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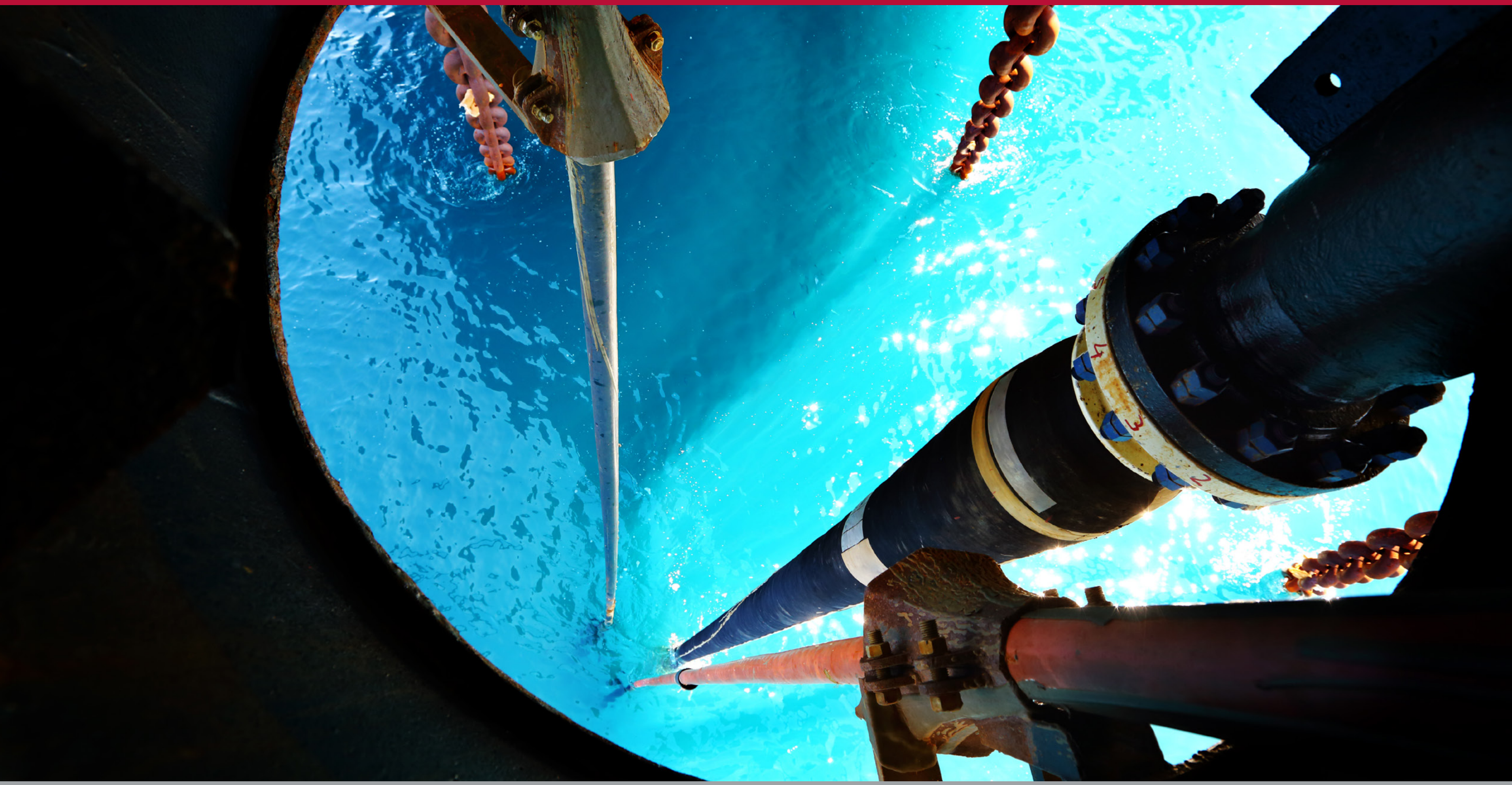

INNOVATION AS AN IMPERATIVE FOR THE MEXICAN OIL INDUSTRY POST ENERGY REFORM

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Introduction

Mexico is among the developing countries that have progressively adopted policies toward a more liberalized and market-oriented economy. Throughout this process, which began in the 1980s, there have been various periods of aggressive privatization of previously government-owned companies. However, in spite of this wave of economic liberalization over the past 30-plus years, it had been very difficult to reach a political agreement to change the monopolistic conditions that prevailed in the energy sector. That changed in 2013 and 2014, when a major structural reform was accomplished in that sector in Mexico. Following that constitutional and legislative achievement, in July 2015 Mexico carried out a first round of oil block bids, beginning the implementation of the energy reform and signaling that the long-awaited opening of the country's oil industry to private and foreign companies had arrived (El Economista 2015a; Foros Milenio 2015). Although not all the oil fields included in that bidding process were awarded—only two of them were sold—the first round of auctions turned out to be very symbolic (El Economista 2015b). To be sure, this did not mean that private or foreign companies were absent from Mexico prior to 2015; the difference is that companies other than Pemex, the national oil company, can now engage in the business of exploration and exploitation, activities that Pemex had previously monopolized under Mexican law.

A recurring argument put forth by the Mexican government to galvanize support for the energy reform was that Pemex lacked the appropriate technology to exploit deepwater oil reserves (Presidencia de la República 2016). This fatal flaw, coupled with the weak financial position of the state-owned company (mostly due to an excessive tax and royalty burden), prevented Pemex from investing in technological research. Thus, the entry of foreign companies was justified on the grounds that opening the energy sector would result in greater technological competence and financial capacity, because these companies would immediately bring their own technological prowess to bear on Mexican oil production. According to Mexican authorities, not only would these major oil companies provide modern technology to tap into deepwater reserves, but by means of collaborative agreements, Pemex and other local organizations would also have the opportunity to upgrade their own technological capabilities. The promise was essentially one of technological transfers.

Some critics of the reform argue that breaking up Pemex's monopoly was not necessary to acquire the technology that the country's energy sector required, since the company in any event had always relied on foreign technology for most of its operations (Domínguez 2008). Others believe that Pemex's financial problems are an obstacle to acquiring technologies that would require enormous amounts of investment and time to assimilate (Miranda 2009). This last line of reasoning stresses that breaking up Pemex's monopoly on the Mexican oil industry will result in enormous gains in productive efficiency and aid the longer-term financial health of the country as a whole. Assessing whether or not this is the case is outside the scope of this paper. This study focuses instead on the technology transfer argument made by the Peña administration and on an issue neglected in much of the subsequent discussion: technological innovation.

It cannot be denied that in the last decades the oil industry has experienced enormous changes in the way innovation is taking place, altering the ways in which companies participate in the industry landscape, among other effects. Under these more dynamic innovation conditions, a few countries, such as Brazil, have achieved what some authors have called "technological catching up." What this means is these countries now participate in the overall innovation efforts of this global industry in a meaningful way (Maleki and Rosiello 2014). The catching-up concept, first used in economics by Abramovitz (1986) to explain the gap reduction in economic output, has been applied in evolutionary studies of technological change to explain how some countries—especially newly industrialized Asian countries such as South Korea, Taiwan, and Singapore—have progressed from the initial adoption of foreign technology transfers to an innovation phase, in which local improvements over that technology are a reality and innovation has become second nature (see, for example, Soete 1988; Shin 2013).

For instance, it is well known that Petrobras, the Brazilian national oil company, has increased its economic performance dramatically thanks to its innovation efforts in deepwater, among other factors. Accounts of the Brazilian catch-up show the importance of the existence of an innovation system systematically fostered by the country itself, which means that different agents with different capabilities interact under policies oriented toward promoting technological learning (Dantas and Bell 2011). Thus, in a world in which oil may be harder and harder to reach, the performance of national industries depends not just on adapting and mastering foreign technology, but also on developing domestic innovative solutions, nurtured by the systematic incentivizing of an innovation culture.

The Purpose and Organization of This Paper

Absent from the discussion of the energy reform in Mexico is an assessment of how important technological innovation is for the future of the country's oil industry. According to various authors (Aboites et al. 2003; Guajardo 2005; Soria 2011), innovation in the Mexican oil industry is largely absent, scant, or declining from already low levels. This observation raises the question of whether the energy reform can contribute to stopping the decline in domestic innovation and improving innovation activities to bring innovation to acceptable levels in the Mexican oil industry. This paper proposes that the energy reform and the overall innovation policy in Mexico do not properly address the complexities involved in innovation within the world oil industry. Based on an innovation system perspective, and drawing from accounts of the evolution of technology and innovation in the Mexican oil industry, the reasons why the country's policy framework is not well suited to promote a catching-up trend in the Mexican oil industry will be explored. The paper ends by making recommendations for building a system of innovation geared toward the oil industry.

The rest of this research paper is organized as follows: First, it briefly reviews the arguments in favor of the energy reform, with an emphasis on the promise of technological transfer and innovation and its implications for innovation development in Mexico. Second, the innovation system perspective applied to the oil industry is used to understand the conditions under which technological catching up may either be made possible or hindered, using Brazil as a comparative case study that may be useful in drawing conclusions for the case of Mexico. Third, the innovation record of the Mexican oil industry is reviewed with special emphasis on the *Instituto Mexicano del Petroleo* (IMP),[1] Pemex's technological research and development arm. The fourth section discusses points missing in Mexican policies that would promote innovation in the oil industry. Finally, some comments primarily geared toward policies that could help nurture a highly innovative environment in the domestic sector are made.

The Premises and Promises of the Energy Reform

One of the main arguments that the Mexican government advanced to justify the energy reform and galvanize public and political support had to do with technology transfers. There is broad recognition of the existence of deepwater oil and shale gas, and also of the lack of technology to access these reserves. Pemex lacks the necessary technology to exploit those resources and cannot develop such technology on its own; additionally, it is in bad shape financially and therefore unable to invest in a solid R&D agenda. Of course, besides this argument there might be a myriad of other reasons to carry out the energy sector reform, but the promise of technology transfers and the possibility of leapfrogging in technological innovation was one of the major arguments made in order to gain support for the reform.

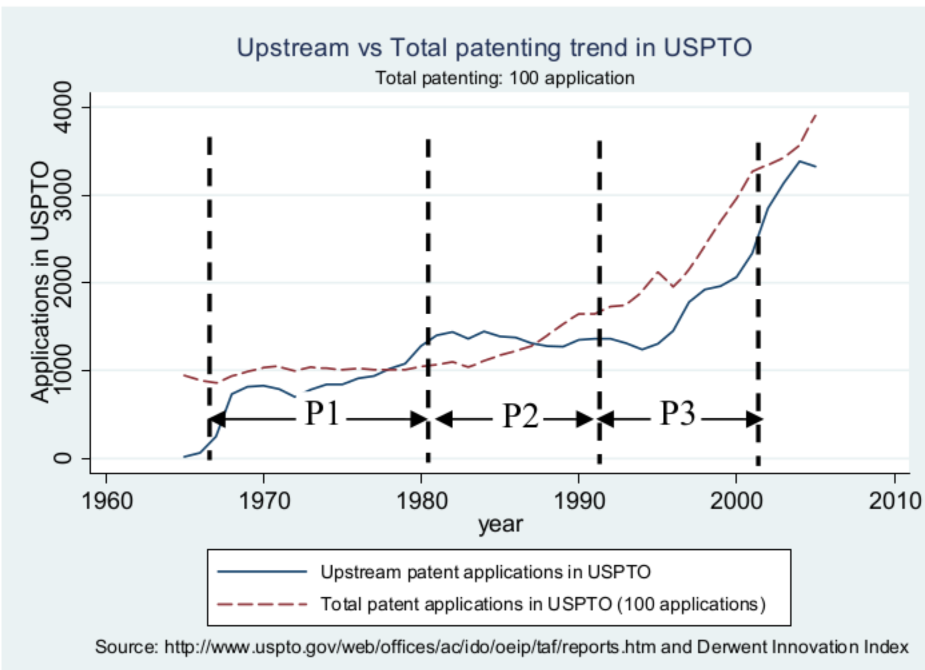
More specifically regarding technology transfers, the reform contains some provisions for guiding Pemex through contracts and joint ventures and for maximizing these transfers. For instance, in the case of acquisitions and public works, the law states that Pemex can waive open bids and use its own discretion, provided that these joint ventures involved technology transfer, among other things (Presidencia de la República 2014a). The few other references to technology are along the same lines. Although these types of provisions can be considered a tool for Pemex's management of technology transfers—that is, for leveraging Pemex's contractual agreements to obtain technology—they are clearly not enough to transmit a powerful message in which Mexican authorities set the tone for an aggressive technology transfer program. When it comes to innovation and the role of the IMP, the provisions are even less clear. In the Hydrocarbons Law, the IMP is mentioned only five times (Presidencia de la República 2014b). In four of those mentions, it is indicated that the IMP should provide information to the new regulatory bodies, and the other indicates that the IMP should continue playing a crucial R&D role, but leaves those functions to be specified later. Therefore, it is easy to conclude that there are only vague references to technology transfers, the IMP, and innovation, in spite of the fact that these issues were key in the public debate (Martínez-Romero 2015).

[1] In English, the Mexican Institute of Petroleum.

Can Catching Up in Innovation Happen in the Oil Industry?

Maleki and Rosiello (2014, 14) argue that few countries have managed to significantly reduce the technological innovation gap—especially in the upstream oil industry—although some have managed to do so marginally, including China, Brazil, Saudi Arabia, and the United Arab Emirates. Using the Derwent Innovation Index, which has a specific classification for patents in the upstream petroleum industry, Maleki and Rosiello (2014, 5) examined U.S. Patent and Trademark Office (USPTO) records from the mid-1960s to 2005 and found that the upstream oil industry in the United Staets has experienced changes in its rate of patenting. They interpret this trend as periods of technological stagnation and opportunities for growth. It is precisely during such times that catching up in innovation is possible (Figure 1).

Figure 1. Upstream versus Total Patenting Trends in the USPTO



Source: Maleki & Rosiello (2014, 3).

The way in which knowledge is created and used in the upstream oil industry has itself undergone an important transformation through the years, something that has implications for the innovation opportunities that can materialize along the chain of innovation. During Period 1 (P1) as defined by Maleki and Rosiello (2014), the industry experienced the emergence of new technical fields like 3-D seismic and horizontal drilling. The central characteristic of that period was *variety*, in the sense that new technologies were added to the knowledge base of the industry. During P2, "it was difficult for operators to manage the increasing range of specialized subcontractors in different technical domains and coordinate the interfaces, [and at that point] integrated services companies took this role" (Maleki and Rosiello 2014, 8). This trend continued during P3.

These changes in the oil industry allowed a surge in specialized suppliers (integrated service companies such as Schlumberger, Baker Hughes, and Halliburton), which took a prominent role in the industry's overall innovation. Perrons (2014, 306-307) reports that in his sample, service companies were responsible for 80 percent of the patents.

This does not mean that well-known international oil companies (Shell, Exxon, etc.) are not innovating within their operations, but that they have either been developing new technologies jointly with or relying entirely on service companies, which are better positioned for marketing and maintaining those technologies that in principle can be applied across different oil companies (Acha 2000, 18). Acha (2000) explains that these international oil companies (also known as "majors") have developed technological capabilities around the integration of different technologies to devise new methodologies of exploration and production (20). In general, these innovations are less likely to be patented. Therefore, following the patents indicator makes it clear that in terms of innovation, integrated service companies have a prominent role—although majors and other players have the ability to innovate in other ways.

Given the circumstances described above, Maleki and Rosiello (2014) argue that innovation in the upstream oil industry has changed from being based on variety-induced complexity to being based on systemic complexity. This means that the "knowledge base of the industry is not developed just by accumulation of knowledge in existing knowledge domains or by simple addition of new technical domains to existing ones, but through interactions and recombinations between existing and new technologies" (Maleki and Rosiello 2014, 9). These circumstances benefit established players who are able to integrate different knowledge domains and erect barriers to latecomers, who may find it difficult to access different pieces of knowledge and integrate them (9).

However, as previously mentioned, despite the systemic complexity prevalent in the oil industry's knowledge base, some countries have managed to reduce—although not completely eliminate—the innovation gap, one such example being Brazil. Still, it is important to clarify that although this country has made good progress in terms of innovation, it is still far behind the leaders of innovation (Maleki and Rosiello 2014). It is also noteworthy that even to achieve the advantages that Brazil has acquired, it has taken enormous efforts framed by coherent public policies to do so. Maleki and Rosiello (2014) propose that late-coming countries that have overcome barriers to innovation in the industry have two characteristics in common: First, they have large oil deposits and their governments have incentives for creating an innovation system to access them. This process is sometimes built around the idea that local firms are in a better position to exploit local opportunities, and most incentives are directed toward these firms. Second, and related to the first, these governments have actively sought to create a set of organizations and have put policies in place to create and foster an innovation system aimed at the petroleum industry.

Regarding the first factor—namely, the availability of large oil deposits—the case of Brazil fits the explanation in the sense that the existence of the pre-salt oil deposits in deep waters triggered innovation efforts to acquire the ability to tap those fossil resources (Florencio 2016). Brazil also incentivized the development of local firms and participation in innovative efforts. In fact, since the end of the 1960s, the Brazilian government has declared that one of its main objectives was guaranteeing the domestic supply of oil products (Guajardo and Pech 2015; Florencio 2016). Among the actions taken by the Brazilian government for this purpose was an aggressive program of human resource training that included sending people abroad, as well as the creation of programs in local universities dedicated to accelerate the creation of an innovation system. As a consequence of these efforts, Petrobras today has a comprehensive training program for its employees that revolves around a solid culture of innovation. Central to building this innovation system was the creation of the Petrobras R&D center known as Cenpes (Guajardo and Pech 2015). Florencio (2016) explains that the Brazilian policy also included the development of local suppliers from the beginning of the new innovation policy as a way of engaging different local players in the industry.

It is reasonable to classify the steps taken by Brazilian authorities in building an innovation system as a sectoral innovation system, a concept put forth by Malerba (2002). This concept stresses the role not only of firms and their complementary businesses, but also that of other non-firm organizations such as universities and knowledge-producing organizations, as well as government policies and regulations that together shape the dynamics of specific economic sectors—all of which constitute, in effect, an innovation ecosystem. Thus, the concept goes beyond traditional industry boundaries as defined by official classifications and places emphasis not only on sector competition but also on cooperation. This last feature of the innovation system concept is relevant to Brazil's case, since Petrobras, which occupies a central role in that country's energy innovation ecosystem, has collaborated with different firms—mainly foreign—in order to build its innovative capacity.

Dantas and Bell (2011) describe this innovation capacity building as a co-evolution between internal capacity expansion and innovation network membership. According to these authors, Petrobras started with only the ability to assimilate foreign technology in the late 1960s. The authors go on to state that the next phase of adaptive capabilities developed by Petrobras came in the period 1985-1991, when Petrobras' network approach evolved from a passive recipient of foreign technology to a more active participant in investing in adaptation and in absorbing technology. The period 1992-1996 was one in which Petrobras dedicated much of its effort to generating new capabilities, and its network activities started to include R&D elements in their own right. Finally, the authors argue that from 1997 to early 2000, Petrobras acquired the technological level to be classified as having strategic capacities. During this last period, the company was more active within its network and was even capable of transferring technology to other parties.

Petrobras' demand for knowledge therefore consisted of complex sets of science and technology knowledge spanning a wide range of scientific disciplines and technological approaches supported by explicit government efforts to build the right institutions in order to incentivize innovation. Senior management of Petrobras was aware that all these knowledge bases could not be completely internalized and sought to build networks for accessing and mobilizing capabilities outside the company's boundaries for the purpose of undertaking specific R&D projects. As a consequence, the company's knowledge networks came to incorporate flows of complex S&T knowledge in core and non-core technologies within established and emerging technological trajectories. Also, as the knowledge sets demanded by the company were distributed among numerous actors, including not only service and equipment suppliers but also S&T organizations and other oil companies—as well as Petrobras itself—the company's networks came to include this widely diverse set of knowledge sources (Dantas and Bell 2011, 1579).

In a detailed analysis of the processes described above, Dantas & Bell (2011) observe that different levels of technical capacity were necessary in order to access different knowledge networks. As Petrobras gradually accumulated capabilities, it was able to establish collaborations with greater knowledge content networks. These authors point out that the degree of knowledge content varied among the different networks in which Petrobras was involved, which means that Petrobras did not achieve frontier innovation levels in all technical fields. Another important issue is that as networks became more knowledge-intensive, Petrobras' decision to enter was based not just on acquiring and adapting external knowledge, but to develop specific knowledge deemed to be strategic to tackle the challenges the company faced. These latter networks required a more scientific and R&D approach that eventually leads to innovation. Thus, it would seem that innovation is not merely the result of a process of evolving capabilities but rather needs deliberate and explicit measures in order to be reached.

Even if the case of Brazil and Petrobras holds important lessons for catching up in innovation for the Mexican oil industry, it is important to note that contrary to the case of Norway—another late comer to the oil industry—Brazil has not been able to increase innovation levels in small and lesser-known local suppliers of the industry. In an effort to reverse this situation, regulations in Brazil have provisions for these local suppliers to be included in deepwater endeavors (Mendonça & de Oliveira 2013).

Florencio (2016) warns against the combination of the Petrobras monopoly and recent local content policies as being detrimental to the development of an innovative set of local suppliers. According to this author, the monopoly on pre-salt oil deposits granted to Petrobras places this company in a hegemonic positions *vis a vis* other companies, including local suppliers. By having to deal almost exclusively with Petrobras, these local suppliers greatly diminish their contact with other international companies at the technological frontline. Also, given the asymmetrical relationship between Petrobras and local suppliers, it is possible that the former can exert pressure to lower the suppliers' prices. This is even more likely given the local content policy, because once the specified percentage of local content is reached, Petrobras is no longer obliged to resort to these suppliers. This situation becomes a bargaining instrument that benefits Petrobras, if the local suppliers want to be included beyond the local content threshold. Ultimately, this situation can lead to underinvestment in innovation by the local suppliers, which in turn hinders innovation in Petrobras itself. Another flaw of this local content policy is that it does not distinguish between different technical sectors. The sectors with higher innovation potential are subject to the same local content policies, which sometimes means having to work with suppliers unable to meet the desired technical standards (Florencio 2016, 251). Overall, this author's warning seems to be on solid ground because of the variety of technical fields involved in the upstream segment.

In summary, the conceptual framework proposed by Maleki and Rosiello (2014) states that innovation catching up in the industry for latecomers depends on three factors: 1) the systemic complexity of the knowledge base, 2) the availability of ample local oil deposits, and 3) the existence of an innovation system that supports the oil industry.

The Evolution of Innovation in the Mexican Oil Industry

Pemex is the central organization in the Mexican oil industry. In spite of occupying this central role, technological development had been a marginal concern for the company. This is even more pronounced in the case of innovation, a task left nominally to the IMP. According to Domínguez Vargas (1998), Pemex's leaders realized that it needed to adopt more modern technologies in order to increase its performance. This author explains how the company elaborated a comprehensive plan in which one of the stated goals was to reduce the gap between the technologies used by world leaders and those at Pemex's disposal. In terms of organizational changes, Domínguez Vargas (1998) states that in 1996 the sub-directorate "Technology and Professional Development" was created, which grouped together functions previously dispersed over four areas, giving more coherence to these efforts (16). The plan also stressed the importance of increasing R&D and staffing levels, which was directly related to the IMP; however, the author also pointed out the IMP's lack of capacity to retain talent and the divestment from some of its fundamental R&D activities (17-18). He advocated for continuity in the administration of the IMP in order to accomplish its critical task, which has not been the norm and is a general negative trait of some Mexican organizations. Even if Pemex did acknowledge its need to strengthen technology development (or adoption) and innovation within the IMP, the results were limited because of financial under-investment in those areas, among other factors.[2] Next, we are going to focus on the development of the innovation capacity of the IMP.

When discussing innovation in Mexico, the IMP stands out as the public entity with the most patents, not just within the oil industry but in the country overall. However, the number of patents alone does not reflect all innovative activity. This is also true for the IMP, which has accumulated capacities in energy facilities design, engineering, and other areas that may not be reflected in the patents it possesses. Even so, patents do represent an important indicator, because organizations such as the IMP are judged to a large extent by

[2] From personal communication with Guillermo Domínguez Vargas on December 14th, 2016. Dr. Domínguez Vargas was in charge of Pemex's Sub-directorate of Technology and Professional Development 1996-2003.

their intellectual property assets. As we will see, based on this intellectual property indicator, the IMP has experienced an important decline in its innovation activity, which is consistent with what some authors identify as a decline in the technology content of the IMP's unpatentable activities (Aboites et al. 2003; Guajardo 2005; Soria 2011). As shown in Table 1, the number of patent applications submitted by the IMP has declined by 37 percent over the last 20 years compared to the previous period of the same length. A simple ratio of patents per year shows that for the period 1973-1993, the average number of patent applications granted was 21.25, while for the period 1994-2014 that average was 13.3.

Table 1. Number of Patents Granted to the IMP (1980-2016, according to application period)

Application period	**1973-1993**	**1994-2014**	**Total**
Patents	425	266	691

Source: Own elaboration based on Soria (2011)[3] with information from IMPI-SIGA.[4]

According to Soria (2011), this decline in the IMP's patenting record is due to an ongoing decline in the learning and capability-building activities of the Mexican oil industry. The first period in Table 1 corresponds more or less to a period that Aboites et al. (2004) call *La triada innovadora* (the Innovation Triad), which can be viewed as the golden age of the IMP, while the second period covers the vanishing of this Innovation Triad (Aboites et al., 2003).

It is not just patents that are in decline. Some authors agree that the IMP is moving away from R&D and other technology-intensive activities to more service-oriented activities with low technological content (Aboites et al. 2003; Guajardo 2004; Soria 2011). Therefore, there are signs that innovation in the Mexican oil industry is in decline. This should also be considered in light of the fact that innovation levels in the Mexican oil industry have historically been rather low compared to international levels.

Analyzing the evolution of the IMP's knowledge base gives us important clues about the ascent of the IMP and its subsequent decline. The IMP was founded in 1965, over three decades after the nationalization of the Mexican oil industry in 1938. Authorities wanted Pemex to enhance its capabilities in exploration and drilling in order to be able to satisfy

[3] We follow Soria's (2011, 547) approach in dividing granted patents by application period, with the first period ending in 1993 and the second starting in 1994 because, as is explained below, it was a turning point for the IMP. In Table 1 there are some minor discrepancies compared to Soria (2011, 547), probably due to the way in which the information has been updated in IMPI-SIGA.

[4] The Instituto Mexicano de la Propiedad Industrial (IMPI) is the Mexican office in charge of intellectual property rights. Sistema de Información de la Gaceta de la Propiedad Industrial (SIGA) is the IMPI's information system. Data were retrieved March 28, 2017, from http://siga.impi.gob.mx/newSIGA/content/common/principal.jsf.
Two queries were used in an advanced search that specified invention patents:
1) FECO:[1980 TO 2016] AND FEPE:[1973 TO 1993] AND DATI: "Instituto Mexicano del Petróleo"
2) FECO:[1980 TO 2016] AND FEPE:[1994 TO 2014] AND DATI: "Instituto Mexicano del Petróleo"

local demand. This required Pemex to develop technologies, and the IMP was created to carry out vast scientific and engineering innovation programs (Guajardo 2004, 4). Guajardo (2005) points out that these initial activities required the help of international companies. This author's interpretation is that in an effort to achieve operational efficiency for Pemex under a *nationalist* policy, Mexican authorities gave enormous financial support and time allotments for the IMP to deliver results; however, in order to do so, innovations from abroad were adopted. Thus, the IMP's initial knowledge base was built on the basis of imported technologies and innovations in the hope that eventually it would develop its own.

While the initial research activities carried out by the IMP were aimed at expanding known oil reserves, the IMP later sought to improve Pemex's refining processes by developing catalysis-related technologies suited for the specific characteristics of the oil found in Mexico. According to Soria (2011), this process started because Pemex wanted to save financial resources by cutting back on purchases from foreign companies, which were considered overpriced. This situation gave rise to an important R&D project with significant gains for the country's oil industry, in the sense that a Mexican organization was able to provide solutions based on R&D efforts at some point in the oil value chain. Soria (2011) characterizes the results of these R&D activities in the area of catalysis as incremental innovations because they improved upon an initial foreign technology. Moreover, the author explains that even though those innovations were the result of IMP efforts, the methods used mimicked the ones of leading foreign companies in the catalysis field. Thus, the IMP innovation was incremental and the learning processes were based on imitation (Soria 2011, 539). These characterizations are consistent with the figures related to the resources invested in basic research versus those in applied research. Soria (2011, 532) reports that between the periods 1972-1986 and 1987-2000, the number of inventors assigned to applied research grew 162 percent, while the number associated with basic research grew 50 percent. In the case of applications for patents over the same period, the increase in those related applied research was 71.4 percent, while the number of those related to basic research only increased 6.1 percent. These figures are revealing in the sense that basic research tends to be more related to radical innovation, while applied research is more related to incremental innovation.

This tendency to favor applied research over basic research is also documented by Guajardo (2004), who describes a tipping point in the mid-1970s: Some people within the IMP were arguing for more basic research in order to tackle what they saw as oncoming challenges for Pemex, while others thought that the IMP should stick to a more applied research agenda to obtain rapid solutions to basic problems present at that moment. Financial and political pressures played in favor of keeping the IMP's orientation as an applied research center. The economic crisis of 1976, coupled with the abundant oil deposits discovered during those years, favored an export-oriented strategy that would provide needed foreign currency at a time when the United States was looking for more secure sources of oil (Guajardo 2005, 109). It seems that this orientation toward exports favored rapidly obtained solutions to increase crude oil production, instead of strengthening other technological fields with a longer-term vision.

In terms of the existence of vast oil deposits—the second factor in our conceptual framework—Mexico did possess such deposits, as was the case in Brazil. However, Mexico started its innovative efforts relatively late and favored an agenda geared more toward applied research rather than a long-term innovation policy. In recent years, even that applied research has been in decline. However, despite the incomplete technological development described so far, the IMP achieved certain technological capacities and some level of innovation that allowed for the development of the Mexican oil industry.

As was mentioned in the conceptual framework, the third element is the development of an innovation system able to nurture a learning process. Mexico's case is not an exception in the sense that in order to achieve innovation—even at low levels—it seems mandatory to have a set of supporting organizations and policies.

Aboites et al. (2004) coined the term "Innovation Triad" to make reference to three entities: the IMP, Pemex, and foreign companies. According to these authors, the relative success in innovation in the catalysis field achieved by the IMP was possible thanks to a specific organizational arrangement in which the IMP was in charge of designing the catalysis-related products, foreign companies were in charge of their production, and Pemex used the technology in its refining processes. Aboites et al. (2004) explain that normally, oil companies buy catalysis-related products from specialized suppliers; however, before the purchase, the suppliers are required to do large-scale testing in order to be able to sell the product. In the case of the IMP, it received specifications from Pemex regarding the technology that the company needed and proceeded with the catalysis-related product design. However, the IMP lacked the facilities to do large-scale testing, and at that point Pemex stepped in by not requiring the tests; that is, Pemex—as the user—waived the requirement, facilitating the development process. At that point, the IMP was free to enter into an agreement with an external company to manufacture the catalysis-related products. This three-way relationship—IMP-Pemex-producer—allowed a significant penetration of the IMP's catalysis-related products into Pemex operations. The results were evident a few years later. The fluid catalytic cracking (FCC) process, which is the IMP catalysis process used by Pemex to refine more than half of its gasoline (Soria 2011, 528), accounted for less than 10 percent of the products used by Pemex in 1989, and the rest was purchased from foreign companies. However, by the year 2000, almost all the products related to the FCC process used by Pemex were designed by the IMP (Aboites et al. 2004). It is important to note that although the catalysis-related products were created by the IMP, the institute had to find a partner to manufacture its products—in this case, well-known U.S. companies such as Engelhard Corporation and Grace.

The Innovation Triad worked well for some time. It helped with Pemex's refining operations and the IMP's R&D activities, and also benefited foreign specialized suppliers through production contracts. One drawback to the arrangement was that in not having the facilities to test and manufacture its products, the IMP had only limited capabilities. Guajardo (2004) mentions that at some point there was the idea of building a plant for the IMP to manufacture its own products. However, officials from Pemex said it was beyond the R&D scope of the IMP and banned the project. It may have been true that operating a manufacturing facility would have transformed the IMP's objectives, but it was also difficult to set up a local private company for production due to market size considerations. Aboites et al. (2004) reported that some local companies actually carried out manufacturing activities but had gone out of business because of market size, given that Pemex-IMP was their only customer. Currency devaluations also rendered raw materials coming from abroad unaffordable. From an innovation system perspective, this might be seen as a failure to develop other players that could have brought other technological capacities to the system.

Despite some good results obtained by the IMP, the relationship between Pemex and the IMP changed in the 1980s from an *ad hoc* arrangement to a more market-oriented and institutionalized relationship. From then on, Pemex no longer had to finance IMP projects in advance. Instead, the specific branch of Pemex dealing with the IMP would only pay for services provided (Guajardo 2005). Aboites et al. (2003) point out that the new orientation of macroeconomic policies and, consequentially, science and technology policy had an impact on the IMP. The agency in charge of implementing research and development policy in Mexico, Consejo Nacional de Ciencia y Tecnología (CONACYT), argued that the government alone cannot fully finance research and development, and that research institutes should seek to adopt a businesslike approach. This resulted in a restructuring of IMP activities into 1) basic and applied research; 2) commercializing products, projects, and services; and 3) graduate education. According to Guajardo (2004), one fundamental obstacle to the IMP commercializing its products more broadly had to do with the fact that more than 90 percent of its operations were dedicated to satisfying Pemex's needs, making it difficult to diversify. Worse yet, Pemex changed the catalysis process used in some of its refineries to technologies not yet mastered by the IMP.[5] Finally, regarding graduate education, one positive note was that such services did provide the IMP with the cash it urgently needed. However, whether this activity should be central to the IMP is a disputed matter. In general terms, the IMP has opted to expand the services it offers to different branches of Pemex and therefore has concentrated on services that bring in cash to cover daily expenses, to the detriment of more R&D-oriented activities (Soria 2011).

More recently, to compensate for Pemex's previous full support of the IMP's activities and in accord with the new science and technology policy driven by CONACYT, the latter institution together with the Energy Ministry (*Secretaría de Energía* [SENER]) has launched a special program to fund hydrocarbon-related research projects.[6] Although this program is basically open to any research institution or company, it is revealing that the IMP stands out as the organization with the most projects authorized by the fund during the period 2009-2012—a total of 29. In a distant second place is the National Autonomous University of Mexico with 7 projects funded, representing roughly 53 percent and 13 percent of the total number respectively.

[5] This change has to do with Pemex's need to refine crudes with more impurities.

[6] For more information, see CONACYT's web page: http://www.conacyt.gob.mx/index.php/fondos-sectoriales-constituidos2/item/conacyt-sener-hidrocarburos.

There are two important points here. First, besides providing the IMP with other financial sources to sustain its fundamental activities, it is implicit in this new CONACYT policy that other players are welcome to expand the oil innovation system, since innovation is conceived of as requiring the recombination and cooperation of different sources of knowledge. However, the results of the program so far seem to indicate that it is difficult for other organizations to attain the needed capabilities to initiate research in hydrocarbon technologies. Moreover, only one of these projects is reported as being conducted jointly by more than one organization, which reveals the lack of collaboration in this area. This is consistent with what was said about IMP's patents, in which co-invention is rare.

The second important aspect is that the last year this fund was in operation was 2012. There is no indication as to why this has been the case, but it should be addressed in the future. However, the CONACYT-SENER hydrocarbon fund has another chapter devoted to developing specialized human resources, which has been consistently offered to date. In this sense, it can be argued that human capital formation has been a central element in CONACYT's support programs. Although it is of fundamental importance to have specialized human capital to develop innovation in this sector, this condition alone is not enough, since these talents need to be inserted into a coherent organizational structure that has the ability to use their research capabilities.

Implications for the Future of Innovation

Regarding the possibility of Mexico being able to innovate in the extraction and refining of oil, some authors (e.g., García-Colín 2008) are skeptical because the technologies used in the upstream segment of the oil industry are well established. Under these circumstances, developing such technologies would be a costly endeavor, and Mexico is better served by importing foreign technology. García-Colín (2008) in fact suggests cutting innovation efforts in those areas in favor of training to adopt and adapt foreign technology. But as shown by Maleki and Rosiello (2014), this supposition is not exactly true. Innovation in the upstream oil industry has experienced a kind of renaissance. What makes catching up with leading countries difficult is that innovation now requires access to pieces of relevant knowledge in different technical fields, and not all can be acquired without the right partnerships. Given this systemic complexity that characterizes the knowledge base of the global oil industry, it is difficult for any late-coming country to reduce the innovation gap.

As was mentioned, even a country like Brazil, which has improved its overall performance in the industry and partially closed the innovation gap, has only managed to increase its innovation levels to a certain point. One may question why a country needs to bother with innovation, which is uncertain and costly, if it cannot significantly reduce the gap. It should be recalled that to a certain extent, the case of Mexico is similar to that of Brazil. The IMP's creation allowed Pemex to go from a domestic company to an important exporter. Thus, some degree of local innovative efforts beyond mere technology transfers seems necessary to truly reap the benefits of local oil deposits, but how much is not clear. In this sense, one possible risk in the future exploitation of Mexican oil deposits under the energy reform of 2013-2014 is that innovation would be completely left to foreign companies, and in the end no actual transfer of technology would occur and no domestic innovation system would be created. In theory, this may pose two problems. The first is that local agents are supposed to be in a better position to identify local problems and look for solutions, but in this scenario no local actors would participate because all innovation would be left in the hand of foreign companies. In this case, solutions proposed by foreign agents may be suboptimal and profitable only for them. The second problem has to do with how the benefits would be shared, if at all. If foreign companies are in charge of innovation, most of the benefits would accrue to them as a reward for their efforts, and most of the new technology would remain proprietary information. Mexico would essentially not inherit any of it, and this would be a failure to deliver on one of the promises contained in the energy reform. The implication here is that local agents can innovate better than foreign ones when it comes to tackling problems specific to local circumstances. If this is true and therefore desirable, a late-coming country like Mexico should continue to build its knowledge base from the advantages that local circumstances provide.

One characteristic of knowledge should be addressed here. Knowledge tends to be path-dependent, which means that what can be done in the future is somehow determined by what is being done today and what has been done in the past. This means that catalysis should continue to be a fundamental part of innovation efforts within the Mexican oil industry. Moreover, the oil extracted in Mexico is heavy and likely to be even heavier in the future, which will require efforts to devise technology that will refine that oil efficiently. Also, the prospect of oil deposits in deeper and deeper water should trigger research efforts to integrate and subsequently develop appropriate technologies to tap those deposits—similarly to what occurred in Brazil, which gradually went from a passive adoption of technology to innovation with the capacity to integrate different types of energy projects with higher degrees of complexity.

There are at least two recent signals that suggest that the IMP is in fact preparing itself to tackle these challenges. The first one is the announcement of a deepwater research center for the IMP in the state of Veracruz (PetroQuiMex 2014). But there is no information yet about how exactly the IMP will participate in technology transfer in the post-energy reform era in this regard. It seems that the Mexican government intends that ensure that Pemex participates in deepwater exploration and oil extraction in collaboration with foreign companies, and the IMP would probably be an instrument to facilitate technology transfers for just that purpose. Although more information is needed, given the declining support for energy R&D-related projects, it is difficult to expect innovation in deepwater technology by the IMP in its own right. Instead, the proposed research center would prepare the IMP to adapt existing technologies for Pemex.[7] The second signal is that the IMP has received media coverage to promote its catalysis-related innovations. Just to mention two examples: First, the IMP has developed a catalysis-related innovation that is supposed to allow the refining of heavier oil in Mexican refineries, which are not designed to refine heavy crudes. The second example is the development of a technique to regenerate catalysis-related technologies that

[7] It is important to point out that years before, the IMP had the intention to develop a deepwater program, but due to lack of financing the project ended. Source: personal communication with Guillermo Domínguez Vargas (December 14th, 2016).

would diminish the environmental impact of those processes. These examples are clearly related to the research capabilities that the IMP has developed and also to the particular characteristics of Mexican oil deposits. Whether these efforts would have a real impact in Pemex's activities is hard to tell, because they are currently in progress. However, one revealing feature is that most of the IMP innovations have been developed with almost no collaboration; between 2010 and 2015, there were only four patents on which the IMP collaborated with other organizations.[8] In any case, we should recall that in terms of total numbers, as shown in Table 1, IMP patenting has been decreasing.

Even if following the innovation path already taken by the IMP seems reasonable, there are still interesting business opportunities in the upstream segment. Beyond the industry shift in which service companies now have the lion's share in terms of patents in comparison with the majors (Perrons 2014), there are other niche opportunities.[9] However, in order to nurture this kind of entrepreneurship in Mexico, the national oil industry should not be conceived of only in terms of state-dependent entities, because it is not feasible for the IMP alone to pursue every possible avenue of technological research. Private firms should also be backed and financed to pursue their own technological development routes throughout the value chain.

The lack of collaboration of the IMP with other organizations and its decline in innovation bring into question whether the way in which the Mexican oil industry is set up favors innovation. From the innovation system perspective, the question is whether the interaction between organizations and policies present in the Mexican oil industry is conductive to innovation. It is important to remember that according to Maleki and Rosiello (2014), in order for any catching up in innovation to happen, a well-designed innovation system should be in place. As we saw earlier, in the case of Brazil, Petrobras was at the center of networks and collaborations. This raises questions about the decision by Mexican authorities to make the IMP an organization independent of Pemex. This is in stark contrast to the case of Brazil, in which the IMP equivalent—Cenpes—is an organic part of Petrobras. This explains why in Mexico, patents are filed by the IMP, while Petrobras does so in Brazil.

Therefore, a critical point in the debate on how to foster innovation in the Mexican oil industry is the status of the IMP as a state-owned and semi-independent organization with the purpose of satisfying Pemex's needs. Guajardo (2005) points out that an intrinsic flaw in this organizational arrangement is that both Pemex and the IMP were conceived of under a *nationalistic* perspective, which favored the pursuit of short-term political goals by the upper management in charge of Pemex instead of long-term productive development goals. One interpretation of this assessment is that the results obtained by Pemex were

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[8] Two of these patents are in collaboration with the Universidad Nacional Autónoma de México; one with the Instituto Politécnico Nacional; and one with Toyo Engineering Corporation (the only foreign partner). Data retrieved from IMPI and SIGA: http://siga.impi.gob.mx/newSIGA/content/common/principal.jsf.

[9] VentureBeat (2012) shows how small companies have entered the oil business with specialized services based on information technologies.

based on initial investments in foreign technology to create the IMP and on the fact that the Mexican oil industry practically started from nothing. Thus, any investment would have yielded some results. However, as we have seen, the knowledge base of the industry has undergone important changes. Since Mexican authorities were more worried about keeping up oil production, investments were primarily directed to those areas and not to technologies that would have prepared the industry for the future. Within this scenario, the future of the IMP in the post-energy reform era is not very clear. There are only marginal notes about the IMP in the 2013-2014 energy reform. Apparently, the Mexican authorities intend to keep the IMP alive despite its weakened R&D and innovation capabilities.

Some Recommendations

Stretching the imagination a little, there are at least four possible routes for the IMP. One would be to incorporate it into Pemex, in the same way that Cenpes is part of Petrobras. In this case, the IMP could play the roles of establishing collaborations with other parties and transferring technologies to Pemex. However, it seems to be too late for this option, since both organizations have developed different organizational cultures and are somewhat incompatible, according to some authors; additionally, the IMP is now autonomous of Pemex and bringing it into the fold seems unlikely. The second possibility would be to continue its role as an independent R&D organization with the ability to deliver results not just to Pemex, but to other companies as well. This option has the advantage of preserving the accumulated knowledge of the IMP and increasing knowledge within the entire industry. Unfortunately, the new regulations do not appear to be helping the IMP to concentrate on the vital task of generating innovation. The third option is to transform the IMP into a technology service center, which seems to be its current fate—at least under the new rules. Under this scheme, the IMP would be able to generate its own financial resources by means of different research activities, including technology transfers to Pemex—not just through R&D, which requires more money and time to carry out. This third option is the most likely path, but it will severely limit the institute's capacity to generate innovation. The fourth option is more radical: the IMP could be dismantled and all of its R&D activities could be transferred to universities and other higher-education institutions. Universities play important roles in innovation in many countries, and it seems that R&D centers at some universities are vital players in this industry with the added advantage that the incentives of universities are not always aligned to a particular business' interests and can produce for an entire industry. However, as shown with the CONACYT-SENER fund, universities in Mexico have a long way to go in acquiring the required capabilities and a critical mass of projects.

Since it appears that the IMP will continue as an important player in the Mexican oil industry, it is important to point out several other variables that may play some part in its innovation record, such as organizational forms and management styles. Guajardo (2004 and 2007) provides a rich set of anecdotal evidence that depicts the IMP as a hierarchical organization. The innovation literature usually portrays innovative companies as having more horizontal structures in which employees have a voice in deciding the direction of R&D. More research is needed on this issue to know if the hierarchical organization of the

IMP has hindered the development of what otherwise would be a more creative organization open to different sources of ideas.

In any case, whether the IMP is to stay or not, the innovation system must be able to nurture and develop new agents able to participate in innovation projects. Given the complexity that characterizes innovation in the oil industry, Mexico requires more than one organization participating in innovation efforts. Also, given the conditions that prevail in the global oil industry, associations and collaborations with foreign partners should be on the agenda of local organizations. Of course, this will be useful if agreements are reached over technology transfers to local agents, something that seems to be lacking both in the past and current situations.

Also, although we have focused on the important role of innovation, the development of technological capabilities among Mexican players should also be a priority in order to reap the benefits of the opening of the sector. This applies to Pemex and other local organizations in the sense that they should seek to be able to innovate in a similar fashion as other international and national oil companies. An important step taken in that direction is the development of different programs geared toward the formation of human resource capital; however it is not clear the way in which this resource will be used to leverage the technological capacity of the local industry.

Final Comments

The short answer to our research question of whether the energy reform can contribute to local innovation in the Mexican oil industry is no. The energy reform is not likely to stop the decline in innovation or improve research levels in the Mexican oil industry. The reform promised modernization in the sector through technology transfers; however, concrete policy measures to ensure this transfer are vaguely defined, not only in the legislation itself but also in the specific public policies designed to advance this agenda. At least, we did not find evidence of a technological road map that delineates the type of technologies to be pursued and the way in which these will be mastered. From the pieces of information that are available, it seems that Pemex will try to upgrade its ability to collaborate with foreign companies, which would mean that the IMP may have a role in technology transfer. However, developing its own technology does not seem to be a goal that Pemex has made explicit. Some may argue that it is better to import technology from leading companies and concentrate on production. However, we think that some local innovation efforts are needed to reap the benefits of future exploration, such as potential deepwater oil deposits. If this does not occur, we would argue that the benefits will flow to foreign companies, and Mexico will not receive its fair share.

The Mexican oil industry has always been dependent on foreign technology, and this will continue in the future. Even innovations achieved by the IMP, such as the catalysis-related technology, were built on foreign technology. The new circumstances of technology generation in the upstream oil industry demand more ambitious methods of acquiring and creating technology. The IMP should find new ways to still be relevant in the transfer and creation of technology, but the Mexican government should not stop there. Neither Pemex nor the IMP should be the only public entities pursuing the development of innovation in the oil industry. Mexican authorities should consider expanding the number of organizations relevant to the future of the industry. There are several opportunities to innovate in niches of the oil industry—the incorporation of information technologies into oil processes, for instance—which need new types of organizations with more flexibility and to be backed by coherent policies aimed at incorporating these organizations into international networks of collaboration.

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