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Contaduría y Administración 64 (3), 2019, 1-32

Contaduría y Administración
Accounting & Management

Efficiency and productivity in transfer units of scientific research results in Mexico

Eficiencia y productividad en las unidades de transferencia de resultados de investigación científica en México

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Recibido el 14 de febrero de 2017; aceptado el 6 de marzo de 2018

Disponible en Internet el: 23 de mayo de 2019

Abstract

The objective of this work is to evaluate and determine the levels of efficiency and productivity among the academic units involved in the technological transfer of scientific research between 2012 and 2013. The empirical research is based on the survey applied to 21 research and higher education centers in Mexico. Two complementary models were designed, a linear data envelopment analysis (DEA method) model and a stochastic frontier analysis (SFA method) model. The results obtained using parametric and non-parametric methods show a strong initial heterogeneity in higher education institutions and public research centers that participate since 2011 in these processes in Mexico. In contrast to other more developed countries, productivity is limited in factors such as number and income from licenses, number of notifications of inventions, expenditure on intellectual property, and experience of technology transfer offices. Finally, a dynamic panel data model was designed in a second sample to evaluate the continuity of the preliminary results for the period between 2014 and 2016; the results show that public expenditure on R&D and the number of academia-industry agreements continue to have a positive impact on the productivity of academic entities.

JEL Codes: I23, O32, O34

Keywords: Productivity and efficiency measures; data envelopment models (DEA); Stochastic frontier models (SFA); dynamic data panel models; University technology transfer units

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Resumen

El objetivo de este trabajo es evaluar y determinar los niveles de eficiencia y productividad entre las unidades académicas involucradas en la transferencia tecnológica de investigación científica entre 2012 y 2013. La investigación empírica se basa en la encuesta aplicada a 21 centros de investigación y educación superior en México. Se diseñaron dos modelos complementarios, un modelo de programación lineal de envolvimiento de datos (método DEA) y un modelo estocástico de frontera (método SFE). Los resultados obtenidos mediante métodos paramétricos y no paramétricos muestran una fuerte heterogeneidad inicial en las instituciones de educación superior y centros públicos de investigación que participan desde 2011 en estos procesos en México. En contraste con otros países más desarrollados, la productividad es limitada en factores como número e ingresos por licencias, número de notificaciones de invenciones, gasto en propiedad intelectual, y experiencia de las oficinas de transferencia tecnológica. Finalmente, se diseñó un modelo de datos de panel dinámico en una segunda muestra para evaluar la continuidad de los resultados preliminares para el período entre 2014 y 2016; los resultados muestran que el gasto público en I+D y el número de acuerdos academia-industria continúan incidiendo positivamente en la productividad de las entidades académicas.

Código JEL: I23, O32, O34
Palabras clave: Medidas de productividad y eficiencia; Modelos de envolvimiento de datos (DEA); Modelos de frontera estocástica (SFE); Modelos de panel de datos dinámicos; Unidades de transferencia de tecnología universitaria

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Introduction

In the last decades, academic institutions of international reference, especially from the USA and Europe, have achieved considerable success in their processes of technological linkage and transference (O'Shea *et al*., 2005; Lerner, 2005; Wright *et al*., 2007; Guerrero *et al*. 2015). These institutions have succeeded in establishing mechanisms to obtain additional and alternative sources of income to traditional forms of university funding, for example, by generating royalties and payments in cash or in kind through licensing and industry-sponsored research projects (Lach and Schankerman, 2004; Mowery *et al*. 2015). Similarly, studies have also highlighted the economic development around these academic centers as a result of the creation of new high-quality jobs linked to the creation of high-tech enterprises (Saxenian, 1996; Shane 2004a, b; Wright *et al*., 2004a, b; Agarwal *et al*., 2014).

However, not all higher research institutions (HEIs), such as those of international reference, have achieved the same levels of performance with respect to their efforts to transfer the results of their scientific research to the market (Bok, 2003; Stephan, 2012). This phenomenon has stimulated a considerable amount of literature in the field of technology management, related to the review of the key factors in the success or failure of university technology transfer (UTT) (Di Gregorio and Shane, 2003; Lerner, 2005; Link *et al*., 2005; O'Kane et al. 2015).

Beyond identifying the factors that explain the processes of university technology transfer, other works have evaluated and measured the levels of efficiency reached by the transfer units of research results. Among these studies, the works elaborated for USA by Thursby and Kemp (2002), Siegel *et al*. (2003), Anderson et al. (2007), and the comparative work for Italy and the United Kingdom by Agasisti and Johnes (2009) stand out; in the same way as the series of works elaborated by Chapple *et al*. (2005) in the United Kingdom; Glass *et al*. (2006), Rossi, (2014), and Curi et al. Most of these studies propose technology transfer offices (TTOs) as objects of analysis and measurement for their strategic role in the results that universities and research centers obtain when licensing or founding new start up and/or spin off companies (Debackere and Veugelers, 2005; Fitzgerald *et al.,* 2015).

In Latin America there are some comparative studies to measure the efficiency of education, the transfer of knowledge, and the performance of universities. For example, in a comparative study of 14 countries, Albornoz (1997) uses physical plant inputs, organizational climate, and members of academic faculties to assess the educational level among HEIs. Deutsch *et al*. (2013), using the results of the PISA test, designed a stochastic frontier model to determine learning efficiency in five Latin American countries. This study concludes that the location of schools, the level of funding, and the self-esteem of students are determining factors in achieving levels of efficiency in school learning. For their part, Cáceres et al. (2014) measure the efficiency through the data envelopment analysis (DEA) method of 15 departments in a Chilean university, resulting in 33% of the departments at the frontier of efficiency.

In Mexico, such studies have focused on evaluating the efficiency and productivity of regional and state innovation systems (Valdez-Lafarga et al., 2015), universities (Güemes-Castorena, 2008; Antonio *et al*., 2012; Becerril-Torres *et al*., 2012), and university faculties and departments (Altamirano-Corro *et al*., 2014). However, there is no work focused on evaluating the efficiency of TTOs (CONACYT, 2013).

For the works that study the measurement and evaluation of the productive performance of UTTs, some authors use a linear programming methodology called DEA and apply it to universities in the United Kingdom (Chapple *et al*., 2005). This technique measures the different productive units according to their level of efficiency in order to establish the reference analysis units (units of higher preference). In this manner, individual efficiency indices are calculated for each productive unit. In a second stage, a series of econometric models are designed using the stochastic frontier analysis (SFA) to identify the relevant factors, in order to determine the levels of both efficiency and inefficiency at the global and regional levels (Chapple *et al*., 2005; Glass *et al*., 2006). These studies highlight the particular context of technology transfer in a country like Mexico where there is no legislation of the Bayh-Dole type, which emerged in the United States.

In Mexico there is also no law initiative like this act, hence the convenience of the methodology used by these authors to identify the factors that explain efficiency in TT. For all these reasons, the objective of this work is to measure and evaluate the levels of efficiency reached by the technology transfer units. Utilizing the methodology introduced by Thursby and Kemp (2002), Chapple *et al*. (2005), and Glass *et al*. (2006), the goal is to achieve this objective. Thus, this study designs both a parametric model (SFA) and a non-parametric model (DEA), with the data collected from the empirical research carried out between the transfer and university linkage offices in Mexico during the period of 2012 to 2013. This study also presents a dynamic data panel model to analyze the factors that contribute to productivity and efficiency in the period from 2014 to 2016.

This work contributes to academic literature by assessing contexts where such public initiatives are still marginal. This study seeks to contribute, in a theoretical way, in the explanation of the levels of efficiency and productivity in countries with a medium level of technological development. Likewise, this empirical analysis intends to set a precedent for the evaluation of productivity in technology transfer units in Latin America and to establish the usefulness of this

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

methodology for the designers of public technology policy and the directors of HEIs, which will have a basis to promote better practices in the transfer of university technology.

Thus, this article is structured by postulating in the following section 2 a theoretical review of the impact of scientific innovation on economic development, as well as the background and set of internal and external indicators that explain productivity in HEIs and public research centers. In section 3, the methodology for estimating the empirical models used in estimating the relative efficiency of universities and research centers is presented. Sections 4 and 5 describe the characteristics of the data and the results obtained in our model(s). Finally, section 6 presents conclusions and an agenda for future research.

Economics of technological innovation and business productivity

Theoretical approaches to scientific innovation, technological change in enterprises and economic development

The literary review regarding the main theoretical contributions on innovation and management of technological administration refers to the seminal ideas of Joseph A. Schumpeter, who highlights the central role of the "disruptive creation" of the entrepreneur in the process of economic development (Schumpeter, 1950). This concept consists in highlighting the preponderant role played by the continuous waves of discoveries and innovations that occur among entrepreneurs with entrepreneurial spirit, and that allow them to obtain greater capacities and competitive advantages to position themselves with better market shares and even with temporary monopolies, by displacing the old production and organization schemes (Wernerfelt, 1984; Scherer, 1986). According to this theoretical approach, innovation is the most relevant factor driving the economic growth and social welfare of a country or region (Mansfield, 1984; Griliches, 1986; Fagerberg, 1994).

Until the 1970s, the predominant economic theory, based on neoclassical postulates, considered that technology was basically information and that its production process was exogenous to the economic system and innovative enterprises. This model of technological change conceptualized R&D as an isolated activity, carried out in research centers, and alien to market incentives. New technologies were considered public information and easily imitated. This model assumes that technology transfer is an automatic process without significant costs based on the "invisible hand" mechanism (Heijs and Buesa, 2016).

An alternative theoretical model to the neoclassical linear model of technological change is the interactive or evolutionary model, developed in the 1980s, which implies radical changes for the technological management of companies or the design of technology policy by the public administration. Evolutionary theory is based on a strong critique of neoclassical theory. The evolutionary school censures neoclassical theory in the exogenous treatment of innovation as a determinant of growth. Likewise, this current of thought criticizes the simplistic neoclassical assertions that state that scientific information is a public good without cost, easily appropriable and that, ultimately, economic development tends towards a maximizing general equilibrium (Nelson and Winter, 1974).

In evolutionary theory, technological change and economic growth are considered to be two interactive processes. Technological change is based on an evolutionary dynamic with gradual increases in technical efficiency, productivity, and process precision. This change occurs within a context with various agents and organisms of the system also known as the innovation ecosystem and the productive fabric, which develops and adapts from the technological capacities available in companies and R&D institutes, the conditions, opportunities, and business decisions (of entrepreneurs, engineers, and scientists) about future technological possibilities and their economic profitability (Dosi et al., 1994; Nelson, 2009). Thus, technology transfer is a costly and cumulative process and follows historical trajectories of continuous change and improvement (Dosi, 1997).

Increasing scientific complexity and interdisciplinarity demands innovation; companies and universities interact and cooperate in routines to improve their skills and technical capacities in environments of high tacit knowledge and difficult to code (Cohen and Levinthal, 1989; Nonaka, 2008; Polanyi, 2009). This demand for diversification in the different technological fields has become too costly in terms of time and financial costs for companies (Teece, 1992). Thus, the set of actors involved in innovation cooperation processes includes companies, academic institutions, scientific laboratories, financial resource managers, intellectual property (IP) legal specialists, NGOs, and government agents (Nelson and Winter, 1982).

In recent decades, the focus of the mission of universities in society has been radically transformed from being generators of basic research to actively participating in economic development (Etzkowitz and Viale, 2010; Stephan, 2012). During the 1990s and early 2000s, the assessment of the impact and outcomes of university technology transfer focused on a multitude of factors including the economic outcomes of technological development (Roessner and Wise, 1994; Storper, 1995; Saxenian, 1996); the generation of patents and radicalization of inventions (Henderson et al., 1998; Shane, 2001); and the role of government laboratories in the commercialization of technology (Kelley, 1997; Crow and Bozeman, 1998).

Consequently, the literature has addressed the study of the series of agreements, licenses, start-ups, contracts, and conditions of use of intellectual property between universities, federal laboratories, and industry (Link et al., 2003; Lockett et al., 2005; Phan and Siegel, 2006; Siegel et al., 2007). Other theoretical studies have also focused on technology transfer offices (TTOs) whose main function has been to facilitate knowledge transfer and commercialization through the licensing to industry of university inventions or other forms of IP (Colyvas et al., 2002; Friedman and Silberman, 2003; Siegel et al., 2004; Belenzon and Schankerman, 2009).

Another series of studies have focused on analyses of flows of investment in research and development, and the positive impact on local economies of knowledge spillovers (Audretsch et al., 2005; Caldera et al., 2010). In this manner, several studies indicate that public funding for university research has also been associated with higher levels of efficiency in TT (Etzkowitz, 2002; Powers and Mc Dougall, 2005). In response, governments interested in fostering industrial activity and technological innovation have channeled significant public resources to universities and research centers. According to Mowery and Nelson (2015), higher levels of public investment in R&D lead to higher levels of discoveries with high industrial potential, implying a greater pool of protected inventions that can be commercialized through university technology transfer (Grimaldi et al., 2011).

While some authors point out that the benefits of investment in research on economic development are not immediate and rather long-term (Feller et al., 1995; Heher, 2005), it is also noted that the development of human capital and scientific and technological capabilities in a context of interconnected social networks is a relevant factor in the effectiveness of research and knowledge transfer (Autio et al., 1995; Lynn, 1996; Bozeman, 2000).

A number of scholarly articles have examined the relationship between spending on

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

intellectual property investments, patent enforcement and maintenance, and efficient university knowledge transfer (Carlson and Fridh, 2002; Siegel, Waldman et al., 2004; Powers and McDougall, 2005; Mc Devitt et al., 2014). Literature has also highlighted that strong patent portfolios help achieve sustainable competitive advantages and greater efficiency in the transfer of scientific research results (Nerkar and Shane, 2003; Schilling, 2010).

Evaluation of performance in the transfer of research results

The academic literature has focused on analyzing the outcomes and productivity of research and development investment expenditures at three levels: (1) systematic; (2) university and its departments; and (3) scientific knowledge transfer units, e.g. TTOs.

The first level has focused on measuring the impact on industry and the national economy. In a seminal paper, Griliches (1979) proposes a methodology for estimating the impact of private and public expenditures on scientific research on gross product in the economy and in sectors with capital-intensive industries associated with knowledge. This author points out the need to mark differences between returns in basic and applied research, as well as the effects of knowledge transmission between companies—spillovers. For its part, Heher (2005, 2006) estimates that the returns on investments in science and technology are positive and oscillate between 2% and 3% with delays of 10 years at the institutional level and up to 20 years at the national level.

At the second level are studies that have been carried out in various countries to measure administrative performance, productivity, and efficiency in universities and faculties. For example, Glass et al. (2006), analyzing data for 98 universities in the United Kingdom during 1996, indicate that ranges in efficiency levels have increased over a decade. In the United States, a wide range of academic articles have been developed focusing on the productivity of HEIs where the found variance in productivity is less than that observed in institutions in the United Kingdom. For example, Reichmann (2004) analyzes 118 American universities, finding that those with the lowest performance are only 32% less productive than the most efficient. This result reveals a greater degree of homogeneity in American universities than their European counterparts; on the other hand, Cobert (2000) in a study of the 24 main master's degree programs in business administration in the United States showed differences of only 8% in educational efficiency. Finally, several studies including institutions in Canada (Mc Millan and Chan, 2006), Austria (Leitner et al., 2007), Australia (Worthington and Lee, 2008), among others, have also analyzed productivity and operational efficiency in higher education. The study in Canada analyzes 45 universities using the DEA and SFA methods, although it finds divergence of results in each method; on the other hand, it achieves consistent results in the order of the individual efficiencies of the universities. The study in Austria emphasizes that both large and small universities have efficiency levels, emphasizing that there is no simple scale level to determine establishment at the efficiency frontier. Finally, the study of 35 universities in Australia between 1998 and 2003 shows an annual growth in productivity of 3.3% mainly due to technological progress.

In a third group of studies, the main line of research revolves around the performance and productivity of technology transfer activities and the performance of TTOs. There are studies based on profit and loss (P/L) financial analysis of the technology transfer offices (Trune and Goslin, 1998; Abrahms et al., 2009), and from the decade beginning in 2000, several studies use: (1) approaches based on production functions, and (2) the frontier production functions approach (Bonaccorsi and Dario, 2004). While in the first case a function is constructed to estimate the average trend of the observations through the regression equation, in the second case, models are constructed based on an optimal reference point at the frontier. Siegel and Phan (2004) describe stochastic frontier analysis (SFA) and data envelopment analysis (DEA) as the two most widely used tools for carrying out this assessment.

While the DEA method uses linear programming to determine levels of efficiency, it is not limited by the assumptions linked to traditional parametric regression analyses, such as the assumption of independence between independent variables. These models incorporate organizational and external factors that directly or indirectly influence the performance of technology transfer. The other method recurrently used in the study of efficiency is the stochastic frontier analysis (SFA), which consists of a parametric model with two functions: (a) efficiency and (b) technical inefficiency (Aigner et al., 1977; Meeusen and Van Den Broeck, 1977). The method estimates an efficiency boundary through the use of a production function and calculates the parameters of the production function through the use of regression. Being a parametric method allows constructing both hypothesis tests and statistical confidence levels.

Table 1 shows the main work carried out on the efficiency of university technology transfer and TTOs. The main input-output variables used in these models include research and development (R&D) expenses, licensing revenues, number of licenses, number of companies founded, royalties, number of research agreements, number of notifications of inventions, size of the TTO, intellectual property expenses, and patents applied and/or obtained. Each of the studies is detailed below, indicating methodology, sample, approach, and the combinations of variables used.

Table 1.

Empirical work on the efficiency of university technology transfer and TTOs

Research Work	Sample/ Countries	Method	Approach	Input variables	Output variables
Thursby and Kemp (2002)	112 universities in the USA	DEA combined with a regression analysis	University-Industry Technology Transfer (UITT)	TTO Size Federal funding Biology faculty Engineering Physics faculty Biology quality Quality engineering Quality physics	Industry Financing Royalties Notifications Applications for new patents Licensing
Thursby and Thursby (2002)	64 universities in the USA	DEA (3 stages). Calculates total productivity factors for each stage (TFP)	Technology Transfer Offices (TTOs)	Stage 1: Federal and industrial financing Staff at TTO Stage 2: Notifications Quality of faculty Stage 3: Notifications Patent Applications	Stage 1: Notifications Stage 2: Patent Applications Stage 3: Licensing and option agreements

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Siegel et al. (2003)	89 universities in the US	SFA	Technology Transfer Offices (TTOs)	Notifications TTO Size Legal expenses	Licensing agreements License revenue
Chapple et al. (2005)	98 universities in the UK	DEA and SFA	Technology Transfer Offices (TTOs)	Revenue for research Notifications TTO Size IP Legal expenses	Licensing agreements License revenue
Glass et al. (2006)	98 universities in the UK	DEA and SFA	University-Industry Technology Transfer (UITT) and teaching activities	Academic Staff Capital expenditure	Research Teaching
Anderson et al. (2007)	57 universities in the USA	DEA	University-Industry Technology Transfer (UITT)	Expenditure on research	Licenses, number of SPOs and Revenue by licenses, patents applied, patents granted
Siegel et al. (2008)	120 universities in the USA and the UK	SFA	Technology Transfer Offices (TTOs)	Expenditure on research, Expenditure on External IP, TTO staff, faculty quality, TTO age	Licenses, number of SPOs, and Revenue by licenses
Agostini and Johnes (2009)	184 universities in the UK and Italy	DEA	University-Industry Technology Transfer (UITT)	Total financial resources Total number of employees and teachers Doctoral students	Number of graduate students Number of external scholarships Number of sponsored R&D agreements
Zhang et al. (2011)	59 research institutes in China	DEA	University-Industry Technology Transfer (UITT)	Support expenditure on R&D Staff Science and Technology Equipment	Number of postgraduate students in training Citations International
Ali and Ahmad (2013)	18 Faculties at Qassim University (Saudi Arabia)	DEA	University-Industry Technology Transfer (UITT)	Students Full-time staff	Number of high school graduates Number of Researchers
Monteiro. (2013)	18 universities in Portugal	DEA	Technology Transfer Offices (TTOs)	Staff en la OTT Gastos de la OTT	Invention notifications Patent Applications Number of spin offs R&D Agreements

Altamirano Corro et al. (2014)	51 Engineering Faculties in Mexico	DEA and ANN	University-Industry Technology Transfer (UITT)	Postgraduate and NRS teachers No. of Consolidated Academic Bodies	Accredited Programs Postgraduate Programs Academic Capabilities
Rossi (2014)	80 universities in the United Kingdom	DEA and regression analysis	Technology Transfer Offices (TTOs) and Universities	Research Scholarships Staff in TT Staff in natural sciences and medicine Engineering and technical staff Staff in Social and Business Cs Staff in arts and humanities	No. of Invention Notifications No. of consultancy contracts No. of Research Contracts Development and training days Public academic events
Tseng et al. (2014)	20 major universities in the USA	Weighting based on 6 factors and correction of patenting effectiveness	Technology Transfer Offices (TTOs)	Income TTO Invention Notifications No. of Pats. appl. No. of Pats. granted No. of Licenses No. of Startups.	Two weighted Indicators: OPM and PCR
Curi et al. (2015)	30 universities in France	DEA	Technology Transfer Offices (TTOs)	TC Employees No. of publications R&D Intensity Level	Patent Application and Extension Software copyright

Source: own elaboration

Thursby and Kemp (2002) utilize the DEA method with the Malmquist approach, in order to track the change in total factor productivity by 112 units of TT in the USA in the period of 1991-1996. These authors use the size of the TTO and the income for federal R&D funding by science area as input variables; and industry funding income, number of licenses, license royalties, number of notifications, and patent applications as output variables. For their part, Thursby and Thursby (2002) applied a three-stage DEA model to 64 universities, evaluating in each phase the input variables that contribute to the growth of the output variables. Anderson et al. (2007) evaluated 57 universities during 2004; these authors used research expenditures as an input variable, and license income, number of licenses, number of options executed, number of start-up, and patents applied and granted with weighting adjustments as output variables. The results suggest that the total licensing revenues in 54 of the 57 universities analyzed could be increased by 659 million dollars, improving their efficiency indices.

There is a representative study using SFA evaluating TT efficiency in 89 universities in the USA between 1991 and 1996 (Siegel et al. 2003). This study uses license income as a

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

dependent variable and three independent variables: (a) disclosure of inventions, (b) number of personnel in the TTO, and (c) amount of legal expense associated with patents. In another study carried out by Siegel et al. (2008), using SFA, 120 TTOs are evaluated in the United Kingdom and the United States, corroborating a lower efficiency in universities in the United Kingdom with respect to those in the United States.

Finally, some studies seek to take advantage of the complementary benefits of the two previous approaches. Thus, Chapple et al. (2005) applied both methods to evaluate the number of licenses in 98 universities in the United Kingdom, estimating a level of efficiency between 26% and 29% using SFA, and a range between 15% and 35% using DEA. This implies a significant margin of productive potential to reach the technical frontier. Meanwhile, Glass et al. (2006) also assessed the relative performance of technology transfer in UK universities using both SFA and DEA. They developed a two-stage model. In stage one, they used DEA for the initial efficiency assessment and identified inefficiency factors linked to environmental and management effects; while in phase two, they identified the statistical noise.

Most studies measuring the efficiency of technology transfer refer to universities in the USA. Thursby and Kemp (2002), Thursby and Thursby (2002), and Anderson et al. (2007) use DEA to measure efficiency at each university; Siegel et al. (2003) apply the SFA method to study the factors that influence performance at the level of the overall set of universities observed. Thursby and Kemp (2002) identified 54 efficient universities out of a total of 81 universities, which represent 67% of the total. This study found positive variations in efficiencies over the period of 1991-1996. Efficiency showed an average annual growth of 7.9%, which could be divided into 0.4% of universities that managed to improve their productivity, and 7.5% as a result of the expansion of the efficiency frontier. On the other hand, Anderson et al. (2007) found only 7 efficient universities out of 54, which is equivalent to 13%. Both studies used the VRS (variable returns to scale) method. Four universities: Brigham Young University, California Institute of Technology, Georgia Institute of Technology, and Massachusetts Institute of Technology were identified as efficient by both studies.

The main difference in these studies of measuring efficiency in university technology transfer and technology transfer offices lies in the use as input or output of some variables. For example, while most studies use income for research as an input variable, Glass (2006) identifies it as an output variable. On the other hand, Thursby and Kemp (2002), establish the number of disclosures of inventions as an output variable to evaluate the efficiency of technology transfer from universities, while two studies, Siegel et al. (2003) and Chapple et al. (2005), define it as an input variable to measure the efficiency of the university technology transfer office. The reason lies in the process that leads to the disclosure of an invention by the faculty, and the role of the university technology transfer office.

These TTOs help encourage scientists to participate in their decision to disclose new discoveries, but in the end, it is the university faculties that have the power to approve whether the disclosure will be shared or not. It is only until the disclosure is done that the work of TTOs begins. Thus, the responsibilities of TTOs are to evaluate and value disclosure, intellectually protect technologies by applying for patent registration, sell licensing contracts for industry, collect royalties, and enforce contractual agreements with licensees. Therefore, disclosure is an input variable when the objective of the model is to measure TTO efficiency (Siegel et al., 2004). On the other hand, disclosure should be considered an output variable in the efficiency measurement of University-Industry Technology Transfer (UITT) model.

On the other hand, Anderson et al. (2007) highlight the importance of comparative studies on efficiency indices of USA universities with respect to their counterparts in Canada, Europe, or Asia to determine sources of technological advantages in different geographies. This author anticipates similarities and discrepancies that USA universities have with other HEIs in different geographic regions. In addition, a group of countries with less developed UTT have also undertaken comparative studies to assess the productivity and efficiency of HEIs. For example, Agostini and Johnes (2009) analyzed the efficiency levels of universities in the United Kingdom and Italy, finding higher levels of productivity in the first country –(0.82 vs. 0.70) during the periods of 2002-2003 and 2004-2005. However, they also found that Italian universities improved their technical performance by approaching the efficiency frontier more systematically over the period than their English counterparts.

In another international study, Zhang et al. (2011) assess efficiency levels in 59 research institutes in China using the DEA method. The input variables used were expenditure on R&D, number of staff members, and equipment for science; the output variables were the number of postgraduate students, citations, and the number of international published articles. This study concludes that there were annual productivity increases of 12.5% between 1998 and 2005. On the other hand, using the same methodology, Ali and Ahmad (2013) measure the level of efficiency of 18 faculties at Qassim University in Saudi Arabia, indicating that the level of efficiency reaches on average of 68%, where only 3 faculties reach the maximum frontier level. In Portugal, Monteiro (2013) analyses 18 TTOs between 2007 and 2011, indicating that productivity grows in early stages of TT, e.g. notification of inventions and patent applications; however, it decreases in advanced stages, i.e. creation of spin-offs or new R&D agreements. Finally, developed countries, but only just beginning their formal processes at UTT, have also focused on measuring the efficiency of their TTOs. Thus, in a study in France, Curi et al. (2015) found that, while on average TTOs in this country have increased their productivity in the short term, newly created TTOs in medical school and hospital contexts show negative efficiency levels.

In Mexico, although studies to measure the efficiency of universities are limited (Güemes-Castorena, 2008), a recent work combining the DEA methodology with that of artificial neural networks (ANN) evaluates 51 engineering faculties in Mexico in the period of 2003 to 2008. The study highlights a great dispersion between the most efficient units that reach 97% and the least efficient that achieve only 15% (Altamirano-Corro et al., 2014).

In recent years, new approaches have been taken to measure productivity and efficiency. Thus, Rossi (2014) has incorporated new output variables to expand UTT results, including consulting contracts, development and training days, and public academic events. For its part, Tseng (2014) constructs a weighted index based on six input variables, such as TTO revenues, invention notifications, number of patent applications and grants, and number of licenses and startups created.

In summary and following the main theoretical works listed here, the following were chosen as input variables of the present model: research expenditure on R&D (Thursby and Kemp, 2002; Thursby and Thurby, 2002; Chapple et al., 2005; Anderson et al., 2007; Siegel et al., 2008), number of professional employees employed at the TTO (Siegel et al., 2008; Zhang et al., 2011; Monteiro, 2013), and expenditure on intellectual property (Siegel at al., 2003; Chapple et al., 2005; Siegel et al., 2008; Monteiro, 2013). As output variables: private expenditure on research and development and number of private university-industry agreements for research and development (Thursby and Thurby, 2002; Thursby and Kemp, 2002; Agostini and Johnes,

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

2009; Monteiro, 2013; Rossi, 2014). It should be noted that other variables including the number of invention notifications, and the number of and income from licenses were discarded in this model due to unsystematic and practically null reports in Mexico.

Finally, it should be noted that variables related to the quality of the faculty, such as age and size of the transfer office, although resources associated with the level of human capital and the degree of experience of the TTO, which are expected to be highly correlated with TT products, these effects and their relationships are considered as factors and not input or output variables in the construction of DEA models.

Methodology

Sample

The subjects of this study are 21 TTOs and industrial liaison offices in Mexican HEIs. It is necessary to point out the existing delay in Mexico with respect to the creation of TTOs with respect to other countries. It is from the conformation of the network of TTOs promoted by the CONACYT and the Ministry of Economy (SE for its acronym in Spanish) in 2011 that the first certified offices are established in different academic, business, and governmental institutions in the country. This implies a delay of more than 40 years with respect to the first TTOs founded in the United States as a result of the Bayh-Dole Act. Hence, the collection of variables that have traditionally been used in other empirical studies on TT is problematic.

The main source of data came through 2 requests for information sent to 19 public research centers attached to the National Council for Science and Technology (CONACYT for its acronym in Spanish) and to 10 of the main public and private universities in Mexico that operate in TT. These requests were made through the portal of the Federal Institute of Access to Information (IFAI for its acronym in Spanish) during the months of March to May 2014, and April to June 2017. In the first request, complete responses were obtained at 21 HEIs, of which 62% had a TTO certified by the CONACYT. In the second request, complete responses were obtained at 19 HEIs where all academic entities except one have a TTO operating within the institution.

A second source of information is the database requested from the CONACYT on the Innovation Stimulus Program (PEI for its acronym in Spanish) for the years 2012 and 2013, which complemented the information on the number and total amount of R&D&i agreements between industry and academic institutions. It should be noted that the PEI is made up of three programs called Innovatec, Innovapyme, and Proinnova, which bring together the main source of resources for innovation projects in the country. A third source of information comes from the Mexican Institute of Industrial Property (IMPI for its acronym in Spanish), an office that was asked through IFAI the total amount of expenses issued by academic institution for the application, review, granting, and maintenance of patents. Finally, both the information concerning the GDP and the R&D intensity indicator by state were extracted from the page of the National Institute of Statistics, Geography and Informatics (INEGI). Table 3 shows the descriptive statistics of the data for the DEA and SFA.

Measurement of variables

Data were obtained in the requested survey for each HEIs and/or PRCs concerning: (1) private expenditure on R&D in millions of current pesos, which is transformed into its natural logarithm; (2) number of contracts between private companies and universities; (3) public expenditure on R&D in millions of current pesos, which is transformed into its natural logarithm; (4) expenditure on intellectual property by TT units in millions of current pesos, which is transformed into their natural logarithm; (5) size, by number of specialized employees of the TTOs; (6) information on whether the institution has a medical school; and (7) degree of regional intensity in R&D measured by degree of regional inventions by state over the national total.

Finally, following Siegel et al. (2003), a series of internal (organizational) and external (environmental) factors were identified as control and measurement variables for the technical inefficiency model equivalent to the degree of R&D intensity, the percentage of regional GDP, the public or private status of the HEIs, and the existence of a medical school in the academic institution (Siegel et al. 2003; Chapple et al. 2005).

Design of econometric models

In order to carry out the analysis, two complementary models are designed in order to incorporate the set of explanatory variables selected from the technology transfer mechanisms, which include a set of internal institutional and organizational variables (input) and of results (output). In this way, the relative productivity of the university-industry technology transfer (UITT) units is estimated. Thus, this study focuses on the stochastic frontier analysis (SFA) method developed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977), complemented by the DEA method. Each method is described in more detail below.

DEA is a method of frontier analysis from nonparametric statistics, which was originally designed to measure not only the financial performance of organizations, but to include other quantitative and qualitative elements of inputs and outputs that are related to efficiency (Charnes, Cooper and Rhodes, 1978). The DEA method has been used to measure the performance and efficiency of operational indicators in productive units, ranging from small communities (Marshall and Shortle, 2005) to countries and nations (Golany and Thore, 1997). DEA uses linear programming algorithms to create a boundary of efficient units, which "envelops" other relatively less efficient units.

One of the main advantages of the DEA method is that it allows the absence of a formal specification of a functional relationship between inputs and outputs. In addition, DEA allows a wide variety of inputs and outputs to be used without assigning an a priori value judgment to the costs and shadow prices of these inputs and outputs (Charnes et al., 1994). The DEA formulation evaluates the relative efficiency of a productive unit by estimating for each unit the measurement of weighted outputs over weighted inputs. There are several variants of DEA programs. The basic model for estimating the boundary with constant returns to scale (CRS) and output orientation can be formulated through the solution to the following mathematical expression:

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

$$min \frac{\sum_{m=1}^{M} vmxmi}{\sum_{s=1}^{S} \mu sysi} \qquad (1)$$

s.a.

$$min \frac{\sum_{m=1}^{M} vmxmj}{\sum_{s=1}^{S} \mu sysj} \geq 1, \quad \forall j$$

$$\mu s, vm \geq 0, \quad \forall s, m$$

Where:
xim is the quantity consumed by productive unit *i* of input *m*
yis is the quantity produced by the productive unit *i* of output *s*
vm is the cost of input *m*
us is the price of output *s*
The previous model is usually simplified through the following equivalent linear program:

$$min \sum_{m=1}^{M} vmxmi \qquad (2)$$

s.a.

$$\sum_{s=1}^{S} \mu sysi = 1$$

$$\sum_{s=1}^{S} \mu sysj - \sum_{m=1}^{M} vm\, xjm \leq 0, \ \forall j$$

$$\mu s, vm \geq 0, \quad \forall s, m$$

The above algorithm looks for the set of prices that minimize the production cost of unit *i* with respect to the value of its product, subject to the minimum cost being equal to 1. If unit *i* is efficient, the cost = 1; if inefficient, the cost is greater than 1. The indices are presented as their inverse to indicate the degree of inefficiency of values less than 1.

The most realistic variable returns to scale (VRS) model incorporates an additional element or independent term e*i*; when e*i* > 0, it implies that the objective function does not pass through the origin. Only if e*i* = 0 does the objective function pass through the origin and CRS is assumed. In this way, the VRS model is expressed through:

$$min \sum_{m=1}^{M} vm\, xmi + ei \qquad (3)$$

s.a.

$$\sum_{s=1}^{S} \mu sysi = 1$$

$$\sum_{s=1}^{S} \mu s\, ysj - \sum_{m=1}^{M} vm\, xjm - ei \leq 0, \ \forall j$$

$$\mu s, vm \geq 0, \quad \forall s, m$$

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

A way of measuring product scale inefficiencies of an inadequate size of the productive unit can be expressed by the following:

$$ES = \frac{EF_{CRS}}{EF_{VRS}} \qquad (4)$$

Also, with the data panel, data envelopment analysis can be used as a program to measure productivity change over time. Fare et al. (1994) suggest changing the geometric mean of two Malmquist indices as a measure of the Total Productivity factor, one of which is based on the technology in period *t* and the other on the technology in period *t* + 1, or

$m(y_{t+1}, x_{t+1}, y_t, x_t)$

$$= \left[\frac{d^t(x_t^{+1}, y_{t+1})}{d^t(x_t, y_t)} X \frac{d^{t+1}(x_{t+1}, y_{t+1})}{d^{t+1}(x_t, y_t)} \right]^{1/2}$$

k = t or k = t + 1, the distance functions d (·) are defined as $[d^k(x_k, y_k)]^{-1} = \max_{ø, λ} ø$

subject to

$-øy_{i,k} + Y_k λ \geq 0$

$x_i - X λ \geq 0$

$λ \geq 0$

and

$[d^t(x_{t+1}, y_{t+1})]^{-1} = \max_{ø, λ} ø$

subject to

$-øy_{i,t+1} + Y_t λ \geq 0$

$x_{i,t+1} - X_t λ \geq 0$

$λ \geq 0$

and

$[d^{t+1}(x_t, y_t)]^{-1} = \max_{ø, λ} ø$

subject to

$-ø y_{i,t} + Y_{t+1} λ \geq 0$

$x_{i,t} - X_{t+1} λ \geq 0$

$λ \geq 0.$

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

The second model called SFA generates a frontier production (or cost) function with a stochastic error term consisting of two components: a conventional random error or "white noise", and a term representing frontier deviations, which is equivalent to relative inefficiency. SFA is often contrasted with data envelopment analysis (DEA). In SFA, a production function is estimated as follows: $y_i = X_i\beta + \varepsilon_i$ (5), where sub-index i denotes university i; product X the input vector; β the vector of unknown parameters; and ε an error term with two components. $\varepsilon_i = V_i - U_i$, where Ui represents a non-negative error term to account for technical inefficiency, or the remnant necessary to produce a product at the frontier, given the set of inputs used, with Vi being a random symmetrical error term. The standard assumption (Aigner et al., 1977) is that Ui and Vi assume the following distributions:

$$U_i \sim \text{i.i.d. } N^+(0, \sigma^2_u),\ U_i \geq 0 \qquad (6)$$

$$V_i \sim \text{i.i.d. } N(0, \sigma^2_v) \qquad (7)$$

That is, the term inefficiency (*Ui*) is supposed to assume a semi-normal distribution, i.e. universities are established (1) "at the frontier" or (2) below it. Some model variants include zero-truncated, exponential, and gamma distributions. An important parameter in this model is $\gamma = \sigma^2_u / (\sigma^2_v + \sigma^2_u)$, the ratio of the standard error of the technical inefficiency to the standard error of statistical noise, which is limited between 0 and 1. It is worth pointing out that $\gamma = 0$ under the null hypothesis of an absence of inefficiency means that all variance can be attributed to statistical noise. In recent years, SFA models that allow the term technical inefficiency to be expressed as a function of a vector of environmental and organizational variables have been developed. This is consistent with the idea that frontier deviations, which measure relative inefficiency in technology transfer units, are related to institutional and organizational factors. The model assumes that Ui are distributed independently with zero truncations of N (m_i, σ^2_u) distribution with $m_i = Z_i\delta$ (8), where Z is a vector of environmental, institutional, and organizational variables that, according to our hypothesis, influence efficiency, and δ is a vector of parameters.

In our case, the econometric programs LIMDEP.10 and NLOGIT.5 have been used to estimate the parameters of the β and δ vectors through the maximum likelihood estimation (MLE) method, and from the simultaneous estimation of the production function and the equation with the terms of inefficiency. On the basis of these parameter values, relative productivity estimates are calculated. The specification of equation (5) is based on the framework of the knowledge production function developed by Griliches (1979), adapted here to the income and number of contracts between universities and industry, used as a proxy of the outcome of the technology transfer between university-company. Thus, a log-linear Cobb-Douglas production function is established for the revenue/number of contracts with three inputs:

$$\ln(PRIVEXP_i) = \beta_0 + \beta_1 \ln(PUBEXP_i) + \beta_2 \ln(PIEXP_i) + \beta_3 \ln(OTTSIZE_i) + V_i - U_i \qquad (9)$$

Where PRIVEXP is the amounts of private expenditure between industry and academia annually; PUBEXP is the total public expenditure on R&D+i annually; PIEXP is the expenditure on intellectual property including patent application, search, and maintenance;

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

TTOSIZE equals the average number of specialized employees annually in the TTO, with the term technical inefficiency (Ui) expressed as follows:

$$Ui= \delta 0 +\_k\ \delta k\ \mathrm{ENV}i+\_m\theta m\ \mathrm{ORG}i+ \mu i \quad (10)$$

Where ENV and ORG are vectors of environmental and organizational factors, respectively, and μ is the classic disturbance term. However, there is a lack of systematic measures of ORG (Siegel et al., 2003). The estimated equation contains only the following environmental/ institutional factors (ENV):

$$Ui= \delta 0 + \delta \mathrm{MMED}i+ \delta \mathrm{PPUBLIC}i+ \delta \mathrm{RINDRD}ij+ \delta \mathrm{QINDOUT}ij+ \mu i \quad (10a)$$

Where MED and PUBLIC are dummy variables indicating whether the university has a medical faculty, and INDRDij and INDOUTij are indices of intensity in R&D of the annual industry, and the average growth of real annual production in state (j) of University i, respectively, during the sample period of 2012-2013.

Table 2.

Specifications of TT production functions and relative efficiency determinants

Output, Input, and relative efficiency variables	Production Function Models			
	1	2	3	4
Dependent or output variables:				
Private R&D expenditure			√	√
Number of R&D agreements	√	√		
Independent or input variables				
- Public expenditure on R&D	√	√	√	√
- Legal fees for IP	√	√		
Number of TTO specialized personnel	√	√	√	√
Inefficiency model				
Dummy for medical school existence		√		√
R&D intensity index based on inventive capacity by state		√		√

Source: own elaboration

In the search to verify the continuity of the previous results, 2 models were elaborated with a new sample for the period of 2014 to 2016. In contrast to the first sample for the years 2012 and 2013, 19 complete and consistent responses were obtained from HEIs in Mexico. The 6 institutions that did not respond or were inconsistent with respect to the first sample were: *Centro de Investigaciones Biológicas del Noroeste* (CIBNOR), *Centro de Investigaciones Avanzadas* (CINVESTAV), *Colegio de Posgraduados* (COLPOS), *Universidad Nacional Autónoma de México* (UNAM), *Instituto Tecnológico de Estudios Superiores de Monterrey* (ITESM), and *Instituto Nacional de Ecología* (INEEC). However, 4 new institutions were added with respect to the first sample including the *Instituto Nacional de Energías Limpias* (INEL), *Universidad Autónoma Metropolitana* (UAM), *Centro de Investigación Aplicada en Tecnologías Competitivas* (CIATEC), and the *Instituto Politécnico Nacional* (IPN).

In these models, the dependent variable used was the number of academic-industry contracts during the reference period, and the following independent variables were estimated: public expenditure through the PEI program, reported expenditure on intellectual property, and number of employees in the TTO of the HEIs. Both the first binomial negative regression model of variable effects and the second data model of dynamic panels were estimated using the statistical program STATA 12, based on a balanced sample of 19 groups of HEIs with a total of 57 observations.

Results

Table 3 presents the statistical description of the first sample. It is possible to observe that the average academic institution generates 34 agreements of collaboration sponsored by the industry generating an income of 48.4 million pesos, receives an average of 176.5 million pesos in federal support for research, employs 4 specialists in its TT units, and spends 98.2 thousand pesos annually in legal expenses of intellectual property.

Table 3.
Descriptive data statistics for DEA and SFA

Variables	Average	Standard Deviation	Minimum	Maximum	Cases
Private Expenditure R&D	48,417,315	49,156,390	650 000	212 505 000	42
Number of R&D Agreements between Private Companies and Higher Education Institutions	33.66667	38.33082	2.0	189.0	42
Public Expenditure on R&D	176,588,859	129,005,000	2 139 000	404 436 000	42
Expenditure on Intellectual Property	98,148.48	120,076.8	100.0	449 656	42
Number of TTO Specialist Employees	3.666667	5.276116	0.0	25.0	42
Dummy medical school existence	0.333	0.354	0	1	42
R&D Intensity Index by Federative Entity	7.771667	10.03221	.01	33.05	42

Source: own elaboration

On the other hand, the matrix of correlation coefficients (Table 4) shows, as might be expected, high levels between the two dependent variables: total private expenditure on academia-industry agreements (LOGPRIVE) and the number of R&D agreements between companies and HEIs (LOGCONTP) equal to 0.7378. Also, as might be expected, the coefficient between expenditure on intellectual property and the size of the TTO shows a moderate level of correlation of 0.458. The rest of the variables do not show signs of high linear association.

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Table 4
Matrix of correlation coefficients

	R&D Private Expenditure	Number of Univ-Ind Agreements	R&D Public Expenditure	Expenditure on Intellectual Property	TTO Staff	R&D Int. Index
R&D Private Expenditure	1.00000					
No. of Univ-Ind Agreements	.73787	1.00000				
R&D Public Expenditure	.37037	.14285	1.00000			
Expenditure on Intellectual Property	.33858	.36336	.17930	1.00000		
TTO Staff	.18844	.12314	.01232	.45891	1.00000	
R&D intensity index	-.04559	.12716	-.36074	.06725	.31439	1.00000

Source: own elaboration

Table 5 shows the results of the DEA models. As can be seen, the data produced by these models show a relative degree of heterogeneity in the composition of efficiency levels in TT units in Mexico. The estimated function has the logarithm of private expenditure on R&D as output variable and the logarithm of public expenditure on R&D, the logarithm of institutional expenditure on IP, and the size by specialized employees of the TTO as input variables. The model calculated with constant returns to scale presents an average efficiency of .86 with a standard deviation of .075, a minimum value of 0.64 (INECC) and a maximum of 1.0 (CIDESI, CIMAT).

Table 5.
Results of the DEA models

Institution	Year	DEA Efficiency Index (CRS) Constant Returns to Scale	DEA Efficiency Index (VRS) Variable Returns to Scale	Change in Technical Efficiency
Centro de Investigación en Alimentación y Desarrollo, A.C. (CIADAC)	2012	.77276	.85717	1.0389
	2013	.80440	.90244	
Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco (CIATEJ)	2012	.88989	.95440	1.03266
	2013	.91895	.97876	
Centro de Tecnología Avanzada A.C. (CIATEQ)	2012	.87588	1.00000	1.01739
	2013	.89049	1.00000	
Centro de Investigaciones Biológicas del Noreste S.C. (CIBNOR)	2012	.75872	.87388	1.02364
	2013	.77666	.88646	

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)	2012	.78308	.88426	0.921063
	2013	.72126	.80526	
Centro de Investigación Científica de Yucatán, A.C. (CICY)	2012	.80060	.88311	0.98012
	2013	.78486	.87562	
Centro de Ingeniería y Desarrollo Industrial (CIDESI)	2012	1.00000	1.00000	0.967738
	2013	.98622	.98622	
Centro de Investigación y Desarrollo en Electroquímica, S.C. (CIDETEQ)	2012	.85528	.92683	0.958439
	2013	.82216	.92442	
Centro de Investigación en Materiales Avanzados, S.C (CIMAV)	2012	.83540	.94845	1.00343
	2013	.83827	.95631	
Centro de Investigación en Matemáticas A.C. (CIMAT)	2012	.98312	.99415	1.01919
	2013	1.00000	1.00000	
Centro de Investigación y de Estudios Avanzados (CINVESTAV)	2012	.85886	.99992	1.0568
	2013	.90764	1.00000	
Centro de Investigaciones en Óptica A.C. (CIOPTAQ)	2012	.86640	.89669	1.03898
	2013	.90018	.92769	
Centro De Investigación En Química Aplicada (CIQA)	2012	.82348	.94238	1.00366
	2013	.82649	.93995	
Colegio de Posgraduados (COLPOS)	2012	.93980	1.00000	0.964524
	2013	.91761	.97511	
Corporación Mexicana de Investigación en Materiales (COMIMSA)	2012	.87040	.93957	1.06298
	2013	.92522	.97652	
Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)	2012	.84810	.94345	1.08238
	2013	.91797	.98936	
Instituto Nacional de Ecología y Cambio Climático (INECC)	2012	.64336	.71415	1.24255
	2013	.79723	.79723	
Centro de Investigación e Innovación en Tecnologías de la Información y Comunicación (INFOTEC)	2012	.93163	1.00000	0.885561
	2013	.83406	1.00000	
Instituto Potosino de Investigación Científica y Tecnológica (IPICYT)	2012	.80829	.91446	0.956827
	2013	.77339	.87415	
Universidad Nacional Autónoma de México (UNAM)	2012	.90104	.98408	0.980224
	2013	.88322	.98200	
Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)	2012	.88867	.97727	0.997723
	2013	.88664	.99689	
TOTAL AVERAGE		.8583	.9383	1.011

Fuente: Elaboración propia

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

In the model with variable returns to scale, the overall average efficiency increases to .938 with a standard deviation of .065. In this case, the minimum observed value is equivalent to .714 (INECC) and the institutions that are located at the frontier of efficiency are CIATEQ, CIDESI, CINVESTAV, CIMAT, and INFOTEC. This indicates that 23% of the total are in efficiency levels on the frontier. When calculating the Malmquist index that measures the change in total annual productivity, no significant change was observed between 2012 and 2013, which represented only a 1.1% increase. On the other hand, when identifying the change in the units of individual efficiency or technical progress by HEIs, significant changes are observed in institutions such as INECC, which, despite being the most inefficient institution in the sample, observed a positive change of 24% between 2012 and 2013. Finally, when calculating the efficiency of the global product scale, it provides an index of 91%.

In another calculated model where the output variable is represented as the logarithm of the number of private contracts between industry and academia, the overall efficiency level decreases to 61%, which implies average inefficiency levels close to 40%, with a standard deviation of 22.5% and a high dispersion, where the minimum value equal to .13 is again obtained by INECC and the maximum value of 1.0 is reached by CIDESI, CIMAT, and CINVESTAV.

On the other hand, based on the sample data, the stochastic frontier complementary model (SFA) was designed with the logarithm dependent variable of total private expenditure on R&D (LOGPRIVE). This model was first contrasted with a translog model, which was rejected by accepting the null hypothesis that the Cobb Douglas model was more suitable[1]. The results of the SFA model with a distribution in the part of zero-truncated normal inefficiency are presented in Table 6.

The results show a sigma value (u)=.58 and a gamma value close to the unit, which implies the rejection of the null hypothesis (H_0=0) that states that there is absence of inefficiency. In the model it can be observed that only the logarithm variable of public expenditure on R&D is significant at a level of 5%. This elasticity indicator shows that a 1% increase in public expenditure on R&D will impact .48% in private investment in university and industry agreements. The model gives a Chi^2 value of 35.2 above the critical value of 14.3 at 99%, which allows to affirm that the SFA model with the inefficiency component is superior to the traditional OLS model.

[1] The value given by the test with distribution $Chi^2 = 6.31 < 16.27$ with 9 gdl at 5% according to Table 1 (Kodde and Palm, 1986).

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Table 6
Stochastic Frontier Analysis Results (Zero-truncated Normal)

Private Expenditure on R&D	Coefficient	Standard Error	Z	Prob. |z|>Z*
Stochastic component of the frontier model				
Constant	3.92406**	1.87177	2.10	.0360
Public Expenditure on R&D	.48759**	.22142	2.20	.0277
Expenditure on Intellectual Property	.05461	.14214	.38	.7008
TTO Size	-.00214	.00979	-.22	.8268
Average of truncated distribution				
Constant	.16415	.27555	.60	.5514
Parameters for random components of e(i)				
ln_sgmaU	.37892	15.31912	.02	.9803
ln_sgmaV	-6.96806	118.9063	-.06	.9533
Heteroscedasticity in the variance of truncated u(i)				
Public or Private	-.56486	15.28020	-.04	.9705
Medicine School	-2.77953	3.61667	-.77	.4422
R&D intensity	.00148	.03862	.04	.9694

***, **, * ==> Significance at 1%, 5%, 10% level.

On the other hand, there does not seem to be any impact on intellectual property spending or on the size of the TTO in the specification of the proposed model. With regard to the inefficiency model, although it has the expected coefficients, it does not appear to be significant either. In other words, the public nature (the vast majority of institutions performing TT) and the possession of a medical school should have a positive impact (negative sign) on private R&D expenditures. The sample collects data in those HEIs that are located precisely in entities with high levels of inventiveness and development, so the variable I_DINTEN does not have any effect on the model.

Table 7
Efficiency indices based on the SFA model with zero-truncated mean distribution

Institution	**Year**	**Degree of efficiency**
Centro de Investigación en Alimentación y Desarrollo, A.C. (CIADAC)	2012	0.365584
	2013	0.513756
Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco (CIATEJ)	2012	0.738796
	2013	0.797906
Centro de Tecnología Avanzada A.C. (CIATEQ)	2012	0.832947
	2013	0.857857

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Centro de Investigaciones Biológicas del Noreste S.C. (CIBNOR)	2012	0.438761
	2013	0.515201
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)	2012	0.512721
	2013	0.292094
Centro de Investigación Científica de Yucatán, A.C.(CICY)	2012	0.466077
	2013	0.438307
Centro de Ingeniería y Desarrollo Industrial (CIDESI)	2012	0.823424
	2013	0.741688
Centro de Investigación y Desarrollo en Electroquímica, S.C. (CIDETEQ)	2012	0.628729
	2013	0.626233
Centro de Investigación en Materiales Avanzados, S.C (CIMAV)	2012	0.727797
	2013	0.747415
Centro de Investigación en Matemáticas A.C. (CIMAT)	2012	0.815556
	2013	0.826913
Centro de Investigación y de Estudios Avanzados (CINVESTAV)	2012	0.996725
	2013	0.996632
Centro de Investigaciones en Óptica A.C. (CIOPTAQ)	2012	0.544052
	2013	0.650843
Centro De Investigación En Química Aplicada(CIQA)	2012	0.692455
	2013	0.688779
Colegio de Posgraduados (COLPOS)	2012	0.589001
	2013	0.782529
Corporación Mexicana de Investigación en Materiales (COMIMSA)	2012	0.699951
	2013	0.796116
Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)	2012	0.711496
	2013	0.82582
Instituto Nacional de Ecología y Cambio Climático (INECC)	2012	0.215406
	2013	0.232079
Centro de Investigación e Innovación en Tecnologías de la Información y Comunicación (INFOTEC)	2012	0.373272
	2013	0.29664
Instituto Potosino de Inv. Científica y Tecnológica (IPICYT)	2012	0.593871
	2013	0.479829
Universidad Nacional Autónoma de México (UNAM)	2012	0.996725
	2013	0.996632
Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)	2012	0.986279
	2013	0.986955
TOTAL AVERAGE		0.66

Fuente: Elaboración propia

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

Finally, the average technical efficiency of the model is equivalent to 0.66 (see Table 7). Thus, the SFA model can be compared with the latest DEA model, which is based on the logarithm output variable of the number of private R&D contracts where the average efficiency reaches a value of 0.61. However, in contrast to the DEA model, this model presents higher levels of heterogeneity among HEIs.

It is necessary to point out that the main cause of the high dispersion of the results of the DEA and SFA models is due to the different magnitudes in resources that each HEI has in Mexico. It is possible to argue that while the DEA models reflect levels of efficiency and relative productivity, the SFA models show absolute efficiency indices based on mean values resulting from a regression. Thus, there are HEIs with relatively high DEA values and low levels in SFA indices. To illustrate the above, Table 8 is presented, with variable data and results in some of the selected HEIs. Thus, when comparing two HEIs with a high level of contrast, it is possible to illustrate the results obtained. For example, the INEEC obtained private contracts (output variable) with a value of $650 thousand pesos, with amounts of public expenditure on R&D (input variable) of $257 million pesos in 2012. In the other extreme, CINVESTAV obtained academic-industry contracts for an amount of $109.2 million pesos driven through an amount of public spending on R&D of $97.5 million pesos in 2013, that is, this research center reached a result 168 times greater with approximately one third of the investment allocated to INEEC. Thus, INEEC obtained DEA indices in the range 0.64-0.71 and 0.215 in the SFA model. Meanwhile, CINVESTAV achieved DEA results in the range .90-1.00 and 0.997 in SFA.

Table 8
Data from the selected HEIs

Institution	Year	Private Expenditure on R&D (millions)	Public Expenditure on R&D (millions)	Expenditure on IP (thousands)	Staff in TTOs	DEA CRS	DEA VRS	SFA
CIADAC	2012	$9.48	$363.17	$4.85	0	.772	.857	.365
	2013	$23.21	$353.19	$10.26	0	.804	.902	.513
CICESE	2012	$18.98	$242.19	$215.18	7	.783	.884	.512
	2013	$3.58	$157.65	$107.06	7	.721	.805	.292
CIMAT	2012	$25.54	$6.90	$5.00	0	.983	.994	.815
	2013	$22.84	$4.34	$5.00	0	1.00	1.00	.827
CIQA	2012	$53.59	$292.76	$72.87	2	.823	.942	.692
	2013	$48.87	$246.59	$162.72	2	.826	.929	.688
CINVESTAV	2012	$156.59	$404.44	$205.54	0	.858	.999	.997
	2013	$109.26	$97.49	$269.96	0	.907	1.00	.997
INEEC	2012	$0.65	$257.00	$10.20	0	.643	.714	.215
	2013	$2.50	$272.00	$0.00	0	.797	.797	.232
INFOTEC	2012	$1.90	$5.70	$0.00	5	.921	1.00	.373
	2013	$0.71	$2.14	$16.40	5	.834	1.00	.296
UNAM	2012	$69.54	$70.96	$383.22	10	.901	.984	.997
	2013	$91.66	$135.49	$449.66	25	.883	.982	.997

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

ITESM	2012	$69.37	$91.04	$314.63	10	.889	.977	.986
	2013	$148.14	$205.40	$319.62	16	.886	.997	.987

Fuente: Elaboración Propia

Similarly, it is possible to point out that a group of HEIs with lower resources and that are highly specialized such as CIADAC, CICESE, and INFOTEC obtain lower SFA indices, resulting in a range of 0.29 to 0.36; conversely, HEIs with multiple research segments and greater opportunities for institutional linkage such as UNAM, ITESM, and CINVESTAV reach levels in the range of 0.98 to 1.00 in the DEA and SFA models. CIQA is the average of the total number of HEIs, which reached a number of private contracts with a value of $48.870 million in 2013, very close to the average of $48.417 million (see Table 3). Thus, CIQA obtained an index of 0.68, very close to the global SFA average equivalent to 0.66. Finally, there is the case of CIMAT, which obtained contracts for $22.8 million in 2013, with only $4.34 million in public spending on R&D. This is the case of CIMAT, which obtained contracts for $22.8 million in 2013, with only $4.34 million in public spending on R&D. Finally, there is the case of CIMAT, which obtained contracts for $22.8 million in 2013 with only $4.34 million in public spending on R&D. This led CIMAT to obtain a DEA-VRS index equal to 1.00 and SFA equivalent to 0.82.

On the other hand, Table 9 shows the results obtained from the negative binomial models and dynamic panel data applied to the second sample of HEIs for the period of 2014-2016.

Tabla 9
Resultados de los modelos binomial negativo y de panel dinámico

Number of Pub-Priv. Agreements	Coefficient	Standard error	Z	Prob. |z|>Z*
Random Effects Negative Binomial Model$^{\alpha}$				
Constant	-4.923**	2.258	-2.18	0.029
LN Public Expenditure R&D	.4571***	.1178	3.88	0.00
LN Expenditure on IP	-.0149	.0648	-0.23	0.818
TTO Size	.0136	.0194	0.70	0.483
Log likelihood = -228.029 Wald Chi2(3) = 16.04 Prob > Chi2 = 0.0011				
***, **, * ==> Significance at 1%, 5%, 10% level.				
Number of Pub-Priv. Agreements	Coefficient	Standard Error	Z	Prob. |z|>Z*
Dynamic panel model - Arellano-Bond estimationβ				
Number of Pub-Priv. Agreements L1	.9438***	.0768	12.29	0.000
Public Expenditure for R&D	1.02e-06***	5.82e-08	17.49	0.000
Expenditure for IP	0	ND		
TTO Size	0	ND		
Instrument for the differentiated equation: (1) Number of Public-Private agreements Wald Chi^2 (1) = 151.06 Prob >Chi^2 = 0.000				

α The Breusch-Pagan Lagrange Multiplier test was applied and Ho var(u)=0 was rejected
β Estimated by the generalized method of moments (GMM), AR (1) test, and White/Huber/Sandwich robust estimator

http://dx.doi.org/10.22201/fca.24488410e.2019.1421

These preliminary results show a relative continuity in the productivity of public expenditure through the PEI on the number of agreements between academia and industry in Mexico[2]. However, spending on intellectual property and the size of specialists working in TTOs does not seem to have an impact—as in the first sample—on efficiency indices in HEIs. On the other hand, according to the result of the dynamic panel data model, it is established that there is a cumulative learning process in HEIs. That is to say, those educational entities that have formalized agreements and conventions in previous years have an average probability of 94% of renewing or creating new schemes of collaboration with the industry.

Conclusions

This article presents the results of efficiency levels in technology transfer units through parametric and non-parametric empirical analysis. These results indicate that there is heterogeneity in the efficiency of TT units in Mexico, especially between those that have implemented a TTO and those that do not have one in operation. Likewise, there is heterogeneity among HEIs with a wide range of scientific research (UNAM, CINVESTAV, ITESM) and among those specialized in a single segment (INEEC, CIADAC). However, the comparison between the period of 2012-2013 does not seem to show any significant change in the overall productivity of the TT units. Likewise, the study makes it possible to discern variables that affect changes in relative productivity between 2012 and 2016, such as public expenditure on R&D, as well as previous experience in the management of agreements between HEIs and private companies.

This work constitutes a seminal investigation on the relative productivity of TT units in Mexico and establishes a basis for the systematic and continuous measurement of these academic organizations. By focusing on the UTT units in Mexico, this study goes beyond those conducted by Guëmes-Castorena (2008) and Antonio et al. (2012), which focus only on the analysis of productivity in public universities. Likewise, this study contrasts with the one carried out by Altamirano-Corro et al. (2014), whose objective is to evaluate engineering faculties in Mexico.

Although other studies in Latin America have pointed to input and output factors to determine the efficiency levels of science and technology (Agapitova et al., 2002), this study contributes to a better understanding of the determinants of efficiency in TTOs and universities in Mexico by designing a type of production function with inputs and products not previously used in the country.

Some studies in Mexico have pointed out the need to establish adequate models for an efficient UTT (Feria, 2011; Necochea et al., 2013); therefore, this work contributes in the same line by recommending the implementation of an evaluation and control system for these schemes. This work also contributes to the design of future policies in innovation and technological development. By pointing out that different levels of regional R&D intensity do not seem to impact higher levels of TT, it is possible to deduce that a policy aimed at strengthening regional specialization schemes allows access to higher levels of efficiency. This should be relevant to the extent that other regions of the country, traditionally with greater

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[1] Coefficient B1 = .4571 of the semi-log model can be interpreted as an elasticity. The increase of X (Public expenditure on R&D) by 1% leads to increases in Y (number of agreements) by a ratio of B1/Y. V. Greene, W. (2011). Econometric Analysis. 7th Ed. New York: Prentice Hall

technological backwardness, are incorporated into university TT processes.

An additional contribution of this study is the determination of input value parameters that TTO and university managers must achieve for an efficient UTT. This is relevant for the organizational planning of intellectual property spending, the staff and specialized personnel to be hired in TTOs, and the search for income from public funding for R&D.

However, there are a number of limitations to this work. On the one hand, the restriction of the first sample to only two time periods, 2012 to 2013. Likewise, the study does not distinguish between public and private income by scientific branch (Thursby and Kemp, 2002). This analysis also does not incorporate variables such as postdoctoral students or the number of teachers carrying out R&D activities, which, it seems, has been very relevant in UTT efficiency studies in less developed countries (Agostini and Johnes, 2009; Zhang et al., 2009; Ali et al., 2013). Furthermore, this study does not incorporate variables that have incipiently been detected in Mexico since 2016, such as systematic invention notifications, negotiation of exclusive and non-exclusive licenses, and creation of spin-off companies. Finally, the development of future works of a qualitative type is to be expected in order to determine with greater precision why some HEIs have such drastic variations in short periods of time in the number of academy-industry and private investment agreements for R&D. All of the above will enrich the results of this study.

Finally, the establishment of new units of relative efficiency (benchmarking) could indicate the true levels of competitiveness of Mexican HEIs and CPIs in a supranational context in terms of technology transfer. While, at the local level, the incorporation of new regional and specialized TTOs leads to a greater level of dispersion in efficiency levels, it will be necessary to carry out comparative analyses of the heterogeneity observed in other countries with that occurring in Mexico (Chapple et al., 2005). Likewise, future works could contemplate the comparison in the performance of TT units with other business and governmental OTTs. Finally, it has been stated that with the notable exception of the *Instituto Tecnológico de Estudios Superiores de Monterrey* (ITESM), private universities in Mexico are scarcely participating in TT dynamics, hence the importance of future analyses to evaluate the productive performance of this type of institutions.

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