left in the first quadrant, as are the data as a whole, because they involve positives values (see Graph 1). Other numeric independent variables have the same behavior: diffusion of inventions (FwPatCit); previous technological knowledge (BwPatCit), and inventor team size (SizeInvT), with BwPatCit having the highest mean (14.9) and the higher maximum value (391).

Figure 4
Mexico: frequency distribution of the dependent variable LinkInd-Scf



Source: Developed by authors, based on USPTO database.

27 We use the number of scientific articles cited (SC) by the Mexican patents granted by USPTO as a proxy variable of academic knowledge used by patents to build the new invention.

Meanwhile, the SizeInvT has the lowest mean (2.7) and the lowest maximum value (13). Even if this variable increases from 1 to 13 inventors, its distribution suggests that only a few inventor teams reach the maximum of 13 and most of them have 2 to 5 inventors. The mean and standard deviation estimation by team ranks confirm this behavior. Indeed, a research team of *2-5 inventors* (InvT_2-5) has the highest mean, in comparison with the other size teams.

On the opposite side, the numeric variables, specifically inventor's mobility (MobIn) and technological sector (TechSector), have the lowest mean (0.11 and 0.41), which likely means that they do not explain the links between scientific activity and innovative activity in the case of Mexico. This type of analysis is not appropriate for the case of dummy variables, because they have only two values, 1 or 0.

Table 2
Model variables distribution (N=959 patents)

Variable	Obs	Mean	Std. Dev.	Min	Max
LinkInd-Sc	959	5.85089	24.29077	0	365
FwPatCit	959	5.20229	12.35052	0	294
BwPatCit	959	14.92075	25.00004	0	391
Cooptec	959	0.02294	0.14979	0	1
SizeInvT	959	2.72888	1.87710	1	13
InvT_1	959	0.40355	0.49086	0	1
InvT_2-5	959	0.52450	0.49966	0	1
InvT≥6	959	0.07508	0.26366	0	1
MovIn	959	0.11887	0.32381	0	1
TechSector	959	0.41502	0.49298	0	1

Source: Developed by authors, based on USPTO database of patents assigned to mexican holders.

The importance of inventor team size (from 2 to 5) and technological sector to explain the links between academic and technological activities is confirmed with the frequency values. In effect, the frequency of InvT_2-5 is 503; in the case of InvT- it is 387. Finally, the frequency for TechSector is 398. On the other hand, the variables *Cooptec, InvT_6* and *MobIn* could not be significant in explaining these links since their frequencies are low (22, 72 and 114, respectively).

The inventor team variables with one inventor (*InvT-1*), teams with 2-5 inventors (*InvT_2-5*) and teams with more than 6 inventors (*InvT_6*) are subsets of the inventor team size variable (*SizeInvT*). This could cause a collinearity problem. In accordance with the matrix correlation, the *InvT-1* and *InvT_6* variables are highly correlated with *SizeInvT*. Also, the *InvT-1* variable is found to be highly correlated with the *InvT_2-5* variable. For this reason, we decided to not estimate the models using the *InvT-1* variable (see Table 2).

Table 3
Mexico: Correlation matrix

Variable	SizeInvT	InvT-1	InvT_2-5	InvT_6
SizeInvT	1			
InvT-1	-0.7535	1		
InvT_2-5	0.3899	-0.8511	1	
InvT_6	0.6613	-0.2343	-0.2992	1

Source: Developed by authors, based on USPTO database of patents.

Outcomes
According to the Poisson model estimations, the best one considers the dependent variable LinkInd-Sc*Mx,in* as a natural logarithm. Also, we calculated the robustness in the errors in order to eliminate intrinsic heteroscedasticity (non-constant variance). As a result, all the independent variables are significant in explaining the links between science and technology in Mexico, with the exception of technological collaboration (*Cooptec*).

Nevertheless, the Poisson model selected has dispersion problems, or in other words, it does not satisfy the Poisson distribution equidispersion characteristic, according to the alpha test (with a different value of 0, 7.53E-08). Therefore, we have proceeded to estimate a negative binomial model.

In Table 4 we present the outcomes of both models. The parameter values estimated in the *Poisson* model and the negative binomial model coincide. That is to say, all the values have statistical significance, with the exception of the technological collaboration variable (*Cooptec*), with a *probability value* of 0.676. However, the negative binomial model does not present a equidispersion problem as the Poisson model does. It is therefore convenient to use the second model in order to prove our research hypothesis.

Despite the statistical significance of the parameter values estimated through the negative binomial model, not every variable explains the propensity toward industry and science links. Indeed, we have confirmed the hypothesis regarding the positive influence of the following variables: previous accumulated knowledge (*BwPatCit*), international inventor's mobility (*MobIn*), technological sector according to degree of scientific intensity (*TechSector*), inventor team size (*SizeInvT*), and particulary the team with 2 to 5 inventors (*InvT_2-5*). In the case of technological knowledge diffusion *(FwPatCit)*, the impact is statistically significant, but negative.

On the opposite side, technological collaboration *(Cooptec)* is not associated with propensity toward industry and science links. Taking into account that university-industry collaboration has a complex dimension, in which co-authorship is only a small aspect, not all the firms with collaboration agreements decide to share a patent, depending on a firm's R&D capabilities (Klitkou, Patel & Campos, 2009). Therefore, co-assignee patents become a proxy variable that partially reflects university-industry collaboration. Few Mexican patents share the co-assignee, and they are mostly identified between universities.

Therefore, we have confirmed the importance of these variables in explaining propensity toward science-industry links.

Table 4
Results of Poisson and Negative Binomial models

Variable/Model	(***Poisson***) Model 1	(Negative Binomial Model) Model 2
FwPatCit	-0.012528	-0.012528
	(0.067)	(0.067)
BwPatCit	0.004151	0.004151
	(0.000)	(0.000)
Cooptec	-0.091485	-0.091485
	(0.676)	(0.676)
SizeInvT	0.061132	0.061132
	(0.001)	(0.001)
InvT_2-5	0.194860	0.194860
	(0.030)	(0.030)
MobIn	0.255096	0.255098
	(0.010)	(0.010)
TechSector	0.540752	0.540752
	(0.000)	(0.000)
Cons_	-0.412646	-0.412644
	(0.001)	(0.001)

Source: Authors' estimations based on USPTO patent database.

Marginal effects
In order to better understand the magnitude of the impact from the independent variables (*BwPatCit*, *MobIn*, *TechSector*, *SizeInvT* and *FwPatCit*) on propensity toward industry-academic links, it is important to estimate the negative binomial marginal effects, or in other words, how an increase of one unit in each variable could influence the propensity toward science-industry links.

The variables with more positive elasticity effects are: *TechSector, MobIn and InvT_2-5*. Lesser effects are found in *SizeInvT,* and even more so, in BwPatCit. The elasticity of *FwPatCit* is negative.

The biggest elasticity effect was found in technological sectors or technological sectors axed to the scientific intensity variable. When there is an increase of one patent classified in one technological sector or one science-intensive technological sector, then propensity toward science and technological links (the number of scientific articles cited in the Mexican patents granted, SC) grows by 71.1%. This result confirms that greater propensity toward scientific articles cited in a patent occurs in science-intensive sectors such as the chemical, computers & communication, drugs & medical, and electric & electronic sectors, as pointed out by Henderson, Jaffe & Trajtenberg (2002);

Bransteter (2003); Branstetter & Ogura (2005); and Brechi *et al*. (2006). Even though the universities-firms relationship is still weak in Mexico, we can appreciate that inventive activity patented in those fields fosters in a highly significant manner the flows of knowledge among science and technology, through scientific citation in patents. In this sense, we underscore the idea that scientific publications with more factor impact are more likely to become a source of technological inventions identified with knowledge intensity. One of the fields in which there is more propensity toward university-firm collaboration in Mexico is biotechnology, classified in the technological category of Drugs and Medical. Firms such as Instituto Bioclon and Laboratorio Silanes are some examples of the interaction between science and industry in biotechnology (see Table 4).[28] Given the importance of petroleum in Mexico, a relative pattern of specialization can be observed in the chemical sector, and significant flow of knowledge in science and industry occur in this field, as illustrated in the large number of scientific publications cited by Grupo Petromex, S.A. (see Table 4).

Another huge influence is from the international inventor's mobility (*MobIn*). According to our elasticities estimations, when there is an additional patent with the presence of a foreign inventor (researcher) on the team, the number of scientific articles cited in the Mexican patents granted (SC) may increase by 38.8%. This result reinforces the idea that not only is the spread of new ideas increased by the international researchers' mobility in general, but particularly important is when foreign researchers are integrated in Mexican research teams and their presence in our country is capitalized by the national universities/institutes and firms. Nevertheless, if S&T policy in Mexico has not extensively fostered the mobility of foreign researchers in order to strengthen research teams, the results show that the effects could be of greater importance. Let us see how the United States has benefitted from the presence of a large number of foreign scientists in developing its extensive patented inventions. Foreign researchers have been involved for quite some time as inventors in US patents, especially in the new paradigm technologies. A study shows that just over three of four parts of patents from the top ten US universities that generated patents during 2011 had a foreign-born inventor on the team (Partnership for New American Economy, 2012). Ninety-nine percent of these patents with foreign-born inventors are found in scientific, technology and math (STEM) fields. Therefore, this report recognizes the relevance of contributions from foreign-born graduates to the US economy.

The elasticity effects are relevant in the case of inventor team size, particulary in teams with two to five inventors. When there is an additional patent with a 2-5 inventor team, our dependent variable (SC) could growby 27.2%. This result emphasizes the importance of the research conducted by inventor teams that in many cases combine the academic and industrial sectors (Brechi *et al*., 2006). Also, this elasticity measure suggests that team size allows for efficient interaction among the researchers who

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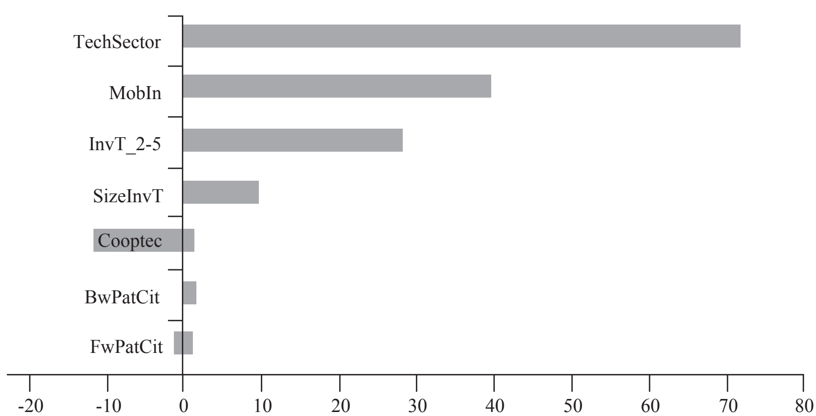
28 Wagner (1998) has an interesting qualitative study concerning this issue in which she conducted interviews with the leaders of science, industry and government. Her research reveals the abyss existing between science and industry; that said, the researchers interviewed manifested their awareness that little scientific progress is transferred to the marketplace. Other studies, especially Master's or PhD theses, have focused their analysis on the links between research institutes and pharmaceutical companies specializing in biotechnology.

contribute to scientific citation as they develop new ideas (invention).[29] In general an increase of one unit in the inventor team size variable has an impact of 8.7% on scientific citation in patents. Singh & Fleming (2010) found that, in a negative binomial model, a team's size and the product of its collaboration has a significant positive impact on higher-quality invention, but it could also be of lower quality.

Unlike the variables mentioned above, we found that technological knowledge diffusion (FwPatCit) has a negative impact elasticity. When one more citation is made in a Mexican patent, there is a 1.8% decrease in propensity toward science and technological links. This can likely be explained by the fact that forward patent citacion concentrates recognition directly from the technological invention but not from the scientific knowledge that provided the basis for the invention. In any case, FwPatCit is associated with the patent's value, and specifically with radical inventions. Mexico is not characterized by innovative efforts, and not even for radical innovation.

Regarding accumulated technological knowledge (BwPatCit), we found that with an increase of one unit of BwPatCit, our dependent variable grew by 0.5%. The importance of BwPatCit in building new knowledge has been established in the specialized literature on this topic, but the fact that this variable has minimal effects suggests that it is associated with the weak intellectual property culture in Mexico (Guzmán, López-Herrera & Venegas-Martínez, 2012). Also, technological knowledge flows are relatively small (Guzmán & Gómez, 2015), and even more so in the case of links among universities and firms.

Figure 5
Marginal effects of the variables affecting the industrial-science links propensity



Source: Own estimation based on model 2.

[29] Singh & Fleming, 2010 argue that, on the one hand, the larger the team, the greater the diversity of knowledge, leading to a higher combinatorial opportunity to discover breakthroughs. On the other, team size can affect the level of strictness in the process of idea selection, affecting the quality of a research team's innovative efforts.

Table 5
Mexican patents granted by USPTO with higher scientific publications' citations by assignee and technological category

Patent No.	Assignee name	Number of publications cited by the patent	Technological category
8,557,950	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García, MX)	365	Chemical
8,431,202	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García MX)	242	Electrical & Electronic
8,470,257	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García, MX)	194	Chemical
7,960,581	Grupo Petrotemex, S.A. de C.V.	194	Chemical
8,178,054	Grupo Petrotemex, S. A. de C. V.	191	Chemical
8,114,356	Grupo Pretrotemex, S.A. de C.V.	191	Chemical
7,932,345	Grupo Petrotemex, S.A. de C.V.	182	Chemical
8,501,986	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García, MX)	158	Chemical
7,943,094	Grupo Petrotemex, S.A. de C.V.	136	Chemical
8,507,249	Universidad Nacional Autónoma de Mexico (Mexico City, MX), The University of British Columbia (Vancouver, CA)	128	Drugs & Medical
8,470,250	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García, MX)	126	Chemical
8,394,770	Universidad Nacional Autónoma de México (Mexico City, MX)	115	Drugs & Medical
8,039,577	Grupo Petrotemex, S.A. de C.V.	102	Chemical
7,956,215	Grupo Petrotemex, S.A. de C.V.	100	Chemical
7,959,879	Grupo Petrotemex, S.A. de C.V.	98	Chemical
8,114,954	Grupo Petrotemex, S.A. de C.V.	90	Chemical
8,043,855	TGT Laboratories, S.A. de C.V.	75	Drugs & Medical
7,807,457	TGT Laboratories, S.A. de C.V.	75	Drugs & Medical
8,075,893	Instituto Bioclon, S.A. de S.V.	73	Drugs & Medical
8,512,706	Instituto Bioclon, S.A. de C.V. (Mexico City, MX)	71	Drugs & Medical
7,858,368	TGT Laboratories, S.A. de C.V.	71	Drugs & Medical
8,389,005	Nuevas Alternativas Naturales Thermafat, S.A.P.I. de C.V. (Monterrey, N.L., MX)	70	Drugs & Medical
8,563,677	Grupo Petrotemex, S.A. de C.V. (San Pedro Garza García, MX)	68	Chemical
8,153,840	Grupo Petrotemex, S.A. de C.V.	67	Chemical
8,002,910	Tubos De Acero De Mexico S.A., Dalmine S.p.A.	66	Mechanical

Patent No.	Assignee name	Number of publications cited by the patent	Technological category
8,221,562	Maverick Tube, LLC (Houston, TX) Ternium México, S.A. de C.V. (San Nicolás de los Garza, Nuevo León, MX)	62	Mechanical
8,053,597	Grupo Petrotemex, S.A. DE C.V.	59	Chemical
7,485,303	Instituto Bioclon, S.A. de C.V.	58	Drugs & Medical
7,223,713	Centro de Investigación en Materiales Avanzados, S.C.	55	Chemical
7,867,723	Escuela Nacional de Ciencias Biológicas, del Instituto Politécnico Nacional	54	Drugs & Medical
6,376,615	Centro de Investigación en Química Aplicada	53	Chemical
8,022,168	Grupo Petrotemex, S.A. de C.V.	50	Chemical
7,749,721	Universidad Nacional Autónoma de México	39	Drugs & Medical
6,777,193	Escuela Nacional de Ciencias Biológicas, del Instituto Politécnico Nacional	36	Drugs & Medical
7,335,759	Universidad Nacional Autónoma de México	35	Chemical
7,935,399	Grupo Petrotemex, S.A. de C.V.	34	Others
7,381,802	Universidad Nacional Autónoma De México	34	Chemical
6,962,794	Universidad Nacional Autónoma de México	34	Drugs & Medical
5,443,980	Universidad Nacional Autónoma de México (UNAM)	33	Drugs & Medical
8,206,218	TDVisión Corporation S.A. de C.V.	32	Others
7,763,292	Instituto Tecnológico y de Estudios Superiores de Monterrey	29	Drugs & Medical
5,661,010	Centro De Investigación y de Estudios Avanzados del I.P.N.	27	Drugs & Medical
8,309,683	Grupo Petrotemex, S.A. de C.V.	26	Chemical
7,496,450	Instituto Mexicano del Petróleo	26	Computer & Communication
8,501,663	Universidad Autónoma de Puebla (Puebla, MX)	25	Chemical
7,209,733	Pay X PDA, LLC	25	Computer & Communication
8,574,850	Instituto Nacional de Ciencias Medicas Y Nutrición (México, MX), The General Hospital Corporation (Boston, MA), Children's Hospital Medical Center (Cincinnati, OH)	24	Drugs & Medical
8,512,591	Mexichem Amanco Holding S.A. de C.V. (Tlalnepantla, MX)	23	Drugs & Medical
8,496,933	Laboratorios Silanes, S.A. de C.V. (Delegacion Benito Juárez, MX)	21	Drugs & Medical
8,333,901	Mexichem Amanco Holding S.A. de C.V.	21	Drugs & Medical
8,173,871	Universidad Nacional Autónoma de Mexico	21	Drugs & Medical

Patent No.	Assignee name	Number of publications cited by the patent	Technological category
7,799,313	Instituto Mexicano del Petroleo	21	Chemical
7,459,174	Investigación De Tecnología Avanzada, S.A. de C.V.	21	Others
6,287,693	Savoir; John Claude	21	Others
6,241,688	Universidad Nacional Autónoma de México	21	Drugs & Medical
5,861,263	Universidad Autónoma De Nuevo León	21	Drugs & Medical
5,578,646	Alfredo Piñeyro-López	21	Drugs & Medical
5,405,754	Universidad Nacional Autónoma de México	21	Drugs & Medical

Source: USPTO database. Patents granted to mexicans.

■ *Conclusions*

The knowledge flows among science and technology in Mexico continue to be weak, to the extent that scientific production at universities is likely far removed from industry needs. First of all, those conducting research have either focused on scientific findings, or if they establish some technological solutions, they are not always able to commercialize them or apply them in industrial sectors. Secondly, Mexican universities have been created in line with their first mission and knowledge generated has traditionally been kept in an ivory tower. Some universities have moved on to their second mission, and with some exceptions, they have begun to interact with firms within a framework of intellectual property and technology transfer. Nevertheless, local firms have not been characterized by having strong absorption capabilities or capabilities oriented toward innovation activities.

This study has attempted to analyze the factors determining the propensity toward knowledge links between industry and scientific fields across Mexican technological sectors. According to our estimations, using a negative binomial model based on 959 Mexican patents granted, as recorded in USPTO data from 1980 to 2013, and using scientific references cited in patents as a dependent variable (proxy of the links among industry and scientific sectors), we have found that greater propensity toward industry and science links is positively associated with the international mobility of inventors, previous technological knowledge, technological knowledge diffusion, science-intensive technological sectors and higher inventor team size, but negatively associated with technological collaboration.

We have identified a huge impact on propensity toward a science-industry link from the elasticity of science-intensive technological sectors, international mobility of inventors, and inventor team size, especially teams with 2 to 5 inventors. Therefore, these estimations of marginal effects suggest that in order to foster science-industry links, government policies must be positioned to support science-intensive industrial activities, to favor the mobility of foreign researchers in Mexican universities and firms, and to encourage knowledge production by teams, especially those with 2 to 5 researchers.

Building a framework for intellectual property proteccion and technology transfer at universities and institutes is a huge and complex challenge, and it must be supported by an active regulatory government policy on science and technology, as US experience has illustrated with the Bayh-Dole Act.

Firms have been passive not only in providing new technological solutions for productive activities, creating new products to confront global competition and developing new management organizations, but also in their approach to universites and their ability to absorb knowledge and interact in terms of collaboration or technology transfer. These firms must internalize the need to invest in achieving these capabilities. The need to change the culture in firms is a matter that requires action by governments, through the establishment of industrial policies with clear objectives and tasks, and an IP policy designed to motivate loval innovation and avoid abuse by multinationals that attempt to extend the patent period of validity.

To the extent that both universities and firms expand their capabilities to build knowledge flows and benefit from them, Mexican society will become richer, given the impact on economic growth and social well-being.

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