WORKING PAPERS

Castellón (Spain)

UNIVERSITAT JAUME I

# Budget Allocation as Innovation Policy? Untapped Potential in Mexico's Higher Education System

Economics Department


Herberto Rodríguez
Víctor Giménez
Javier Ordóñez
Emili Tortosa-Ausina


2025 / 04

# Budget Allocation as Innovation Policy? Untapped Potential in Mexico's Higher Education System

**Herberto Rodríguez**
UPAEP México
Center for Economic Intelligence and Research
herberto.rodriguez@upaep.mx

**Víctor Giménez**
Universitat Autònoma de Barcelona
Department of Business
victor.gimenez@uab.es

**Javier Ordóñez**
Universitat Jaume I
IEI & Department of Economics
javier.ordonez@eco.uji.es

**Emili Tortosa-Ausina**
IVIE & IIDL & Universitat Jaume I
Department of Economics
tortosa@uji.es

**2025 / 04**

**Abstract**

This study analyzes the efficiency and productivity of Mexican state universities from 1989 to 2017, a period marked by significant reforms in higher education funding mechanisms. Using a methodological approach that combines direct and indirect (budget-constrained) sequential technology frontiers, we construct a Malmquist productivity index that decomposes efficiency into four components: direct technical efficiency change, direct scale efficiency, input allocative efficiency, and indirect frontier shift. This quadripartite decomposition allows us to calculate the GAIN function, measuring the additional efficiency that universities could achieve through better resource allocation within existing budget constraints. Our analysis of 34 public state universities reveals considerable heterogeneity in efficiency patterns, with productivity improvements primarily driven by technological advancement (frontier shifts) rather than better resource allocation. By 2017, universities could potentially improve their efficiency by 52% through optimized resource allocation alone, without requiring additional funding. Cluster analysis identifies distinct strategic groups among universities, with varying efficiency profiles and improvement opportunities. Our findings suggest that while Subject to Performance Budget (STP) programs introduced in the 1990s contributed to overall efficiency improvements, they have not necessarily led to better resource allocation decisions, as evidenced by increasing bureaucratization and staff-to-faculty ratios. These results have important implications for higher education funding policies in developing economies, suggesting that significant performance improvements could be achieved through better allocation decisions even within existing budgetary constraints.

**Keywords:** Higher Education, Efficiency, GAIN Function, Mexico

**JEL classification**: I21, H52, C14

# Budget Allocation as Innovation Policy? Untapped Potential in Mexico's Higher Education System*

Herberto Rodríguez
*UPAEP México*

Víctor Giménez
*Universitat Autònoma de Barcelona*

Javier Ordóñez
*Universitat Jaume I and IEI*

Emili Tortosa-Ausina
*Universitat Jaume I, IIDL and Ivie*

May 21, 2025

**Abstract**

*This study analyzes the efficiency and productivity of Mexican state universities from 1989 to 2017, a period marked by significant reforms in higher education funding mechanisms. Using a methodological approach that combines direct and indirect (budget-constrained) sequential technology frontiers, we construct a Malmquist productivity index that decomposes efficiency into four components: direct technical efficiency change, direct scale efficiency, input allocative efficiency, and indirect frontier shift. This quadripartite decomposition allows us to calculate the GAIN function, measuring the additional efficiency that universities could achieve through better resource allocation within existing budget constraints. Our analysis of 34 public state universities reveals considerable heterogeneity in efficiency patterns, with productivity improvements primarily driven by technological advancement (frontier shifts) rather than better resource allocation. By 2017, universities could potentially improve their efficiency by 52% through optimized resource allocation alone, without requiring additional funding. Cluster analysis identifies distinct strategic groups among universities, with varying efficiency profiles and improvement opportunities. Our findings suggest that while Subject to Performance Budget (STP) programs introduced in the 1990s contributed to overall efficiency improvements, they have not necessarily led to better resource allocation decisions, as evidenced by increasing bureaucratization and staff-to-faculty ratios. These results have important implications for higher education funding policies in developing economies, suggesting that significant performance improvements could be achieved through better allocation decisions even within existing budgetary constraints.*

**Key words and phrases**: Higher Education, Efficiency, GAIN Function, Mexico

**JEL Classifications**: I21, H52, C14

**Communications to**: Emili Tortosa-Ausina, Departament d'Economia, Universitat Jaume I, Campus del Riu Sec, 12071 Castelló de la Plana, Spain. Tel.: +34 964387168, e-mail: `tortosa@uji.es`.

*We thank Emili Grifell-Tatjé and Pablo Arocena for their valuable comments and suggestions. Emili Tortosa-Ausina acknowledges the financial support of MCIN/AEI/10.13039/501100011033 (Ministerio de Ciencia e Innovación, PID2020-115450GB-I00) the Valencian regional government (Generalitat Valenciana, CIPROM/2022/50). The usual disclaimer applies.

# 1. Introduction

The importance of higher education institutions (HEIs) is based on their ability to promote economic growth, social mobility and well-being. Higher education is considered a social good, it creates intellectual capital (Sala-i Martin and Barro, 1995), it has an impact on local economic development (Agasisti et al., 2019; Crespo et al., 2022); It promotes social mobility (Haveman and Smeeding, 2006) and is expected to improve quality of life, happiness and well-being (Cuñado and Pérez de Gracia, 2012; Yakovlev and Leguizamon, 2012). Today, in egalitarian societies, higher education is considered a universal right (López-Segrera, 2012). However, markets alone are not able to provide this educational service efficiently. Public funding and government support are necessary to compensate for market failures and to provide this public good (Wigger and von Weizsäcker, 2001).

The global expansion of higher education systems, coupled with their increasing costs, has triggered a major public debate on the relevance of continued financial support for higher education in a context of growing societal needs and limited public financial resources. In recent decades, the efficiency of higher education institutions (HEIs) has become a topic of research and discussion in policy circles and the academic community. The strong interest in this topic can perhaps be attributed to the continuous cuts in public funding, the increased efforts to achieve transparency and accountability in the budgets of institutions, the global expansion of university rankings, and the increasing competition among HEIs (Mungaray et al., 2006). In recent years, numerous studies have analyzed the efficiency of higher education institutions using different techniques, levels of analysis, samples, and selections of inputs and outputs. De Witte and López-Torres (2017) presents a very complete compilation of previous studies on efficiency in education.

In the specific case of Mexico, its higher education system underwent a massive expansion in the 1960s and 1970s, driven mainly by the demographic window, the entry of women into the labor market, and increasing government efforts to improve primary and secondary education throughout the country. During this expansion, however, the system proved to be highly inefficient and unsatisfactory in dealing with the growing number of students (Organisation for Economic Co-operation and Development, 2019). At the time, enrollment was the only factor taken into account in the allocation of federal funds, which was highly politicized and heavily dependent on the negotiating skills of university administrators (Secretaría de Educación Pública, 2018). The lack of a standardized system for measuring the effectiveness of the use of federal funds, as well as the emergence of a large number of low-quality private institutions, required the implementation of new reforms and the introduction of innovative funding formulas in order to change the practice of fixed budget allocations to a more flexible and performance-based funding practice.

In the late 1980s and early 1990s, the Mexican government created a series of programs and policies aimed at modernizing the entire higher education system. Among the most important policies implemented are the establishment of an evaluation system for higher education institutions, the promotion of competition between institutions (public and private), the promotion of enrollment growth and educational quality, the promotion of scientific research and technological development, the promotion of better management practices, and the modification of funding schemes. With these policies, the Mexican public higher education system has created specific programs to establish funding based on performance or Subject to Performance Budget (STP). From the point of view of public policy, the existence of public funding directed to higher education institutions, especially the STP, requires the evaluation of its impact on improving the efficiency of the Mexican higher education system (de Wit et al., 2005; Kent, 2005; Rubio Oca et al., 2005).

The objective of this study is to analyze whether the public policies implemented by the Mexican government in the 1980s and 1990s have had a relevant impact on increasing the efficiency of higher education institutions—which has been far less analyzed than both its US and European counterparts (see, for instance Herberholz and Wigger, 2021). A first contribution of this paper is the construction of both direct and indirect (budget constrained) sequential technology frontiers to measure efficiency and productivity change using data from 34 public state universities in Mexico over the period 1989-2017. Universities in our work are assumed to be cost-constrained output maximizers, since data on budget and budget allocation are available for all Mexican state universities. Few studies in higher education, such as Glass (1998); Glass et al. (2002), have analyzed efficiency using the cost-constrained or indirect approach in general due to the availability of budget data. This is important because allocative efficiency can be calculated and can provide important insights into how higher education institutions should become more efficient by allocating their budgets more intelligently.

A second contribution of this paper is the estimation of direct and indirect geometric Malmquist indices to decompose productivity gains into direct technical efficiency change, allocative efficiency change, and indirect frontier shift. A third contribution of this paper is the construction of a sequential technology frontier that assumes that the input-output mix used in previous years is always available and is part of the technology in period $t$, in other words, successive reference production sets are nested within one another (Alene, 2010) to our knowledge, no other work in higher education has done so.

Finally, a fourth contribution is the long time period analyzed. While the majority of previous studies have focused on evaluating the efficiency of HEI over a few academic years, this study analyzes a long time period (26 years), which allows for a more accurate evaluation since most public policies have medium and long term effects. Previous studies have focused on HEI in Mexico, such as Avilés-Sacoto et al. (2014) Altamirano-Corro and Peniche-Vera (2014) and Sagarra et al. (2017), among others. However, to the best of the authors' knowledge, this is the only study that analyzes the efficiency of higher education institutions in Mexico over a long period of time. Measuring efficiency over the years will help us to better determine the impact of public policies on HEIs' efficiency in the long run.

Our main findings provide a clear panorama of a general improvement in university efficiency over the 1989-2017 period, though this improvement has been relatively modest with a productivity gain driven primarily by technological advancement (frontier shifts) rather than better resource allocation. While the Subject to Performance Budget (STP) introduced in the 1990s has contributed to overall efficiency improvements, our analysis reveals that Mexican universities have not achieved optimal resource allocation—as evidenced by the GAIN function showing that by 2017, universities could potentially improve their efficiency by 52% through better budget allocation alone, without requiring additional funding. The policy implications are significant: rather than increasing funding, substantial efficiency gains could be achieved through improved budget allocation guidelines, targeted interventions based on university-specific inefficiency sources, and incentives for optimal faculty-to-staff ratios. This has important implications for higher education funding policies in developing economies, as significant performance improvements can be achieved within existing budgetary constraints.

The structure of the paper is as follows: Section 2 provides a review of the existing literature on higher education efficiency and the Mexican context; the methodology that allows to measure efficiency and productivity is presented in Section 3; Section 4 is the description of the data and variables used in the model; Section 5 5 presents the empirical results of the analysis; and finally, section 6 concludes the paper.

## 2. Background

The education sector provides an interesting but complex context for efficiency analysis because HEIs are non-profit and use multiple inputs to produce multiple outputs. Furthermore, the budgetary restrictions and quality education issues have made the measurement of productivity and efficiency essential in monitoring and evaluating the performance of HEI. There are different approaches to the study of efficiency. De Witte and López-Torres (2017) revised 90 papers that analyze the efficiency of universities, colleges, business schools, university departments, research programs and research/university teachers. Their work provides important insights on the HEIs efficiency literature. In this section we present a short literature review on the efficiency of higher education literature worldwide and in Mexico. We compare research approaches and provide an overview of the problems faced by different studies. Likewise, we list the inputs and outputs applied in previous studies, as well as the units of analysis.

## 2.1. The Mexican Higher Education System

In Mexico, as in most countries of the world, the financing and provision of higher education institutions has become one of the main issues on the public agenda. In recent decades, a great public debate has been extended about the relevance of continuing to support Mexican higher education institutions (HEIs), as well as in the methods of financing and evaluation of such institutions in a context of growing social needs and limited public financial resources (Mungaray et al., 2006).

Since the late 1980s, Mexico's demographic dividend has increased the demand for higher education, leading to the creation of numerous public and private institutions. The majority of the newly created institutions belong to the private sector. However, most of the increase in enrollment has been absorbed by existing public institutions. Since public universities are largely dependent on government funding, in the early 1990s the Mexican higher education system underwent a series of reforms and policies designed to modernize and make deep structural improvements. Among the most relevant policies implemented were the establishment of an evaluation system, the promotion of competition among institutions, the endorsement of enrollment growth and educational quality, the support of scientific research and technological development, the promotion of better management practices and the partial modification of the funding allocation rules (Kent-Serna, 2009; Sagarra et al., 2015).

In 1996, the Program for the Improvement of the Faculty (PROMEP) was designed. The objective of PROMEP was to increase the number of highly qualified full-time faculty in public universities. Two programs were launched in 2001: The Integral Program for Institutional Strengthening (PIFI), aimed at faculty members, and the National Scholarship Program (PRONABES), aimed at students. PIFI is based on two core concepts: academic capacity, which refers to the academic profile of faculty members; and academic competitiveness, which refers to the number of certified academic programs. PIFI aimed to encourage institutions to use public funds more efficiently and transparently. On the other hand, PRONABES was formulated to promote equity among graduates by providing scholarships to low-income students (Galaz-Fontes et al., 2009).

Other notable policies and changes designed to improve the higher education system were the creation of the Additional Ordinary Subsidy Assignment Model Fund and the consolidation of ANUIES and some other non-governmental institutions such as the Council for Higher Education Accreditation (COPAES) and the Inter-Institutional Committees for Higher Education Evaluation (CIIES). Likewise, the National Council of Science and Technology (CONACYT) has offered important economic and reputational incentives for graduate programs recognized in the Registry of Quality Graduate Programs (PNPC) (Martínez-Prats et al., 2022).

Perhaps the most notable government policy designed for higher education institutions was the creation of a new fund: the federal special budget. This is a Subject to Performance Budget (STP), which is given to universities in a variable proportion based on their performance. It grants funds for special projects aimed at improving the quality of education and increasing enrollment in PNPC, the percentage of full-time professors in graduate programs, and the percentage of students who graduate. Currently, it is one of the main sources of funding for higher education institutions. This STP budget was created in collaboration between the Mexican Ministry of Education (SEP) and the National Association of Universities and Institutes of Higher Education (ANUIES). It uses a formula called "CUPIA", which takes into account a multi-variable approach based on teaching and research indicators. (ANUIES, 2003).

The funding system and the type of funds that higher education institutions have access to determine most of their resource allocation and investment decisions. STP budgets have been applied in many countries using different approaches such as incremental budgeting, activity-based formula models, performance-based outcome models and, more recently, efficiency-based funding (Sexton et al., 2012). In Mexico, the implementation of all these policies and reforms, especially the creation of the STP budget, has triggered a great competition among universities and has allowed the federal government to exercise greater control over the performance of public institutions and to implement a better evaluation and accountability of public funds. However, their impact on improving the efficiency of higher education institutions remains to be assessed.

### 2.2. Higher Education Institutions' efficiency

Various methods have been used to measure the productivity of HEIs, such as Ordinary Least Squares (OLS), Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA); the method used in this paper. DEA was first introduced in 1988 by Ahn et al. (1988). The authors developed a study using the Charnes et al. (1978) (CCR) approach to analyze aspects of the production behavior of public and private doctoral-granting universities in the U.S. They found inefficiencies of up to 35% for universities without medical schools and 20% for universities with medical schools; the study allows for the identification of significant differences in efficiency levels and productive scale between groups of universities. This work represents a milestone in the study of university efficiency.

The studies that followed Ahn et al. (1988) used different methodologies and were applied to multi-year data with different samples. One of the early examples of these studies is that developed by Beasley (1990); the author constructed a model to compare UK physics and chemistry university departments for the academic year 1986-1987; the results provided good insights into the differences in efficiency between university departments and how this efficiency could be improved. However, the study was limited by data availability and could not prove the existence of a relationship between department size and efficiency. Later, Beasley (1995) used the same sample and presented a model for simultaneously determining the teaching and research efficiency of university departments.

Similarly, Breu and Raab (1994) measured the relative efficiency of the top 25 national universities and national liberal arts colleges in the U.S., as ranked by News and World Report in 1992. Their findings revealed an important correlation between efficiency and student satisfaction, suggesting that resources spent on prestige and reputation do not necessarily increase student satisfaction. However, because this study did not use a random sample, the efficiency scores had a narrow variance; a broader sample would yield broader efficiency scores. Also in the U.S., Thursby (2000) used data on the quality of 104 economics Ph.D.-granting departments in 1993 collected by the National Research Council. The results of this study indicated that resources were the main determinants of output and quality measures.

Using a similar methodology, Korhonen et al. (2001) analyzed the academic research performance of universities and research institutes of the Helsinki School of Economics. The authors presented an outcome-oriented system for evaluating academic research and proposed the creation of a set of indicators to identify the most preferred combination of outputs and inputs. In addition, the results highlighted the importance of evaluating efficiency within departments and across universities.

Some studies have focused on exploring scale and scope efficiency. An example is the study developed by Bonaccorsi et al. (2006) in 45 Italian universities from 1995 to 1999. The results show that size and diversification are not necessarily good at the university level. According to the authors, economies of scale and scope are not the most important drivers of efficiency in higher education. Similarly, Worthington and Lee (2008) found that among Australian universities, the largest productivity growth was not found in the larger and older universities, but in the smaller and newer ones.

Other studies have compared different methods of measuring efficiency or provided validation of alternative methods. The study by Johnes (2006a) examined the advantages and disadvantages of different methods for measuring the efficiency of higher education institutions. Another very influential example is the study by Johnes et al. (2008) in which the authors analyze 121 HEIs in England. The results show that estimates of economies of scale and scope vary depending on the estimation technique used. Following this line of research, Bougnol and Dulá (2006) compare ranking schemes in the U.S., concluding that the model is a critical aspect in the ranking of universities.[1]

Finally, some studies have deepened the analysis of productivity changes over time to distinguish between changes in technical efficiency and intertemporal shifts in the efficiency frontier.

[1] In this line, see also Giménez and Martínez (2006), which is one of the few studies that, like us, also focus on cost efficiency.

The most notable cases include Flegg et al. (2004) and Thanassoulis et al. (2011) in the United Kingdom; Agasisti and Johnes (2010) and Agasisti et al. (2012) in Italy; Worthington and Lee (2008) in Australia; Kempkes and Pohl (2010) in Germany; and Agasisti and Pérez-Esparrells (2010) in Italy and Spain.

Flegg et al. (2004) used the Malmquist to decompose the efficiency of 45 universities in the United Kingdom. The results accounted for a 51.5% increase in productivity over the period 1980/81-1992/93. Similarly, Worthington and Lee (2008) used the Malmquist indexes (Caves et al., 1982) to decompose into efficiency change, technological change, pure efficiency change, and scale efficiency change. They found an average annual productivity growth of 3.3% for 35 Australian universities over the period 1998-2003. Later, Agasisti and Johnes (2010) conducted a cross-country study between 127 English and 57 Italian public universities, decomposing into efficiency change and frontier shift for the two countries in two different time periods. Their results provided evidence of country-level differences and a general increase in efficiency in the academic year 2003/04. This conclusion was supported by the evidence provided by Agasisti and Pérez-Esparrells (2010), which decomposed the efficiency of 57 Italian public universities and 44 Spanish public universities into efficiency change and frontier shift. The results show an important shift of the efficiency frontier in Italian universities and remarkable differences at the country level in the academic year 2004/2005. Similarly, the study of Agasisti et al. (2012) on 147 Italian university departments is decomposed into efficiency change and frontier shift and found evidence of a deterioration of the technology frontier over the period 2004-2007. Finally, Kempkes and Pohl (2010) was decomposed into efficiency change and frontier shift and the results showed that out of the 72 German universities in the sample, productivity increased faster in East German universities than in West German universities over the period 1998-2003. This paper also provides comparisons between different quantitative approaches to constructing efficiency frontiers.

### 2.2.1. Decision Making Units (DMUs)

The efficiency of higher education institutions has been studied at various levels of data: students, academic programs, academic departments, universities, and cross-country comparisons. Examples of cross-country studies include the one developed by Joumady and Ris (2005) for eight European countries; the one developed by Wolszczak-Derlacz and Parteka (2011) for seven European countries. These studies have provided important evidence on the impact that a region's economic development, demographic changes, or a country's specific government programs have had on HEI efficiency and how this varies across countries. However, this type of analysis is scarce and more research is needed to obtain measures for cross-country comparisons.

The majority of previous studies on the efficiency of higher education institutions have focused on comparing universities within a country and identifying the factors that enable efficiency levels. Examples are the studies developed by Avkiran (2001) for Australia; Izadi et al. (2002) for the United Kingdom, Bonaccorsi et al. (2006) for Italy, McMillan and Chan (2006) for Canada, Johnes and Schwarzenberger (2011) for Germany, Johnes and Li (2008) for China, and Kuo and Ho (2008) for Taiwan, among many others. Some relevant work has been developed to measure the efficiency of academic departments; examples are the studies by Beasley (1990, 1995) and Agasisti et al. (2012). Other studies have focused on evaluating the effectiveness of academic programs, such as the studies by Haksever and Muragishi (1998) and Colbert et al. (2000).

The recent availability of individual-level data for higher education institutions has provided an opportunity to measure student performance within universities. Examples of this are the study by Thanassoulis and Silva Portela (2002), which measures the efficiency of students within and across schools; and the study by Johnes (2006b), which decomposes the efficiency of economics graduates from UK universities. This level of analysis makes it possible to identify institutional and individual outcomes and to determine the effect of individual performance on institutional efficiency. However, data at this level are rarely available and future research using individual units of analysis is needed. For the Mexican case, we decided to select each public university as the relevant decision making unit (DMU); the full list is reported in Table 1.

#### 2.2.2. The selection of variables

The efficiency literature assumes that HEIs transform inputs into outputs. One of the major limitations of most studies seems to be the definition and selection of variables, given the availability of data. There is no definitive standard guide or agreement on the selection of inputs/outputs. As measures of inputs, most papers include variables corresponding to the institution, such as teacher characteristics and learning environment characteristics. Common measures of teacher characteristics are: education, experience, number of publications, and salary. Common measures of learning environmental characteristics are: number of academic members, number of non-academic members, class or university size, and general expenditures. However, there is a growing debate about the real impact of university inputs on student performance: while some authors argue that the effect is not significantly positive, others have claimed that since these variables are endogenously determined, their impact would depend on the model specification (De Witte, 2015).

As measures of educational output, most papers include graduation rates, post-graduation employment rates, and average test scores. For research outputs, the number of peer-reviewed articles and books published, the number of citations, patents, awards received, and the amount of grants or income received are usually selected. However, according to De Witte (2015), there are two main issues in selecting outputs. First, they capture the effect of previous educational inputs of previous educational levels, not only those obtained in higher education institutions. And second, the measures include only short- and medium-term outcomes, not the long-term educational benefits.

Over time, the variables have become more diverse and specific and have adopted different mixes of outputs and inputs. Recent studies such as Giménez and Martínez (2006) have included variables such as teaching quality (according to student opinion)—although authors such as Beasley (1990) had suggested that teaching quality is not a direct output of the university department, but a proxy for person-specific increases in knowledge.

The correct specification of inputs and outputs is crucial in efficiency analysis, as the use of aggregate data can lead to misleading results. This was illustrated by Johnes's (2006b) study of 2,547 economics graduates from UK universities in 1993. The authors decompose efficiency into two components: one attributable to the university and one attributable to the student. The results of the study show that the units of analysis are very important to avoid misleading results.

### 2.3. Research on HEIs' efficiency in Mexico

In the specific case of Mexico, few studies have focused on measuring the efficiency of its universities. Guemes-Castorena (2001) calculates the relative efficiency of Mexican state universities to propose appropriate inefficiency-based funding models; the study of Avilés-Sacoto et al. (2014) uses a Cobb-Douglas methodology in a two-stage model to evaluate the performance of 36 undergraduate business programs in the US and one in Mexico. Likewise, the study by Altamirano-Corro and Peniche-Vera (2014) evaluates the efficiency of 13 faculties in a public university using the methods of Analytic Hierarchy Process (AHP) and DEA. The results of these studies contributed significantly to the research on university efficiency in Mexico and provided evidence for the application of mixed methods. We expand this burgeoning literature considering an alternative approach with some advantages to the previously considered methods (aw we shall see below), which enable focusing on other research questions, and also considering a longer time period.

## 3. Methodology

The measurement of productivity and efficiency is essential in monitoring and evaluating the performance of HEIs. There are mainly two approaches in the empirical measurement of HEIs efficiency: parametric techniques such as Ordinary Least Squares (OLS) and Stochastic Frontier Analysis (SFA), or non-parametric techniques such as Data Envelopment Analysis (DEA), the methodology used in this paper. Within these techniques, many studies have relied on the method of frontier analysis which builds an efficient frontier considering each Decision-Making Unit (DMU) at different time periods (Färe et al., 1988). Numerous studies have relied on non-parametric techniques, specifically, on Data Envelopment Analysis (DEA). DEA was first introduced by Charnes et al. (1978) and it was initially used to measure the efficiency of non-profit organizations. In recent years, DEA has been successfully applied to analyze a diverse rank of non-profit and profit organizations such as schools (Agasisti and Bonomi, 2014), universities (Johnes and Li, 2008), banks (Fukuyama and Weber, 2009), credit companies (Fukuyama et al., 1999) and electric companies (Blázquez-Gómez and Grifell-Tatjé, 2011) among others.

This study models the efficiency of 34 HEIs in Mexico using DEA methodology. The model specification is output oriented because Mexican public universities face a demand driven market. Federal programs and funds for HEIs in Mexico, including the National Development Plan (PND), aim to raise university entry numbers. Therefore, the increase in the enrollment in public universities represents an incentive for university growth. We use university level data to calculate direct and indirect sequential technology. Inputs are divided in two: fixed and variable. In the direct technology all inputs are considered fixed while in the indirect technology some inputs are considered variable. Given the limited number of observations (only 34 HEIs per year), this study adopts sequential technology in order to generate robust results that can compensate for the small number of DMUs and the abundance of inputs and outputs. In sequential technology, production sets are nested into one another which allows enclosing frontiers from previous years. It assumes that DMUs can always produce at least what they have produced before, so inputs-outputs mix used in previous periods are always available and part of the technology in period and technological regression is not possible (Alene, 2010; Chen et al., 2008; Nin et al., 2003).

The application of direct and indirect sequential technology approaches offers some useful tools for evaluating DMUs performance, which are relevant in contexts like ours, where budgetary constraints play a crucial role. Specifically, direct sequential technology captures how universities transform current inputs into outputs while accounting for capabilities built up over time—such as institutional knowledge and research capacity. Meanwhile, indirect (budget-constrained) sequential technology enhances this analysis by explicitly considering how universities allocate limited financial resources across different inputs to maximize their outputs. This dual approach is especially valuable for evaluating public universities, as managers must make strategic decisions about resource allocation while operating under fixed budgets (Heaton et al., 2023; Xiong et al., 2022). The complementary nature of these approaches allows researchers to decompose efficiency gains into multiple components—including technical efficiency, scale efficiency, allocative efficiency, and frontier shifts—providing deeper insights into how universities can improve their performance through both better operational practices and more optimal budget allocation decisions.

### 3.1. Direct and indirect sequential technology

In many productivity assessment studies, the Direct Technology is popular due to the fact that is relatively easier to build data sets with the right selection of inputs and outputs to compute direct frontiers; whereas, the Indirect Technology also known as "Cost Constrained" is rarely used because information about the prices of inputs and total budgets is needed and is not always available. Indirect Frontiers are computed using linear programming models, allowing the amounts of inputs to vary, subject to prices and a budget constraint; that is why the indirect frontier is further away and contains the Direct Frontier; Indirect Efficiency scores must be equal or lower than Direct Scores (Färe et al., 1988).

We rely on the characteristics and relationship between Direct Sequential Technology and Indirect Sequential Technology to provide a decomposition in four sub-indexes of an Indirect Malmquist Index (IM); our particular interest is in the possibility to build an input allocative efficiency sub-index that would provide specific information about how the HEIs' managers are using their budgets to allocate it in the inputs that will produce the most efficient combination of outputs.

Let $X_v^{it} = (x_{v1}^{it}, \ldots, x_{vL}^{it}) \in R_+^L$ denote the variable input vectors with input prices vector $W^{it} = (w_1^{it}, \ldots, w_L^{it}) \in R_+^L$ and budget $C^t = (c^{1t}, \ldots, c^{It}) \in R_+^I$; $X_f^{it} = (x_{f1}^{it}, \ldots, x_{fM}^{it}) \in R_+^M$ denote fixed input vectors of producer $i = (1, \ldots, I)$ to produce the vector of outputs $Y^{it} = (y_1^{it}, \ldots, y_N^{it}) \in R_+^N$ in time period $t = 1, \ldots, T$.

The production set of direct sequential technology (Färe et al., 1994; Tulkens and Vanden Eeckaut, 1995), from the point of time $s = 1$ until $s = t$ of feasible combinations of input vectors and output vectors is given by the production set $T_{Direct}^{(I(1,t))} = \{(y^{is}, x_v^{is}, x_f^{is}) : x_v, x_f \text{ can produce } y\}$. Since in sequential technology $T_{Direct}^{(I(1,t))} = \bigcup_{(s=1)}^{t} T_{Direct}^{(I(s,s))}$ successive sequential reference production sets, have the property of being nested into one another, that is $T_{Direct}^{(I(1,t))} \subseteq T_{Direct}^{(I(1,t+1))}$ for every $t = 1, \ldots, T-1$, then we can define a production frontier $f_{Direct}(x) = max\{y : (y, x_v, x_f) \in T_{Direct}^{(I(1,t))}\}$ as the outer boundary of the production set $T_{Direct}^{(I(1,t))}$ (Grifell-Tatjé and Lovell, 2015).

The indirect sequential production technology $T_{Indirect}^{(I(1,t))}$ determines the efficiency level by estimating the maximum amount of outputs than can be produced in $t$ subject to a budget constraint denoted as $c^{it} \geq \sum_{l=1}^{L} w_l^{it} x_{vl}^{it}$ (Färe et al., 1988). The indirect sequential production set, from the point of time $s = 1$ up until $s = t$, $T^{(I(1,t))}_{Indirect} = \{(y^{is}, \frac{w^{is}}{c^{is}}, x^{is}_{f}) : \frac{w}{c}, x_f$ can produce $y\}$. Since in the indirect sequential technology $T^{(I(1,t))}_{Indirect} = \bigcup^{t}_{(s=1)} T^{(I(s,s))}_{Indirect}$ successive sequential reference production sets, have again the property of being nested into one another, that is $T^{(I(1,t))}_{Indirect} \subseteq T^{(I(1,t+1))}_{Indirect}$ for $t = 1, \ldots, T-1$, then we can define a production frontier $f_{Indirect}(x) = max\{y : (y, \frac{w}{c}, x_f) \in T^{(I(1,t))}_{Indirect}\}$ as the outer boundary of the production set $T^{(I(1,t))}_{Indirect}$.

For calculating the level of efficiency relative to the frontier of best practice DEA uses distance functions. The direct distance function measures the greatest factor $\theta$, by which the outputs $y^{it}$ can be expanded given the level of inputs $y^{it}$. It is given by:

$$[D^{it}_{O}(x_v{}^{i}t, x_f{}^{i}t, y^{it})]^{-1} = max\{\theta : (\theta y^{it}) \in T^{(I(1,t))}_{Direct}\} \tag{1}$$

The indirect distance function measures the greatest factor $\theta$, by which the outputs $y^{it}$ can be expanded given the level of inputs, for the producer $i$ under period's $t$, it is given by:

$$[ID^{it}_{O}(x^{it}_{f}, \frac{w^{it}}{c^{it}}, y^{it})]^{-1} = max\{\phi : (\phi y^{it}) \in T^{(I(1,t))}_{Indirect}\} \tag{2}$$

where $\phi$ is the output-oriented Debreu-Farrell efficiency measure (Blázquez-Gómez and Grifell-Tatjé, 2011). Distance functions can take values from zero to one. If the value of the distance function is equal to one, the producer is placed on the frontier which means it is efficient for both direct and indirect output distance functions. If the value of the distance function is under one, the producer is under the frontier and not reaching their best practice achievement levels. To determine the value of the distance functions, it is necessary to solve the following linear programming model for period $t$ described by Färe et al. (1994) for the Direct Technology:

$$\begin{gathered}[D^{it}_{o}(x^{it}_{f}, x^{it}_{v}, y^{it})]^{-1} = \max_{\theta,\lambda} \theta, \\ s.t.\{\theta y^{i't}_{n} \leq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} y^{is}_{n}, x^{i't}_{vl} \geq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} x^{is}_{vl}, x^{i't}_{fm} \geq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} x^{is}_{fm}, \lambda^{is} \geq 0\}\end{gathered} \tag{3}$$

where $i'$ is the evaluated unit.

For the indirect technology, it is necessary to solve the following linear programming model also described by Färe et al. (1994):

$$\begin{gathered}[ID^{it}_{o}(x^{it}_{f}, \frac{c^{it}}{w^{it}}, y^{it})]^{-1} = \max_{\phi,\lambda,x_v} \phi, \\ s.t.\{\phi y^{i't}_{n} \leq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} y^{is}_{n}, x^{i't}_{vl} \geq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} x^{is}_{vl}, x^{i't}_{fm} \geq \sum_{s=1}^{t}\sum_{i=1}^{I} \lambda^{is} x^{is}_{fm}, c^{i't} \geq \sum_{l=1}^{L} w^{i't}_{l} x^{it}_{vl}, \lambda^{is} \geq 0\}\end{gathered} \tag{4}$$

Following Grosskopf et al. (1997) note that the choice variables for the direct distance function (3) are $\theta$ and $\lambda$, while the choice variables for the indirect distance function problem (4) are $\phi$, $\lambda$ and $x_v$; the prime notation denotes data for the observation (HEI) under evaluation. Note that previous linear programs exhibit Constant Returns of Scare (CRS) and satisfy strong disposability of outputs (Färe et al., 1994; Glass, 1998).

### 3.2. The Indirect Malmquist index and its decomposition.

Malmquist Index is a temporal approach introduced by (Caves et al., 1982) that expand the estimations of DEA and differentiate between changes in technical and scale efficiency in a given year and technological shifts in the efficiency frontier (changes over time). It has been widely used in efficiency studies since it was applied with DEA in Färe et al. (1994); Alene (2010). Some of the most remarkable studies using Malmquist Index in the analysis of efficiency in education are: Glass (1998), Flegg et al. (2004), Worthington and Lee (2008), Agasisti and Johnes (2010), Agasisti and Pérez-Esparrells (2010), Kempkes and Pohl (2010), Agasisti et al. (2012), and Thanassoulis et al. (2011), among others.

Malmquist Index calculates the ratio of input or output distance functions to measure the productivity change of two time periods: $t$ (base period) and $t+1$ (Alene, 2010). According to Färe et al. (1994), the output-oriented Indirect Malmquist Indexes in $t$, $t+1$ for DMU $i$ are given by:

$$IM_o^t = \frac{ID_o^{it}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o{}^{it}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)} \tag{5}$$

$$IM_o{}^{t+1} = \frac{ID_o{}^{it+1}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o{}^{it+1}\left(x_f{}^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)} \tag{6}$$

The Geometrical Indirect Malmquist is equal to the geometric mean of the Indirect Malmquist Index in $t$ and the Indirect Malmquist Index in $t+1$:

$$IM_o = \left[\frac{ID_o{}^{it}\left(x_f{}^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o{}^{it}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)} \times \frac{ID_o{}^{it+1}\left(x_f{}^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o{}^{it+1}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)}\right]^{1/2} \tag{7}$$

The underlying assumption when applying DEA to calculate the Malmquist productivity index is to construct a best practice frontier in each time period as a reference technology. It can be decomposed in two components: one that evaluates with respect to the efficiency frontier in the current period (the relative movement over the change in technical efficiency), and another that evaluates with respect to the technology in a given base period (shifts in the efficiency frontier). When inefficiency exists, then efficiency growth over time can be separated into movements due to improvements of the DMU towards the efficiency frontier and movements that result from the frontier shifting up over time (Flegg et al., 2004; Worthington and Lee, 2008).

After some simple algebraic manipulations, we obtain:

$$IM_o^t = \frac{D_o{}^{it+1}\left(x_f^{it+1}, x_v{}^{it+1}, y^{it+1}\right)}{D_o{}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)} \times \frac{\frac{ID_o{}^{it+1}\left(x_f^{it+1}, \frac{c^{it+1}}{w_0^{it+1}}, y^{it+1}\right)}{D_o^{it+1}\left(x_f^{it+1}, x_v^{it+1}, y^{it+1}\right)}}{\frac{ID_o{}^{it}\left(x_f^{it}, \frac{c^{it}}{w^{it}} y^{it}\right)}{D_o{}^{it}\left(x_f^{it}, x_v, y^{it}\right)}} \times \frac{ID_o{}^{it}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o{}^{it+1}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)} \tag{8}$$

$$IM_o^{t+1} = \frac{D_o{}^{it+1}\left(x_f{}^{it+1}, x_v{}^{it+1}, y^{it+1}\right)}{D_o{}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)} \times \frac{\frac{D_o{}^{it+1}\left(x_f{}^{it+1}, \frac{c^{it+1}}{w^{it+1}} y^{it+1}\right)}{D^{it+1}\left(x_f{}^{it+1, x_v{}^{it+1}, y^{it+1}}\right)}}{\frac{ID_o{}^{it}\left(x_f{}^{it}, \frac{c^{it}}{w^{it}} y^{it}\right)}{D_o{}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)}} \times \frac{ID_o{}^{it}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)}{ID_o{}^{it+1}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right)} \tag{9}$$

The square root of the product of Equations (8) and (9) is the decomposition for the Indirect Geometric Malmquist we arrive to a similar result as in Fukuyama et al. (1999):

$$\begin{aligned} IM_o = & \underbrace{\frac{D_o^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1})}{D_o^{it}(x_f^{it}, x_v^{it}, y^{it})}}_{\text{direct technical efficiency}} \times \underbrace{\frac{\frac{ID_o^{it+1}(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1})}{D_o^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1})}}{\frac{ID_o^{it}(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it})}{D_o^{it}(x_f{}^{i}t, x_v^{it}, y^{it})}}}_{\text{input allocative efficiency}} \times \\ & \underbrace{\times \left[\frac{ID_o^{it}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right) \times ID_o^{it}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o^{it+1}\left(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it}\right) \times ID_o^{it+1}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}\right]^{1/2}}_{\text{technological change}} \end{aligned} \tag{10}$$

In equation (10) we decompose the indirect geometric Malmquist as the product (from left to right) of the direct technical efficiency change (10).a, the input allocative efficiency change (10).b and the technological change (10).c; in each of the three components, values less than one mean deterioration (productivity loss) and values greater than one, improvement (productivity gain).

Then we extend our analysis to develop a further decomposition of the geometric Malmquist index. From Färe et al. (1994) and Glass (1998), we know that cost direct output scale efficiency can be expressed as:

$$S_o^{it}\left(x_f^{it}, x_v^{it}, y^{it}\right) = \frac{D_{o,V}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)}{D_o{}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)} \tag{11}$$

where $D_{o,V}^{it}\left(x_f^{it}, x_v{}^{it}, y^{it}\right)$ denotes variable returns to scale (V). This last equation is computed analogously to (1), but with the additional restriction $\sum_{s=1}^{t+1}\sum_{i=1}^{I}\lambda^{is} = 1$.

When equation (11) has a value of one, the DMU $i$ is scale efficient and when its value is greater than one, the DMU is scale inefficient. Then, we obtain:

$$IM_o = \underbrace{\frac{D_o^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1})}{D_o^{it}(x_f^{it}, x_v^{it}, y^{it}}}_{\text{a)direct technical efficiency change}} \times \underbrace{\frac{S_o^{it}(x_f^{it}, x_v^{it}, y^{it})}{S_o^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1})}}_{\text{b)direct scale efficiency}} \times \underbrace{\frac{\frac{ID_o^{it+1}(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1})}{D_o^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1}}}{\frac{ID_o^{it}(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1})}{D_o^{it}(x_f^{it}, x_v^{it}, y^{it})}}}_{\text{c)input allocative efficiency}} \times$$
$$\times \underbrace{\left[\frac{ID_o{}^{it}\left(x_f^{it}\frac{it}{w^{it}}, y^{it}\right) \times ID_o{}^{it}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}{ID_o^{it+1}\left(x_f^{it}\frac{c^{it}}{w^{it}}, y^{it}\right) \times ID_o{}^{it+1}\left(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}\right)}\right]^{1/2}}_{\text{d)indirect frontier shift}} \tag{12}$$

This expression for the Indirect Geometrical Malmquist index is then decomposed in 4 sub-indexes (12).a, (12).b, (12).c, (12).d; from left to right: expression (12).a measures direct technical efficiency change based on the direct technology; the second expression (12).b indicates changes in cost direct scale efficiency; the third expression (12).c is the input allocative efficiency change that provides information if the efficiency in mix selection constrained to HEI's; again if there has been an improvement, the expression takes values higher than 1, if there has been no change, it equals one and if it has worsen, it takes values lower than one. The last expression (12).d measures the indirect frontier shift form period $t$ to period $t+1$.

### 3.3. The GAIN function

Finally, this study calculates the "gain" in output resulting from the structural reform in the assignment of STP budget in Mexico. We measured this "gain" via the GAIN function as described by Grosskopf et al. (1999), which is equal to the ratio of the output achieved given the current allocation of inputs and the potential output achievable when HEIs are able to re-allocate their inputs in an optimal mix. That is, the ratio of the direct distance scores of HEI $i$ in time $t$, and the indirect distance score of HEI $i$ in time $t$, both with CRS and strong disposability of outputs technology:

$$GAIN = \frac{D_o^{it}(x_f^{it}, x_v^{it}, y^{it})}{ID_0^{it}(x_f^{it}, \frac{c^{it}}{w^{it}}, y^{it})} \tag{13}$$

The measure represents the additional efficiency that could be achieved if the HEI $i$ in time $t$ allocates its resources in a more efficient manner. It is, therefore, a measure of allocative efficiency given the prices of the HEIs (Grosskopf et al., 1999). The GAIN Function can only take values superior or equal to one, because $ID_0^{it+1}(x_f^{it+1}, \frac{c^{it+1}}{w^{it+1}}, y^{it+1}) \leq D_0^{it+1}(x_f^{it+1}, x_v^{it+1}, y^{it+1})$. This expression collects the radial distance between the output isoquant of technology $T_{Direct}^{I(1,t+1)}$ and $T_{Indirect}^{I(1,t+1)}$, where $T_{Direct}^{I(1,t+1)} \subseteq T_{Indirect}^{I(1,t+1)}$. As Grosskopf et al. (1999) pointed out, $T_{Direct}^{I(1,t)} \subset T_{Indirect}^{I(1,t)}$ when a HEI does not allocate efficiently its budget. This expression can be interpreted as a measure of the efficiency gained by an efficient selection of inputs by the HEI: a value equal to one indicates an efficient mix, while a value superior to one, implies that it is possible to choose a better input mix that produces a higher amount of output.

## 4. Data

We use data at the university level and detailed information on inputs, outputs, prices, and budgets of all 34 public state universities in Mexico from 1989 to 2017. The details are reported in Table 2, which provides descriptive statistics, including mean, minimum, maximum and standard deviation of all input and output variables (for selected years). Each university represents a Decision Making Unit (DMU). The table contains the list of all DMUs. The dataset was collected by the Mexican Secretariat of Public Education (SEP); some of the information was publicly available, while other data was gathered through a request for information to the National Institute for Access to Information and Data Protection (*Instituto Nacional de Transparencia, Acceso a la Información y Protección de Datos Personales*, INAI). All financial data from this study is expressed in thousands of pesos and has been adjusted to 2008 constant prices.

Four measures of inputs have been selected: Full-time Equivalent Faculty ($FTEFaculty$), Non-Academic Staff ($Staff$), General Expenses ($GExpenses$), and Subject to Performance Budget ($STPBudget$).

- Full-time Equivalent Faculty ($FTEFaculty$, $x_1$) is computed as the number of full-time faculty plus half the number of part-time faculty, plus the number of lecturing hours per week taught by hourly professors divided by 40 (assuming that a full-time professor could teach as many as 40 hours per week).
- $Staff$ ($x_2$) is defined as the number of non-academic staff members working at the university.
- $GExpenses$ ($x_3$) is measured as the sum of all current expenses not including salaries.
- $STPBudget$ ($x_4$) is defined as the sum of Federal and State Extraordinary budgets assigned to the universities according to their performance. The STP Budget is tied to specific expenses, hence its allocation cannot be modified by the HEIs' administrators and it is considered a fixed input ($x_f$).

The first three inputs represent the university's expenses in the ordinary budget; they are considered variable ($x_v$) since they can be discretionarily allocated by the HEIs' administrators, as long as the budget is not exceeded. When using Indirect Technology, an optimal allocation of the variable inputs ($x_v$) is the one that maximizes HEIs' efficiency levels. The prices for these inputs are defined as follows: $W1FTEFaculty$ ($w_1$) is the average full-time equivalent wage per HEI; $W2Staff$ ($w_2$) is the average wage of non-academic staff members divided per HEI; finally, the price $W3GExp$ ($w_3$) is equal to 1 since $GExpenses$ is already expressed in monetary units. See Table 2.

HEIs produce a variety of outputs. However, most studies in HEIs, like Salmi (2009), focus on three key factors: education, research output, and knowledge transfer as services provided by universities. For the purposes of this study, there was not sufficient available data on knowledge transfer or other services provided by universities to society. Therefore, the three measures of outputs selected are weighted enrolment ($WEnrolments$, $y_1$), weighted graduates ($WGraduates$, $y_2$), and weighted SNI ($WSNI$, $y_3$).[2] Although this might be *a priori* a problematic issue, we should also consider that the measurement of knowledge transfer is particularly difficult, as it does not exist a widely accepted metric for it.

$WEnrolments$ ($y_1$) is measured as the weighted average of incoming students in all higher education levels. Students entering an undergraduate degree are multiplied by a factor of 1, and students entering university at a graduate level are multiplied by a factor of 1.5. This is considering that, according to data from the Secretary of Public Education (SEP) Secretaría de Educación Pública (2018), the average cost of a graduate student is approximately 1.5 times the cost of an undergraduate student. Even though enrolment is often included as an input, in the specific case of Mexican public universities, the demand-driven market represents an incentive for university growth. This is because some federal funds and programs are conditioned to the university enrolment numbers, including the National Program for Higher Education Diario Oficial de la Federación 28/12/2023 (2023), whose aim is to increase enrolment in public universities in the country.

The variable $WGraduates$ ($y_2$) is measured as the number of students graduating yearly from all university levels. Students obtaining an undergraduate degree are multiplied by a factor of 1, and students obtaining a graduate degree are multiplied by a factor of 1.5. This is considering that, according to data from INEE (*Instituto Nacional para la Evaluación de la Educación*, or National Institute for Educational Evaluation) and UNAM (*Universidad Nacional*

[2]SNI (*Sistema Nacional de Investigadores*, or National System or Researchers) in Mexico is a national evaluation and recognition system established in 1984 by the National Council for Science and Technology (CONACYT). The program identifies and supports the most productive researchers across Mexican universities and research centers through a classification system with three levels (SNI I, II, and III), providing financial incentives and prestige to researchers based on their research productivity, training capabilities, and institutional involvement. In the context of this study, SNI membership serves as a proxy for research quality, with weighted SNI representing the financial value of different researcher tiers used to measure research output at Mexican state universities.

*Autónoma de México*, or National Autonomous University of Mexico), the average cost of a graduate student is approximately 1.5 times the cost of an undergraduate student.

Finally, the number of research professors in the National System of Researchers (*Sistema Nacional de Investigadores*, SNI) is used as a proxy for university research. $WSNI$ ($y_3$) is measured as the weighted average of all SNI research professors working at the university. The weights were assigned according to the financial incentive received by each of the SNI levels, as per the Ministry of Governance Mexico (SEGOB).

Regarding the evolution of the different variables, as shown in Table 2, and from the input side, there has been an increase in the average $FTEFaculty$ and $Staff$ members over the last 26 years. However, since 2006, this increase has been significantly higher for staff members. The $WEnrollment$ to $Staff$ ratio has been rapidly decreasing in recent years, compared to the $WEnrollment$ to $FTEFaculty$ ratio. The number of students per full-time equivalent faculty member has also increased, which might imply that further investments in faculty members are necessary to offset the continuous rise in enrolment numbers. However, the average $FTEFaculty$ price is higher than the average $Staff$ price, and the difference between the two has widened over time.

As for the ratio of $WSNI$ to $FTEFaculty$, it has been increasing over the course of the study, which indicates that Higher Education Institutions (HEIs) are investing more in research and quality education. The $STPBudget$ increased as a percentage of the Total Budget from 0% in 1989 to nearly 23% in 2009, but then it decreased to barely 6% by 2017.[3] The Total Budget to $WEnrollment$ ratio has been increasing, which indicates that there has been an increase in the expenditure per student at HEIs. Furthermore, the ratio of $GExpenses$ to $WEnrollment$ and the ratio of $STPBudget$ to $WEnrollment$ have been increasing recently, which implies that HEIs are receiving more budget per student.

There is a consistent increase in total weighted enrollment and degrees. However, with a 5-year lag, terminal efficiency is below 20%, which means that less than 20% of the students enrolled in all universities obtain a degree. This number has increased since 1989, but it is still very low and can be worrisome for efficiency measures.

## 5. Results and discussion

A summary of the computed results for all HEIs efficiency scores is shown in Table 3. On the one hand, we observe the number of HEIs that are efficient by year and by score. As expected, the direct VRS yields a higher number of efficient HEIs compared to the direct CRS scores, with the year 1992 (not reported but available upon request) having the most HEIs with efficient scores in both measures. On the other hand, for the Indirect CRS scores, Table 3 also

[3]Detailed information for all years is available from the authors upon request.

reports that only 3 universities were efficient in the year 1989 according to the indirect CRS, and no other HEI in any other year reached efficiency. We can then assume that budget allocation during the year 1989 was the most efficient compared to the following years; recall we are using a sequential frontier approach, so every year is compared with all the previous years for all HEIs. The efficient HEIs for the year 1989 are the Benemérita Universidad Autónoma de Puebla (BUAP), Universidad Autónoma Benito Juárez de Oaxaca (UABJOAX), and Universidad Autónoma del Estado de Morelos (UAEMOR), which are characterized by having smaller enrollments and more balanced faculty-to-staff ratios compared to their less efficient counterparts. These three universities operated at relatively modest scales with better resource allocation decisions, particularly in their faculty management strategies, which contributed to their ability to achieve full efficiency under the indirect CRS model in that first year of the sequential frontier analysis

In Table 4, we report the corresponding average efficiency scores for direct VRS, direct CRS, and indirect CRS scores. These scores are also shown in Figure 1. As expected, direct VRS scores are higher than direct CRS scores since a VRS technology is more relaxed than the CRS one. We also observe that indirect CRS scores are lower than direct CRS scores because the indirect frontier is always further and contains the direct frontier. We can clearly observe a positive tendency for improvement in all scores through time, but we also witness an efficiency loss during the first years analyzed until the year 1994. Presumably, this effect might exist since during those years (1989-1994) the Tequila Crisis had an indirect effect on university budgets and costs due to inflation and public budget restrictions. We can also observe that the efficiency improvement is more significant for the direct VRS score, second for the direct CRS score, and that the direct CRS score had only marginal improvement. Intuitively, we know that HEIs have not been very good at allocating their budgets in inputs that produce better results on outputs.

In Figure 2, we show the evolution of the indirect geometric Malmquist score and its decomposition described in Equation (12); again, we observe that there has been only a slight improvement in pure (direct) technical efficiency and scale efficiency, a loss in allocative efficiency and an improvement in the frontier shift that is driving the general efficiency improvement or productivity gain expressed by de geometric Malmquist index score. This improvement likely reflects two key factors: first, the significant expansion in total enrollment during the observed period due to demographic trends; and second, the increasing research productivity of professors, driven by incentives to join CONACYT's National Researcher's System, which provides substantial economic benefits to researchers who meet its standards.

To better understand our results, we build a ranking index of each of the geometric average of efficiency scores type that is showed in Table 5; among the best HEIs performers, the Universidad Autónoma del Estado de Hidalgo (UAEHGO) leads in pure technical (direct) efficiency change and allocative efficiency change (first and third components of equation (12), respectively), the Universidad Autónoma del Carmen (UNACAR) in scale efficiency change (second component of equation (12)), the Universidad Autónoma del Estado de Morelos (UAEMOR) in frontier shift (fourth component of equation (12)) and, for the geometric Malmquist index (l.h.s. of equation (12)), the Universidad Autónoma del Estado de Hidalgo (UAEHGO) also leads. The Universidad Autónoma de Aguas Calientes (UAAGS) ends up with the best GAIN index score, computed from equation (13), implying that, despite being the university with the narrowest gap between direct and indirect scores, it still has room to improve to gain an additional 9.77% efficiency by better allocating inputs to produce outputs. This result is particularly interesting, as it would have been more difficult to achieve with other techniques.

Among the worst performers we get the Universidad Autónoma de Campeche (UACAMP) in pure technical (direct) efficiency change (first component of Equation (12)), the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH) in scale efficiency change (second component of Equation (12)), the Universidad Autónoma de Guerrero (UAGRO) in allocative efficiency change (third component of Equation (12)), the Instituto Tecnológico de Sonora (ITSON) in frontier shift (fourth component of Equation (12)) and the Universidad Autónoma Benito Juárez de Oaxaca (UABJOAX) being the worst performer according to the geometric Malmquist index (l.h.s. of Equation (12)). Regarding the GAIN index in Equation (13), the worst performer is the Universidad Autónoma de Guerrero (UAGRO), this university has a huge gap of 170% to improve in allocative efficiency.

These poor performance patterns suggest several underlying challenges. The Universidad Autónoma de Guerrero's allocative inefficiency may stem from a historical tendency to prioritize administrative staff over faculty, or from operating in a context of resource scarcity that has led to reactive rather than strategic budget decisions. For Universidad Michoacana de San Nicolás de Hidalgo, the scale inefficiency potentially reflects either underutilization of resources or operating at a scale that exceeds their optimal capacity given available inputs. The technical inefficiency at UACAMP might indicate outdated teaching methodologies or insufficient investment in educational technology and infrastructure.

The implications of these disparities are significant: underperforming institutions not only drain public resources but also fail to provide optimal educational outcomes for their students, potentially limiting social mobility in their regions. Without targeted intervention to address specific inefficiency sources, these institutions risk falling further behind, creating a two-tiered system where students' educational opportunities depend heavily on which university they can access. Policymakers should consider differentiated support strategies, with UAGRO particularly needing guidance on optimal resource allocation and budget management training for administrators to close its enormous 170% efficiency gap.

### 5.1. Geometrical Malmquist index: quadripartite decomposition and analysis of productivity distributions

We examine now productivity change across Mexican universities by decomposing the indirect geometric Malmquist index into its four components (direct technical efficiency, scale efficiency, input allocative efficiency, and frontier shift) going beyond the analysis of average trends. Instead, we employ kernel density estimation to examine the full distribution of each component, revealing heterogeneity in performance improvements across institutions. Using sequential counterfactual distributions, we isolate the relative contribution of each factor to overall productivity gains, identifying whether efficiency improvements stem from better technology, optimal scale, or smarter resource allocation. Accordingly, expression (12) can be rewritten more succinctly as follows:

$$IM_o = TE \times SE \times AE \times FS \tag{14}$$

which implies that the changes in the Malmquist index can be written as a quadripartite decomposition of direct technical efficiency change ($TE$), direct scale efficiency ($SE$), input allocative efficiency ($AE$), and indirect frontier shift ($FS$).

This quadripartite decomposition has the feature of allowing to construct counterfactual distributions by sequential introduction of each of these factors. Therefore, it is possible to ascertain the degree to which each of the four components contributes more greatly to the formation of the distribution of productivity ($IM_o$). For this, we employ nonparametric densities, estimated via kernel smoothing.

Under these considerations, the relative contribution of direct technical efficiency change to the distribution of the Malmquist index

$$IM_o^{TE} = TE \tag{15}$$

would be isolating the effect on the distribution of university performance (measured via the indirect Malmquist index) of changes in technical efficiency only. This is illustrated in Figure 3a, which depicts the corresponding nonparametric density estimated via kernel smoothing, showing that most universities are relatively close to unity—i.e., they are stagnant. By inspecting visually the densities, some additional relevant information is unraveled, such as the existence of some specific universities whose efficiency gains are well above the average, as shown by the bumps in the upper tail of the distribution. The mean of the distribution of efficiency change is indicated by a vertical line which is almost coincidental with stagnation.

By adding sequentially the rest of the factors, we would have that the distribution of the variable

$$IM_o^{TE \times SE} = TE \times SE \tag{16}$$

would isolate the effect of direct scale efficiency, and the joint effect of direct technical efficiency change and direct scale efficiency. The corresponding density in Figure 3b is represented by the dotted line, and contributes to a very small shift in the joint distribution. Indeed, the distributions are quite similar, with the exception of the bumps in the upper tail, which are smoothed out for the case of $IM_o^{TE\times SE}$—a feature that could partly be related to the effect of the bandwidth. The similarity between both distributions is reinforced by the closeness of the averages (represented by the dashed and dotted vertical lines).

Regarding the relative contribution of input allocative efficiency, we have that

$$IM_o^{TE\times SE\times AE} = TE \times SE \times AE \tag{17}$$

would be isolating the joint effect of direct technical efficiency change, direct scale efficiency, and input allocative efficiency. The corresponding density ($IM_o^{TE\times SE\times AE}$) is represented by the dashed-dotted line in Figure 3c, which shows actually a negative overall impact on the distribution of $IM_o$—the probability mass shifts towards the lower tail. However, although the allocative efficiency problems experienced by some universities dominate (the average, corresponding to the dashed-dotted vertical line, is below those corresponding to $IM_o^{TE}$ and $IM_o^{TE\times SE}$), some universities still over-perform the others in this variable, as shown by the persistent bumps in the upper tail of the distribution.

Finally, we factor in the relative contribution of the indirect frontier shift:

$$IM_o^{TE\times SE\times AE\times FS} = TE \times SE \times AE \times FS \tag{18}$$

The decomposition of productivity reveals striking heterogeneity in how Mexican universities achieved efficiency gains. Figure 3 demonstrates that the dominant factor driving overall productivity improvements has been the indirect frontier shift (Figure 3d), with a distribution centered well above unity, indicating technological progress across the system. The mean indirect frontier shift of approximately 1.04 reflects system-wide advances in educational technology and research capabilities. In contrast, the distribution of direct technical efficiency change (Figure 3a) clusters tightly around unity with minimal variation, suggesting stagnation in operational practices across institutions. The scale efficiency component (Figure 3b) displays similar characteristics, with most universities achieving neither gains nor losses, positioning them close to their optimal operating size.

The most concerning finding emerges from the input allocative efficiency component (Figure 3c), where the distribution shows a leftward shift, with many universities experiencing efficiency losses. This pattern indicates widespread deterioration in resource allocation decisions across the system. The analysis reveals that while technological advancement has propelled system-wide improvements, the inability to optimize resource allocation has limited potential gains.

The counterfactual analysis demonstrates that technological progress alone cannot compensate for poor allocation decisions. Universities that managed to maintain or improve allocative efficiency, however few, achieved substantially better overall productivity gains. These distributional insights highlight the critical importance of addressing resource allocation inefficiencies to fully capitalize on technological investments in the Mexican higher education system.

### 5.2. Efficiency clusters across Mexican universities

Attempting to make a better synthesis of our results, we ran a cluster analysis using the $K$-means algorithm; we show the elbow diagram in Figure 4 and the graphical clusterization of the DMUs in 4 clusters using the scores obtained in Table 5 in Figure 5. In Table 6 we show each DMU with their average efficiency scores and the cluster to which they belong according to our analysis. We observe that 5 universities belong to cluster 1, 3 universities belong to cluster 2, 17 to cluster 3 and 9 to cluster 4.

The HEIs in cluster 1, have pure technical (direct) efficiency and allocative efficiency loss, while have a slight improvement in scale efficiency and an improvement above all in frontier shift. The HEIs belonging to cluster 2, have important improvements in pure technical efficiency and frontier shift, and slight improvements in scale efficiency, and a very small loss in allocative efficiency. Regarding cluster 3, the HEIs belonging to this group show a very small pure technical efficiency and scale efficiency improvements, a small allocative efficiency loss, and an important frontier shift gain. HEIs belonging to cluster 4, show small pure technical (direct) efficiency and allocative efficiency loss, and a small-scale efficiency improvement while we observe a frontier shift gain.

Table 6 also reports the averages corresponding to the efficiency components of each cluster, and in Figure 2 we graph the overall evolution of these magnitudes. We find that the universities belonging to cluster 2 have had the highest productivity gains, on average, followed by the universities of cluster 1; both have productivity gains above the average; the universities of cluster 3 have gained productivity close to the average and finally universities of cluster 4 have gained productivity scores below the average.

It is interesting to notice that no cluster has been able to gain allocative productivity (for all of them, as reported in Table 6, the magnitude is lower than 1), what may be reflecting that the process of bureaucratization has been general for the system with the exception of 5 universities: Universidad Autónoma del Estado de Hidalgo (UAEHGO), Universidad Autónoma de Querétaro (UAQRO), Universidad Autónoma del Carmen (UNACAR), Universidad Autónoma de Aguascalientes (UAAGS) and Universidad Autónoma de Yucatán (UADY), as showed in

Table 4. These exceptional universities appear to have implemented distinctive governance models and resource allocation strategies. UAEHGO, which leads in allocative efficiency, has maintained a governance structure emphasizing academic leadership in budget decisions rather than administrative control. UAQRO and UADY have invested heavily in long-term academic planning with multiyear budget frameworks that prioritize faculty development over administrative expansion. UNACAR, despite its relatively small size, has leveraged its regional specialization in engineering and petroleum studies to create efficient resource allocation models responding to industry partnerships. UAAGS has implemented systematic cost-benefit analyses for all major budget allocation decisions, maintaining one of the lowest administrative-to-faculty ratios in the system. Unlike most other institutions where administrative positions have proliferated in response to increasing reporting requirements from STP programs, these five universities have successfully integrated compliance requirements into existing academic structures rather than creating parallel administrative units, enabling them to maintain better faculty-to-staff ratios and more efficient resource distribution patterns.

Finally, regarding the GAIN index, in Figure 6 we show that it has been steadily increasing throughout the study period, implying a deterioration in allocative efficiency. By 2017, the average GAIN score reached 1.52, revealing a substantial opportunity to improve efficiency by 52% simply through better resource allocation without requiring additional funding. These results would suggest that investing more in faculty rather than administrative staff could yield significantly better outputs across all three key performance indicators: enrollment, graduation rates, and research production. According to these findings, responding to regulatory pressures by expanding administrative positions rather than investing in academic personnel might not always be the best strategy.

In Figure 7, we present the GAIN Index by cluster, revealing important strategic differences. Cluster 2 universities demonstrate superior resource allocation practices with a GAIN Index of 1.21 by 2017, positioning them closest to their efficiency frontier. In contrast, Cluster 4 universities show the poorest allocation decisions with a substantial GAIN Index of 1.58, leaving considerable room for improvement. Clusters 1 and 2 fall between these extremes with values of 1.42 and 1.40 respectively. These cluster-specific findings suggest that tailored intervention strategies could be more advisable (rather than "one size fits all" approaches), with particular attention to helping Cluster 4 universities reform their governance structures and decision-making processes around resource allocation. More broadly, our GAIN analysis indicates that Mexican higher education could benefit more from reallocating existing resources toward instructional capacity than from increasing overall funding levels—a finding with substantial implications for national education policy in resource-constrained environments.

## 6. Conclusions

The performance of higher education institutions represents a critical concern worldwide from multiple perspectiveseconomic sustainability, educational quality, and societal impact. Public universities, in particular, face distinctive challenges as they navigate the competing demands of expanding access, maintaining academic excellence, and demonstrating accountability for public resources. These institutions increasingly operate in environments characterized by fiscal austerity, intensifying competition for funding, and escalating expectations from stakeholders. The resulting imperative to maximize efficiency while preserving educational quality has become a defining challenge for university administrators and policymakers alike. Our study addresses these challenges by analyzing the evolution of efficiency in state universities in Mexico from 1989 to 2017, a period characterized by significant reforms in higher education funding and management. Our methodological approach combines traditional efficiency measurement techniques with the so-called GAIN function, which was introduced by Grosskopf et al. in 1999 and, despite its advantages in terms of providing insights into both technical and allocative efficiency under budget constraints, it had never been used before to assess the performance of higher education institutions.

The case of Mexican state universities is particularly relevant, due to the country's ongoing transition toward knowledge-based economic development within significant resource constraints. These insights are particularly relevant in this context, where higher education evolution mirrors challenges faced by other developing countries, with increasing enrollment demands coinciding with limited public funding. This intersection of growing needs and constrained resources has created efficiency imperatives that have been barely examined through comprehensive methodological approaches until this study.

Results can be explored from a myriad of perspectives. First, while Mexican state universities have experienced general efficiency improvements over the studied period, these gains have been primarily driven by frontier shifts rather than better resource allocation. This suggests that while the sector as a whole has advanced technologically, individual institutions have not optimized their input combinations. Indeed, our GAIN function analysis reveals that by 2017, universities could potentially improve their efficiency by 52% through better resource allocation alone, without requiring additional funding. The results are corroborated by the counterfactual analysis, according to which optimized resource allocation would have yielded substantially higher educational outputs within the same budget constraints across the entire sample period.

Our analysis was complemented via a cluster analysis, which identified significant heterogeneity across institutions. Some of the most efficient universities show balanced improvements across all efficiency dimensions examined, while others displayed strong technological progress but poor allocative efficiency. This heterogeneity suggests that a one-size-fits-all policy approach may be inappropriate in the context of Mexican state universities, and that targeted interventions focusing on resource allocation might be more effective.

In this regard, our findings also indicated that the Subject to Performance Budget (STP), an initiative based on output-oriented metrics and competitive funding allocation, introduced in the 1990s had mixed effects. While it contributed to overall efficiency improvements, it had not necessarily led to better resource allocation decisions within universities. This was evidenced by increasing bureaucratization trends, with staff-to-faculty ratios rising, despite evidence that investing in faculty tends to produce better outputs.

These results have important policy implications. While the Mexican higher education system has successfully improved its technological frontier, there remains substantial room for efficiency gains through better resource allocation. Our analysis suggests that policymakers could prioritize some policies related to: (i) developing guidelines for optimal input allocation, particularly regarding the balance between academic and administrative staff; (ii) considering introducing specific incentives for efficient resource allocation within the existing performance-based funding framework; and (iii) implementing differentiated policies that account for the heterogeneous nature of institutions and their specific inefficiency sources.

These findings are particularly relevant given the growing importance of higher education in developing economies and the constant pressure on public resources. Our results suggest that significant improvements in university performance could be achieved even within existing budget constraints, through better allocation decisions.

For future research, we suggest extending this analysis to include other types of public higher education institutions in Mexico, and to investigate the relationship between allocative efficiency and regional economic development. Additionally, studying how the COVID-19 pandemic has affected resource allocation patterns could provide valuable insights for future policy design. The methodological approach we developed, combining the Malmquist productivity index with the GAIN function, offers a robust framework that could be applied to similar budget-constrained public institutions beyond the Mexican higher education context.

## References

Agasisti, T., Barra, C., and Zotti, R. (2019). Research, knowledge transfer, and innovation: The effect of Italian universities' efficiency on local economic development 2006–2012. Journal of Regional Science, 59(5):819–849.

Agasisti, T. and Bonomi, F. (2014). Benchmarking universities' efficiency indicators in the presence of internal heterogeneity. Studies in Higher Education, 39(7):1237–1255.

Agasisti, T., Catalano, G., Landoni, P., and Verganti, R. (2012). Evaluating the performance of academic departments: An analysis of research-related output efficiency. Research Evaluation, 21(1):2–14.

Agasisti, T. and Johnes, G. (2010). Heterogeneity and the evaluation of efficiency: the case of Italian universities. Applied Economics, 42(11):1365–1375.

Agasisti, T. and Pérez-Esparrells, C. (2010). Comparing efficiency in a cross-country perspective: the case of Italian and Spanish state universities. Higher Education, 59(1):85–103.

Ahn, T., Charnes, A., and Cooper, W. W. (1988). Some statistical and DEA evaluations of relative efficiencies of public and private institutions of higher learning. Socio-economic Planning Sciences, 22(6):259–269.

Alene, A. D. (2010). Productivity growth and the effects of R&D in African agriculture. Agricultural Economics, 41:223–238.

Altamirano-Corro, A. and Peniche-Vera, R. (2014). Metodología AED-RNA para la estimación de la eficiencia institucional: El caso de las dependencias de educación superior (DES) de ingeniería de México. Revista Electrónica Nova Scientia, 6(12):356–378.

ANUIES (2003). Modelo de asignación adicional del subsidio federal ordinario para las instituciones públicas de educación superior. Documento para la XXII Sesión Ordinaria del Consejo de Universidades Públicas e Instituciones Afines, 28 y 29 de noviembre. México.

Avilés-Sacoto, S., Cook, W., and Güemes-Castorena, D. (2014). Competitiveness among Higher Education Institutions: A Two-Stage Cobb-Douglas Model for Efficiency Measurement of Shools of Business. The Business and Economics Research Journal, 7(1):91–115.

Avkiran, N. K. (2001). Investigating technical and scale efficiencies of Australian universities through data envelopment analysis. Socio-economic Planning Sciences, 35(1):57–80.

Beasley, J. E. (1990). Comparing university departments. Omega, 18(2):171–183.

Beasley, J. E. (1995). Determining teaching and research efficiencies. Journal of the Operational Research Society, 46(4):441–452.

Blázquez-Gómez, L. and Grifell-Tatjé, E. (2011). Evaluating the regulator: Winners and losers in the regulation of Spanish electricity distribution. Energy Economics, 33(5):807–815.

Bonaccorsi, A., Daraio, C., and Simar, L. (2006). Advanced indicators of productivity of universitiesAn application of robust nonparametric methods to Italian data. Scientometrics, 66(2):389–410.

Bougnol, M. L. and Dulá, J. H. (2006). Validating DEA as a ranking tool: An application of DEA to assess performance in higher education. Annals of Operations Research, 145(1):339–365.

Breu, T. M. and Raab, R. L. (1994). Efficiency and perceived quality of the nation's "top 25" National Universities and National Liberal Arts Colleges: An application of data envelopment analysis to higher education. Socio-Economic Planning Sciences, 28(1):33–45.

Caves, D., Christensen, L., and Diewert, W. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. Econometrica, 50(6):1393–1414.

Charnes, A., Cooper, W., and Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2:429–444.

Chen, P.-C., Yu, M.-M., Chang, C.-C., and Hsu, S.-H. (2008). Total factor productivity growth in China's agricultural sector. China Economic Review, 19(4):580–593.

Colbert, A., Levary, R. R., and Shaner, M. C. (2000). Determining the relative efficiency of MBA programs using DEA. European Journal of Operational Research, 125(3):656–669.

Crespo, J., Peiró-Palomino, J., and Tortosa-Ausina, E. (2022). Does university performance have an economic payoff for home regions? Evidence for the Spanish provinces. Industry and Innovation, 29(4):564–596.

Cuñado, J. and Pérez de Gracia, F. (2012). Does education affect happiness? Evidence for Spain. Social Indicators Research, 108(1):185–196.

de Wit, H., Jaramillo, I., Gacel-Ávila, J., and Knight, J. (2005). Higher Education in Latin America The International Dimension. Ther World Bank, Washington, D.C.

De Witte, K. (2015). Contemporary Economic Perspectives in Education. Leuven University Press, Leuven.

De Witte, K. and López-Torres, L. (2017). Efficiency in education: A review of literature and a way forward. Journal of the Operational Research Society, 68(4):339–363.

Diario Oficial de la Federación 28/12/2023 (2023). Programa nacional de educación superior 2023-2024.

Färe, R., Grosskopf, S., and Lovell, C. (1988). An indirect approach to the evaluation of producer performance. Journal of Public Economics, 37:71–89.

Färe, R., Grosskopf, S., and Lovell, C. A. K. (1994). Production Frontiers. Cambridge University Press, Cambridge.

Flegg, A., Allen, D., Field, K., and Thurlow, Y. (2004). Measuring the Efficiency of British Universities: A Multi-Period Data Envelopment Analysis. Education Economics, 12(3):231–249.

Fukuyama, H., Guerra, R., and Weber, W. L. (1999). Efficiency and Ownership: Evidence from Japanese Credit Cooperatives. Journal of Economics and Business, 51:473–487.

Fukuyama, H. and Weber, W. L. (2009). Estimating indirect allocative inefficiency and productivity change. Journal of the Operational Research Society, 60(11):1594–1608.

Galaz-Fontes, J., Gil-Antón, M., Padilla-González, L., Sevilla-García, J., Arcos-Vega, J., and Martínez-Stack, J. (2009). The academic profession in mexico: Changes, continuities and challenges derived from a comparison of two national surves 15 years apart. RIHE International Seminar Reports, 13.

Giménez, V. M. and Martínez, J. L. (2006). Cost efficiency in the university: A departmental evaluation model. Economics of Education Review, 25(5):543–553.

Glass, J. C., McKillop, D. G., and O'Rourke, G. (2002). Evaluating the productive performance of UK universities as cost-constrained revenue maximizers: An empirical analysis. Applied Economics, 34(9):1097–1108.

Glass, M. a. (1998). A Cost Indirect Evaluation of Productivity Change in UK Universities. Journal of Productivity Analysis, 19:153–175.

Grifell-Tatjé, E. and Lovell, C. K. (2015). Productivity Accounting. Cambridge University Press, Cambridge, MA.

Grosskopf, S., Hayes, K. J., Taylor, L. L., and Weber, W. L. (1997). Budgetconstrained frontier measures of fiscal equality and efficiency in schooling. The Review of Economics and Statistics, pages 116–24.

Grosskopf, S., Hayes, K. J., Taylor, L. L., and Weber, W. L. (1999). Anticipating the consequences of school reform: A new use of DEA. Management Science, 45(4):608–620.

Guemes-Castorena, D. (2001). An Efficiency-Based Decision Making Model for Higher Education Funding in Mexico. Bell & Howell, Ann Arbor.

Haksever, C. and Muragishi, Y. (1998). Measuring value in MBA programmes. Education Economics, 6:11–26.

Haveman, R. and Smeeding, T. (2006). The role of higher education in social mobility. The Future of Children, pages 125–150.

Heaton, S., Teece, D., and Agronin, E. (2023). Dynamic capabilities and governance: An empirical investigation of financial performance of the higher education sector. Strategic Management Journal, 44(2):520–548.

Herberholz, L. and Wigger, B. U. (2021). Efficiency of European universities: A comparison of peers. Research Policy, 50(9):104314.

Izadi, H., Johnes, G., Oskrochi, R., and Crouchley, R. (2002). Stochastic frontier estimation of a CES cost function: The case of higher education in Britain. Economics of Education Review, 21(1):63–71.

Johnes, G., Johnes, J., and Thanassoulis, E. (2008). An analysis of costs in institutions of higher education in England. Studies in Higher Education, 33(5):527–549.

Johnes, G. and Schwarzenberger, A. (2011). Differences in cost structure and the evaluation of efficiency: the case of German universities. Education Economics, 19(5):487–499.

Johnes, J. (2006a). Data envelopment analysis and its application to the measurement of efficiency in higher education. Economics of Education Review, 25(3):273–288.

Johnes, J. (2006b). Measuring teaching efficiency in higher education: An application of data envelopment analysis to economics graduates from UK Universities 1993. European Journal of Operational Research, 174(1):443–456.

Johnes, J. and Li, Y. U. (2008). Measuring the research performance of Chinese higher education institutions using data envelopment analysis. China Economic Review, 19(4):679–696.

Joumady, O. and Ris, C. (2005). Performance in European higher education: A nonparametric production frontier approach. Education Economics, 13(2):189–205.

Kempkes, G. and Pohl, C. (2010). The efficiency of German universities—Some evidence from nonparametric and parametric methods. Applied Economics, 42(16):2063–2079.

Kent, R. (2005). La dialéctica de la esperanza y la desilusión en políticas de educación superior en México. Revista de la Educación Superior, 34(134):63–79.

Kent-Serna, R. (2009). Las Políticas de Educación Superior en México durante la modernización un análisis regional. ANUIES.

Korhonen, P., Tainio, R., and Wallenius, J. (2001). Value efficiency analysis of academic research. European Journal of Operational Research, 130(1):121–132.

Kuo, J. S. and Ho, Y. C. (2008). The cost efficiency impact of the university operation fund on public universities in Taiwan. Economics of Education Review, 27(5):603–612.

López-Segrera, F. (2012). The Political Economy of Higher Education. Emerald Insight, Bingley.

Martínez-Prats, G., Silva-Hernández, F., Mijael-Altamirano, S., and Ramos-Rentería, R. (2022). Pertinence of educational quality in PNPC Posgraduate Programs. Revista Interamericana de Investigación, Educación y Pedagogía-RIIEP, 15:339–361.

McMillan, M. L. and Chan, W. H. (2006). University efficiency: A comparison and consolidation of results from stochastic and nonstochastic methods. Education Economics, 14(1):1–30.

Mungaray, A., Ocegueda, J., and Ocegueda, M. (2006). Closing the gap between public state universities in Mexico. An assessment of public financing in 1988-2003. Gestión y Política Pública, 15(1):145–168.

Nin, A., Arndt, C., and Preckel, P. V. (2003). Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach. Journal of Development Economics, 71(2):395–415.

Organisation for Economic Co-operation and Development (2019). The Future of Mexican Higher Education: Promoting Quality and Equity. OECD Publishing, Paris.

Rubio Oca, J., Silva Espinosa, M. d. C., and Torres Mejía, D. (2005). Acciones de transformación de las universidades públicas mexicanas 1994-2003. Anuies - Asociación Nacional de Universidades e Instituciones de Educación Superior, México D.F.

Sagarra, M., Mar-Molinero, C., and Agasisti, T. (2017). Exploring the efficiency of Mexican universities: Integrating Data Envelopment Analysis and Multidimensional Scaling. Omega, 67:123–133.

Sagarra, M., Mar-Molinero, C., and Rodríguez-Regordosa, H. (2015). Evaluating the success of educational policy in Mexican Higher Education. Higher Education, 69(3):449–469.

Sala-i Martin, X. and Barro, R. (1995). Technological diffusion, convergence, and growth. Center Discussion Paper 735, Economic Growth Center (EGC), Yale University, New Haven.

Salmi, J. (2009). The Challenge of Establishing World-class Universities. World Bank Publications, Washington, D.C.

Secretaría de Educación Pública (2018). Principales cifras del sistema educativo nacional 2017-2018. Reporte estadístico, Secretaría de Educación Pública, Ciudad de México.

Sexton, T. R., Comunale, C. L., and Gara, S. C. (2012). Efficiency-based funding for public four-year colleges and universities. Education Finance and Policy, 7(3):331–359.

Thanassoulis, E., Kortelainen, M., Johnes, G., and Johnes, J. (2011). Costs and efficiency of higher education institutions in England: a DEA analysis. Journal of the Operational Research Society, 62:1283–1297.

Thanassoulis, E. and Silva Portela, M. D. C. A. (2002). School outcomes: Sharing the responsibility between pupil and school. Education Economics, 10(2):183–207.

Thursby, J. G. (2000). What do we say about ourselves and what does it mean? Yet another look at economics department research. Journal of Economic Literature, 38(2):383–404.

Tulkens, H. and Vanden Eeckaut, P. (1995). Non-parametric efficienct, progress and regress measures for panel data: Methodological aspects. European Journal of Operational Research, 80:474–499.

Wigger, B. U. and von Weizsäcker, R. K. (2001). Risk, resources, and education: Public versus private financing of higher education. IMF Staff Papers, 48(3):547–560.

Wolszczak-Derlacz, J. and Parteka, A. (2011). Efficiency of European public higher education institutions: A two-stage multicountry approach. Scientometrics, 89(3):887–917.

Worthington, A. C. and Lee, B. L. (2008). Efficiency, technology and productivity change in Australian universities, 19982003. Economics of Education Review, 27(3):285–298.

Xiong, X., Yang, G.-l., Zhou, D.-q., and Wang, Z.-l. (2022). How to allocate multi-period research resources? Centralized resource allocation for public universities in China using a parallel DEA-based approach. Socio-Economic Planning Sciences, 82:101317.

Yakovlev, P. and Leguizamon, S. (2012). Ignorance is not bliss: On the role of education in subjective well-being. The Journal of Socio-Economics, 41(6):806–815.

**Table 1:** Mexican State Universities

| DMU | University |
|---|---|
| BUAP | Benemérita Universidad Autónoma de Puebla |
| ITSON | Instituto Tecnológico de Sonora |
| UAAGS | Universidad Autónoma de Aguascalientes |
| UABC | Universidad Autónoma de Baja California |
| UABCS | Universidad Autónoma de Baja California Sur |
| UABJOAX | Universidad Autónoma Benito Juárez de Oaxaca |
| UACAMP | Universidad Autónoma de Campeche |
| UACHIH | Universidad Autónoma de Chihuahua |
| UACHIS | Universidad Autónoma de Chiapas |
| UACJ | Universidad Autónoma de Ciudad Juárez |
| UACOAH | Universidad Autónoma de Coahuila |
| UADY | Universidad Autónoma de Yucatán |
| UAEHGO | Universidad Autónoma del Estado de Hidalgo |
| UAEMEX | Universidad Autónoma del Estado de México |
| UAEMOR | Universidad Autónoma del Estado de Morelos |
| UAGRO | Universidad Autónoma de Guerrero |
| UANAY | Universidad Autónoma de Nayarit |
| UANL | Universidad Autónoma de Nuevo León |
| UAQRO | Universidad Autónoma de Querétaro |
| UASIN | Universidad Autónoma de Sinaloa |
| UASLP | Universidad Autónoma de San Luis Potosí |
| UATAMPS | Universidad Autónoma de Tamaulipas |
| UATLAX | Universidad Autónoma de Tlaxcala |
| UAZAC | Universidad Autónoma de Zacatecas |
| UCOL | Universidad de Colima |
| UGTO | Universidad de Guanajuato |
| UGUAD | Universidad de Guadalajara |
| UAJATAB | Universidad Juárez Autónoma de Tabasco |
| UJEDO | Universidad Juárez del Estado de Durango |
| UMSNH | Universidad Michoacana de San Nicolás de Hidalgo |
| UNACAR | Universidad Autónoma del Carmen |
| UNISON | Universidad de Sonora |
| UQROO | Universidad Autónoma de Quintana Roo |
| UVER | Universidad Veracruzana |

**Table 2:** Summary statistics, selected years

| Year | Statistic | Inputs | | | | Input prices | | | Outputs | | | Total budget |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *FTEFaculty* ($x_1$) | *Staff* ($x_2$) | *Gexpenses* ($x_3$) | *STPBudget* ($x_4$) | *W1FTEFaculty* ($\omega_1$) | *W2Staff* ($\omega_2$) | *W3GExp* ($\omega_3$) | *WEnrollment* ($y_1$) | *WGraduates* ($y_2$) | *WSNI* ($y_3$) | |
| 1989 | Mean | 1,167 | 1,101 | 94,546 | — | 238 | 144 | | 16,326 | 610 | 54 | 502,275 |
| | St. Dev. | 1,090 | 1,164 | 93,766 | — | 77 | 88 | — | 18,419 | 672 | 70 | 463,584 |
| | Max. | 5,574 | 5,059 | 412,292 | — | 447 | 423 | 1 | 96,368 | 3,430 | 266 | 2,086,627 |
| | Min. | 156 | 110 | 8,483 | — | 94 | 38 | 1 | 1,158 | 13 | — | 44,908 |
| 1996 | Average | 1,429 | 1,210 | 163,182 | 69,994 | 231 | 145 | 1 | 20,490 | 1,499 | 145 | 712,879 |
| | St. Deviation | 1,279 | 1,262 | 210,549 | 49,725 | 39 | 58 | — | 18,256 | 1,697 | 205 | 636,580 |
| | Max | 6,189 | 5,310 | 1,045,721 | 297,656 | 296 | 345 | 1 | 80,147 | 8,920 | 872 | 2,771,806 |
| | Min | 125 | 67 | 20,448 | 21,756 | 108 | 46 | 1 | 951 | 1 | — | 116,822 |
| 2003 | Mean | 1,603 | 1,787 | 459,498 | 94,107 | 232 | 104 | 1 | 26,137 | 2,115 | 326 | 1,073,292 |
| | St. Dev. | 1,352 | 2,016 | 548,864 | 67,473 | 51 | 32 | — | 22,443 | 2,055 | 370 | 944,328 |
| | Max. | 6,504 | 10,105 | 2,794,255 | 315,763 | 319 | 214 | 1 | 112,537 | 9,641 | 1,444 | 4,634,072 |
| | Min. | 252 | 99 | 70,110 | 8,605 | 138 | 55 | 1 | 2,656 | 139 | 9 | 186,623 |
| 2010 | Mean | 1,728 | 2,356 | 476,062 | 206,353 | 267 | 108 | 1 | 31,676 | 3,282 | 828 | 1,385,909 |
| | St. Dev. | 1,338 | 2,378 | 626,196 | 189,109 | 61 | 31 | - | 27,155 | 2,757 | 834 | 1,213,170 |
| | Max. | 6,913 | 12,393 | 3,038,583 | 998,267 | 384 | 219 | 1 | 135,619 | 14,126 | 3,698 | 5,930,243 |
| | Min. | 314 | 220 | 17,272 | 10,356 | 141 | 56 | 1 | 3,817 | 220 | 87 | 227,547 |
| 2017 | Mean | 2,071 | 2,749 | 458,624 | 100,888 | 289 | 113 | 1 | 40,647 | 4,251 | 1,562 | 1,809,384 |
| | St. Dev. | 1,698 | 2,800 | 427,213 | 92,871 | 73 | 32 | — | 36,943 | 3,520 | 1,390 | 1,546,767 |
| | Max. | 8,724 | 14,085 | 2,134,329 | 474,567 | 425 | 221 | 1 | 174,947 | 15,282 | 6,239 | 7,848,163 |
| | Min. | 395 | 258 | 48,223 | 11,477 | 177 | 53 | 1 | 5,671 | 523 | 182 | 293,896 |

*FTEFaculty*: Full-time Equivalent Faculty (number of full-time faculty plus half the number of part-time faculty, plus the number of lecturing hours per week taught by hourly professors divided by 40) ; *Staff*: Non-Academic Staff (number of non-academic staff members working at the university); *Gexpenses*: General Expenses (sum of all current expenses not including salaries); *STPBudget*: Subject to Performance Budget (sum of Federal and State Extraordinary budgets assigned to the universities according to their performance); *W1FTEFaculty*: Average full-time equivalent wage per HEI ; *W2Staff*: Average wage of non-academic staff members divided per HEI; *W3GExp*: Price of General Expenses (equal to 1 since General Expenses is already expressed in monetary units); *WEnrollment*: Weighted Enrollment (weighted average of incoming students, where undergraduate students are multiplied by a factor of 1 and graduate students by 1.5); *WGraduates*: Weighted Graduates (number of students graduating yearly, where undergraduate degrees are multiplied by a factor of 1 and graduate degrees by 1.5); *WSNI*: Weighted SNI (weighted average of all SNI research professors working at the university, weighted according to the financial incentive received by each of the SNI levels); Total Budget: All financial data expressed in thousands of pesos and adjusted to 2008 constant prices.
Source: Own elaboration.

**Table 3:** Summary of results, number of efficient and efficient HEIs

| Summary | 1989 | 1996 | 2003 | 2010 | 2017 |
|---|---|---|---|---|---|
| | Number of efficient and inefficient universities | | | | |
| | $Direct(t,t,C,S)$ | | | | |
| Efficient | 11 | 8 | 6 | 6 | 10 |
| Inefficient | 22 | 26 | 28 | 28 | 24 |
| | $Direct(t,t,V,S)$ | | | | |
| Efficient | 17 | 13 | 11 | 11 | 15 |
| Inefficient | 16 | 21 | 23 | 23 | 19 |
| | $Indirect(t,t,C,S)$ | | | | |
| Efficient | 3 | 0 | 0 | 0 | 0 |
| Inefficient | 30 | 34 | 34 | 34 | 34 |
| Total DMUs | 33 | 34 | 34 | 34 | 34 |

Notes: $Direct(t,t,C,S)$: Direct frontier with constant returns to scale and strong disposability; $Direct(t,t,V,S)$: Direct frontier with variable returns to scale and strong disposability; $Indirect(t,t,C,S)$: Indirect (budget-constrained) frontier with constant returns to scale and strong disposability. Universities with an efficiency score of 1 are considered efficient.

**Table 4:** Summary of results, HEIs' efficiencies

| Summary | 1989 | 1996 | 2003 | 2010 | 2017 |
|---|---|---|---|---|---|
| | | | $Direct(t,t,C,S)$ | | |
| Average | 0.7568 | 0.7410 | 0.7066 | 0.7690 | 0.8138 |
| Std. Dev. | 0.2337 | 0.2127 | 0.1797 | 0.1615 | 0.1648 |
| | | | $Direct(t,t,V,S)$ | | |
| Average | 0.8418 | 0.8222 | 0.8398 | 0.8381 | 0.8546 |
| Std. Dev. | 0.2272 | 0.1983 | 0.1703 | 0.1660 | 0.1702 |
| | | | $Indirect(t,t,C,S)$ | | |
| Average | 0.6719 | 0.5556 | 0.5266 | 0.5353 | 0.5867 |
| Std. Dev. | 0.2398 | 0.1949 | 0.1724 | 0.1529 | 0.1726 |

Notes: $Direct(t,t,C,S)$: Direct frontier with constant returns to scale; $Direct(t,t,V,S)$: Direct frontier with variable returns to scale; $Indirect(t,t,C,S)$: Indirect (budget-constrained) frontier with constant returns to scale. Efficiency scores range from 0 to 1, where 1 indicates efficient university.

**Table 5:** Ranking by geometric average efficiency type and GAIN, 1989–2017

| | | Tech. Eff. | University | Scale Eff. | University | Alloc. Eff. | University | Frontier | University | G. Malmq. | University | GAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UAEHGO | 1.0461 | UNACAR | 1.0150 | UAEHGO | 1.0069 | UAEMOR | 1.0744 | UAEHGO | 1.0922 | UAAGS | 1.0977 |
| 2 | UACJ | 1.0313 | UATAMPS | 1.0110 | UAQRO | 1.0053 | UACAMP | 1.0704 | UACHIS | 1.0750 | UADY | 1.1259 |
| 3 | UACHIS | 1.0306 | UAGRO | 1.0105 | UNACAR | 1.0035 | UABCS | 1.0652 | UAEMOR | 1.0580 | UGTO | 1.1655 |
| 4 | UAZAC | 1.0172 | UACAMP | 1.0099 | UAAGS | 1.0024 | BUAP | 1.0628 | UACJ | 1.0579 | UAQRO | 1.2097 |
| 5 | UANAY | 1.0105 | UANL | 1.0086 | UADY | 1.0017 | UNACAR | 1.0497 | UAQRO | 1.0565 | UATLAX | 1.2576 |
| 6 | UJEDGO | 1.0096 | UACOAH | 1.0081 | UVER | 0.9995 | UGTO | 1.0494 | UADY | 1.0519 | UABCS | 1.2765 |
| 7 | UATAMPS | 1.0091 | UAEMEX | 1.0064 | UACHIS | 0.9973 | UANAY | 1.0474 | UNACAR | 1.0511 | UCOL | 1.2783 |
| 8 | UADY | 1.0083 | UABC | 1.0038 | UJEDGO | 0.9973 | UMSNH | 1.0450 | UANAY | 1.0469 | UASLP | 1.3146 |
| 9 | UAQRO | 1.0073 | UACHIS | 1.0037 | UGTO | 0.9965 | UCOL | 1.0441 | BUAP | 1.0465 | UACAMP | 1.3269 |
| 10 | UANL | 1.0059 | UACHIH | 1.0031 | UCOL | 0.9959 | UAQRO | 1.0427 | UAZAC | 1.0464 | UAEMOR | 1.3481 |
| 11 | UABC | 1.0056 | ITSON | 1.0029 | UATLAX | 0.9958 | UASLP | 1.0424 | UGTO | 1.0457 | UACJ | 1.3565 |
| 12 | BUAP | 1.0000 | UADY | 1.0026 | UACJ | 0.9948 | UACHIS | 1.0421 | UACAMP | 1.0443 | UMSNH | 1.3711 |
| 13 | UAEMEX | 1.0000 | UASLP | 1.0019 | UASIN | 0.9941 | UQROO | 1.0414 | UABCS | 1.0405 | UJEDGO | 1.3807 |
| 14 | UASIN | 1.0000 | UGUAD | 1.0015 | UABCS | 0.9932 | UAEMEX | 1.0413 | UAEMEX | 1.0361 | UNACAR | 1.3927 |
| 15 | UATLAX | 1.0000 | UACJ | 1.0014 | UANL | 0.9930 | UJATAB | 1.0412 | UABC | 1.0358 | UAEHGO | 1.4105 |
| 16 | UGTO | 1.0000 | UAEHGO | 1.0011 | ITSON | 0.9929 | UGUAD | 1.0401 | UASLP | 1.0337 | UABC | 1.4194 |
| 17 | UGUAD | 1.0000 | UAQRO | 1.0005 | UASLP | 0.9924 | UAAGS | 1.0395 | UAAGS | 1.0325 | UANAY | 1.4549 |
| 18 | UNISON | 1.0000 | UAZAC | 1.0003 | UACAMP | 0.9922 | UADY | 1.0387 | UJEDGO | 1.0317 | UACHIS | 1.4846 |
| 19 | UQROO | 1.0000 | BUAP | 1.0000 | UMSNH | 0.9919 | UAZAC | 1.0375 | UATLAX | 1.0314 | UVER | 1.5060 |
| 20 | UVER | 1.0000 | UATLAX | 1.0000 | UAZAC | 0.9911 | UACHIH | 1.0371 | UMSNH | 1.0299 | UNISON | 1.5200 |
| 21 | UAEMOR | 1.0000 | UGTO | 1.0000 | UATAMPS | 0.9902 | UABC | 1.0368 | UANL | 1.0296 | UANL | 1.5636 |
| 22 | UMSNH | 0.9999 | UQROO | 1.0000 | UABC | 0.9897 | UATLAX | 1.0358 | UQROO | 1.0275 | UASIN | 1.5763 |
| 23 | UAGRO | 0.9988 | UCOL | 0.9999 | UANAY | 0.9893 | UAEHGO | 1.0357 | UATAMPS | 1.0265 | UAZAC | 1.5809 |
| 24 | UASLP | 0.9974 | UNISON | 0.9999 | UAEMEX | 0.9887 | UASIN | 1.0318 | UCOL | 1.0260 | UATAMPS | 1.5812 |
| 25 | UACHIH | 0.9944 | UANAY | 0.9998 | UNISON | 0.9879 | UACJ | 1.0297 | UASIN | 1.0254 | UGUAD | 1.5894 |
| 26 | ITSON | 0.9937 | UJATAB | 0.9998 | UABJOAX | 0.9877 | UAGRO | 1.0292 | UGUAD | 1.0233 | BUAP | 1.5901 |
| 27 | UJATAB | 0.9933 | UASIN | 0.9997 | UAEMOR | 0.9868 | UNISON | 1.0281 | UACHIH | 1.0184 | UQROO | 1.6280 |
| 28 | UAAGS | 0.9916 | UABCS | 0.9997 | UQROO | 0.9867 | UJEDGO | 1.0251 | UVER | 1.0170 | UABJOAX | 1.6541 |
| 29 | UCOL | 0.9867 | UJEDGO | 0.9996 | UACOAH | 0.9851 | UANL | 1.0220 | UJATAB | 1.0166 | UAEMEX | 1.7066 |
| 30 | UABJOAX | 0.9850 | UAAGS | 0.9993 | BUAP | 0.9847 | UVER | 1.0212 | UNISON | 1.0156 | UACHIH | 1.7230 |
| 31 | UABCS | 0.9839 | UABJOAX | 0.9991 | UACHIH | 0.9844 | UABJOAX | 1.0209 | UAGRO | 1.0106 | ITSON | 1.9040 |
| 32 | UACOAH | 0.9834 | UAEMOR | 0.9979 | UJATAB | 0.9833 | UACOAH | 1.0198 | ITSON | 1.0035 | UJATAB | 2.1199 |
| 33 | UNACAR | 0.9831 | UVER | 0.9963 | UGUAD | 0.9824 | UATAMPS | 1.0161 | UACOAH | 0.9958 | UACOAH | 2.1528 |
| 34 | UACAMP | 0.9737 | UMSNH | 0.9936 | UAGRO | 0.9729 | ITSON | 1.0142 | UABJOAX | 0.9924 | UAGRO | 2.7904 |

Notes: This table ranks all 34 universities by their geometric average performance from 1989–2017 across six different efficiency measures. Universities are ranked from best (1) to worst (34) for each metric. Tech. Eff.: Direct technical efficiency change; Scale Eff.: Direct scale efficiency change; Alloc. Eff.: Input allocative efficiency change; Frontier: Indirect frontier shift; G. Malmq.: Geometric Malmquist index; GAIN: Allocative efficiency gap indicating potential improvement through better resource allocation. Values greater than 1 indicate improvement, less than 1 indicate deterioration. University acronyms match those in Table 1.

**Table 6:** Summary of efficiencies by cluster, 1989–2917

| University | Technical efficiency | Scale efficiency | Allocative efficiency | Frontier shift | Indirect Malmquist productivity index |
|---|---|---|---|---|---|
| | | | Cluster 1 | | |
| BUAP | 1.0000 | 1.0000 | 0.9847 | 1.0628 | 1.0465 |
| UABCS | 0.9839 | 0.9997 | 0.9932 | 1.0652 | 1.0405 |
| UACAMP | 0.9737 | 1.0099 | 0.9922 | 1.0704 | 1.0443 |
| UAEMOR | 1.0000 | 0.9979 | 0.9868 | 1.0744 | 1.0580 |
| UNACAR | 0.9831 | 1.0150 | 1.0035 | 1.0497 | 1.0511 |
| Average | 0.9881 | 1.0045 | 0.9921 | 1.0645 | 1.0481 |
| | | | Cluster 2 | | |
| UACHIS | 1.0306 | 1.0037 | 0.9973 | 1.0421 | 1.0750 |
| UACJ | 1.0313 | 1.0014 | 0.9948 | 1.0297 | 1.0579 |
| UAEHGO | 1.0461 | 1.0011 | 1.0069 | 1.0357 | 1.0922 |
| Average | 1.0360 | 1.0021 | 0.9997 | 1.0358 | 1.0750 |
| | | | Cluster 3 | | |
| UAAGS | 0.9916 | 0.9993 | 1.0024 | 1.0395 | 1.0325 |
| UABC | 1.0056 | 1.0038 | 0.9897 | 1.0368 | 1.0358 |
| UACHIH | 0.9944 | 1.0031 | 0.9844 | 1.0371 | 1.0184 |
| UADY | 1.0083 | 1.0026 | 1.0017 | 1.0387 | 1.0519 |
| UAEMEX | 1.0000 | 1.0064 | 0.9887 | 1.0413 | 1.0361 |
| UANAY | 1.0105 | 0.9998 | 0.9893 | 1.0474 | 1.0469 |
| UAQRO | 1.0073 | 1.0005 | 1.0053 | 1.0427 | 1.0565 |
| UASIN | 1.0000 | 0.9997 | 0.9941 | 1.0318 | 1.0254 |
| UASLP | 0.9974 | 1.0019 | 0.9924 | 1.0424 | 1.0337 |
| UATLAX | 1.0000 | 1.0000 | 0.9958 | 1.0358 | 1.0314 |
| UAZAC | 1.0172 | 1.0003 | 0.9911 | 1.0375 | 1.0464 |
| UCOL | 0.9867 | 0.9999 | 0.9959 | 1.0441 | 1.0260 |
| UGTO | 1.0000 | 1.0000 | 0.9965 | 1.0494 | 1.0457 |
| UGUAD | 1.0000 | 1.0015 | 0.9824 | 1.0401 | 1.0233 |
| UJATAB | 0.9933 | 0.9998 | 0.9833 | 1.0412 | 1.0166 |
| UMSNH | 0.9999 | 0.9936 | 0.9919 | 1.0450 | 1.0299 |
| UQROO | 1.0000 | 1.0000 | 0.9867 | 1.0414 | 1.0275 |
| Average | 1.0007 | 1.0007 | 0.9924 | 1.0407 | 1.0344 |
| | | | Cluster 4 | | |
| ITSON | 0.9937 | 1.0029 | 0.9929 | 1.0142 | 1.0035 |
| UABJOAX | 0.9850 | 0.9991 | 0.9877 | 1.0209 | 0.9924 |
| UACOAH | 0.9834 | 1.0081 | 0.9851 | 1.0198 | 0.9958 |
| UAGRO | 0.9988 | 1.0105 | 0.9729 | 1.0292 | 1.0106 |
| UANL | 1.0059 | 1.0086 | 0.9930 | 1.0220 | 1.0296 |
| UATAMPS | 1.0091 | 1.0110 | 0.9902 | 1.0161 | 1.0265 |
| UJEDGO | 1.0096 | 0.9996 | 0.9973 | 1.0251 | 1.0317 |
| UNISON | 1.0000 | 0.9999 | 0.9879 | 1.0281 | 1.0156 |
| UVER | 1.0000 | 0.9963 | 0.9995 | 1.0212 | 1.0170 |
| Average | 0.9984 | 1.0040 | 0.9896 | 1.0218 | 1.0136 |

Note: This table reports geometric mean efficiency change indices by university and cluster from 1989-2017. Technical efficiency: Direct technical efficiency change; scale efficiency: Direct scale efficiency change; allocative efficiency: Input allocative efficiency change; frontier shift: Indirect frontier shift; IM: indirect Malmquist productivity index. Clusters were determined using *k*-means algorithm based on efficiency performance patterns. Values greater than 1 indicate improvement, less than 1 indicate deterioration.

**Figure 1:** Average efficiency scores, all universities

This figure displays the evolution of efficiency scores for Mexican state universities from 1989 to 2017. Three different efficiency measures are shown: Direct VRS (solid line) represents efficiency under variable returns to scale, Direct CRS (middle dashed line) shows efficiency under constant returns to scale, and Indirect CRS (bottom dashed line) represents budget-constrained efficiency.

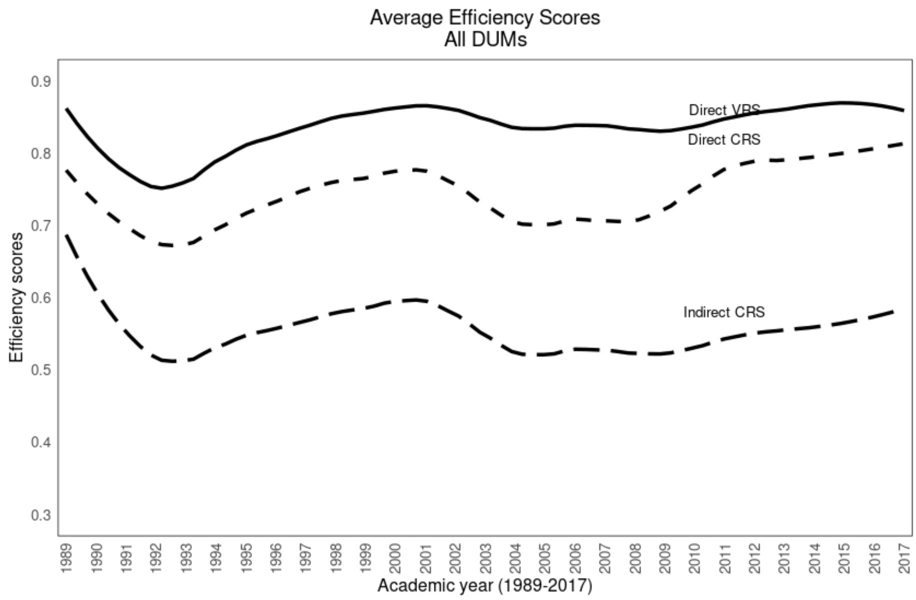


**Figure 2:** Mexican public universities, productivity components

This figure illustrates the decomposition of productivity change in Mexican state universities from 1989 to 2017, displaying the four components of the indirect geometric Malmquist index. The graph shows Technical Efficiency (dotted line), Scale Efficiency (short-dashed line), Allocative Efficiency (bottom solid line), and Frontier Shift (top dashed line), along with the overall Malmquist Index (middle dashed line).

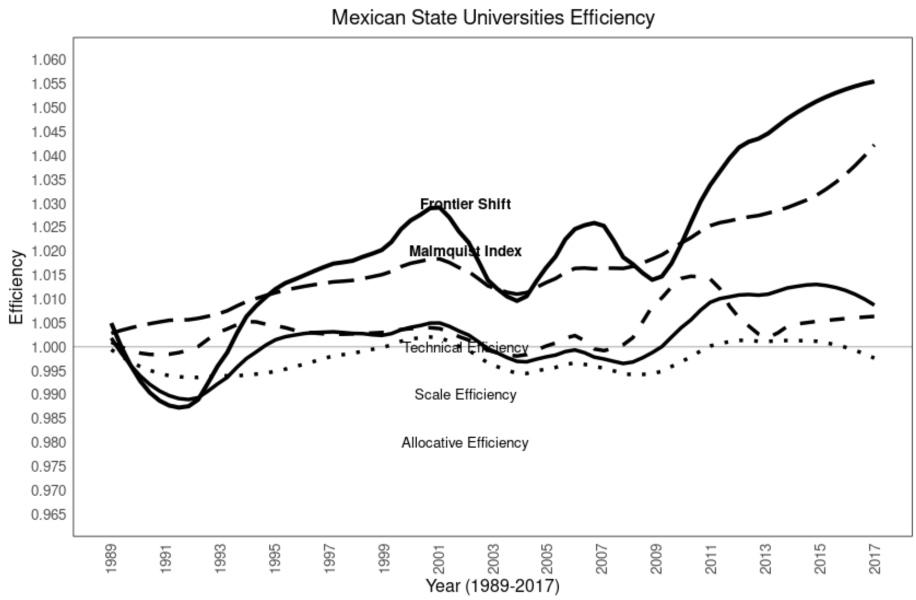
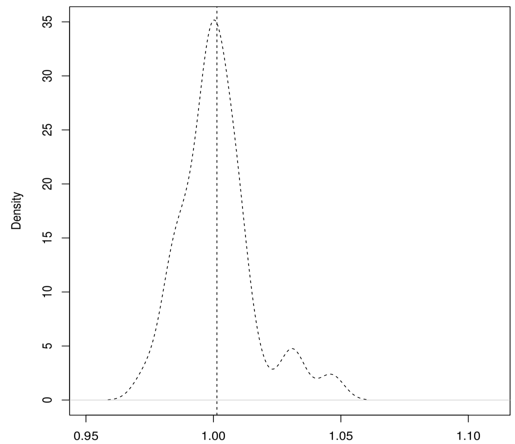


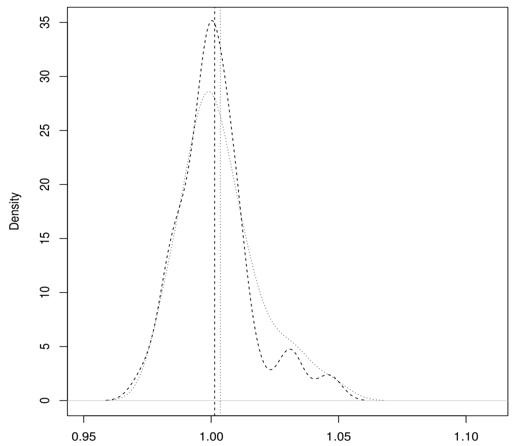
**Figure 3:** Relative contributions to the indirect Malmquist index ($IM_o$)

This figure presents kernel density estimations showing the distribution of each component contributing to productivity change across Mexican universities from 1989 to 2017. Panel (a) shows direct technical efficiency change (TE), panel (b) displays direct scale efficiency (SE), panel (c) shows input allocative efficiency (AE), and panel (d) presents indirect frontier shift (FS). Vertical lines represent component means. This sequential visualization illustrates how productivity improvements stem primarily from technological advancement rather than better resource allocation or operational practices (with substantial heterogeneity across institutions).

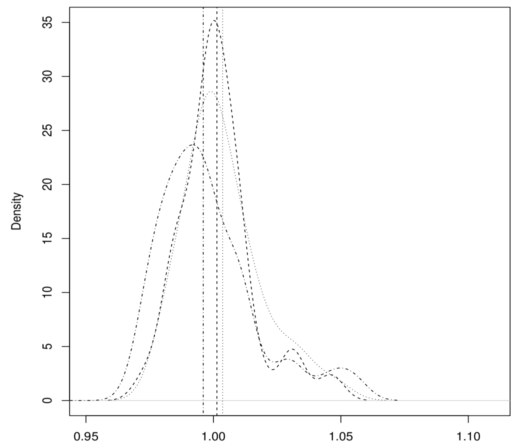
**(a)** Effect of direct technical efficiency change ($TE$)




**(b)** Effect of direct scale efficiency ($SE$)




**(c)** Effect of input allocative efficiency ($AE$)




**(d)** Effect of indirect frontier shift ($FS$)

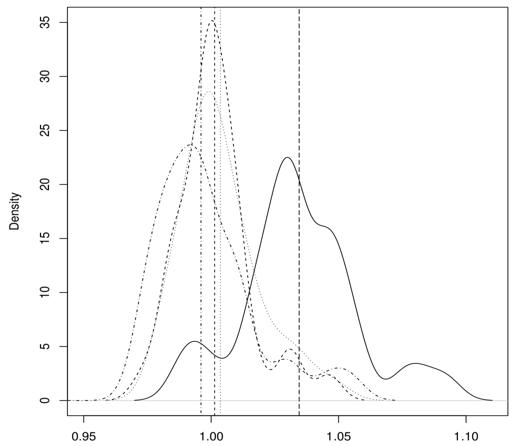


**Figure 4:** Elbow diagram

This figure presents the elbow diagram used for determining the optimal number of clusters for grouping Mexican state universities based on their efficiency patterns from 1989 to 2017. The $x$-axis shows the number of clusters ($k$) considered, while the $y$-axis displays the total within-cluster sum of squares, which measures within-cluster variance. The diagram exhibits a characteristic "elbow" shape, with diminishing returns in variance reduction as the number of clusters increases. The substantial decrease in total within-cluster sum of squares occurs until $k = 4$, after which the curve flattens, indicating that additional clusters provide minimal improvement in explaining the variance in the data.

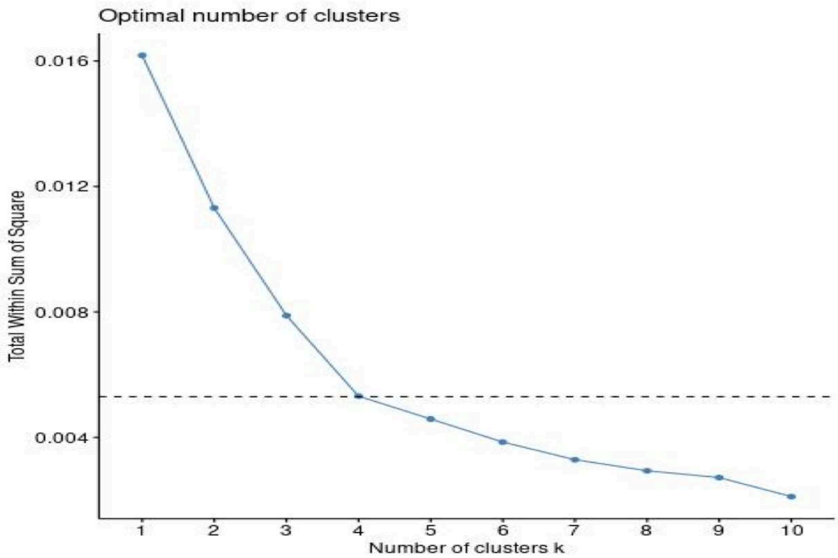


**Figure 5:** Mexican state universities by cluster

This figure presents the visual representation of the four clusters of Mexican state universities identified through *K*-means clustering based on their efficiency performance from 1989 to 2017. The two-dimensional plot displays universities positioned according to the first two principal components (*Dim*1 and *Dim*2) which capture 38.95% and 26.82% of the total variance, respectively. Cluster 1 (red, 5 universities) contains institutions characterized by technical and allocative efficiency losses but strong frontier shift improvements. Cluster 2 (green, 3 universities) represents high-performing institutions with substantial technical efficiency and frontier shift improvements. Cluster 3 (turquoise, 17 universities) comprises the largest group with modest efficiency improvements across most dimensions. Cluster 4 (purple, 9 universities) shows universities with below-average productivity gains and poorest allocative efficiency.

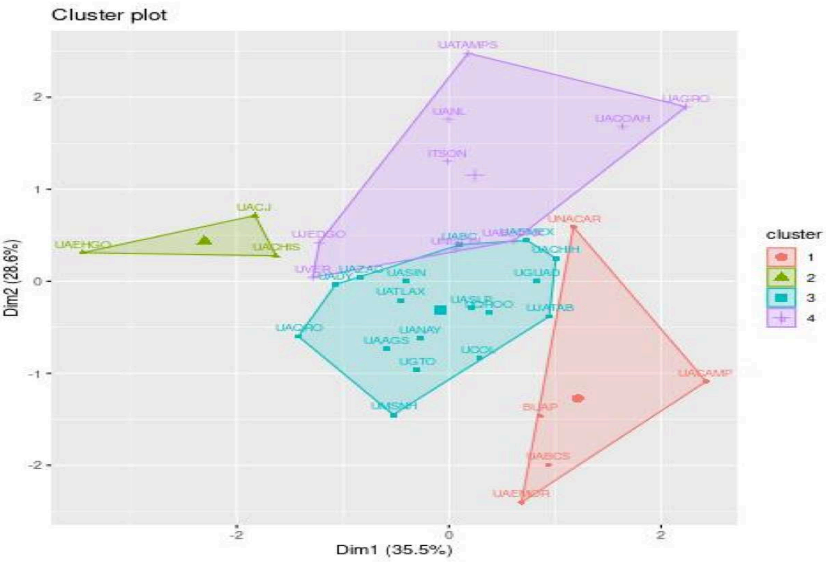


**Figure 6:** GAIN, Mexican public state universities

This figure displays the GAIN function values for Mexican state universities from 1989 to 2017. The GAIN function, defined as the ratio between direct distance scores and indirect distance scores, measures the additional efficiency that could be achieved through optimal resource allocation within existing budget constraints. The steadily increasing gap between Direct CRS (middle dashed line) and Indirect CRS (bottom dashed line) efficiencies illustrates the deteriorating allocative efficiency over time.

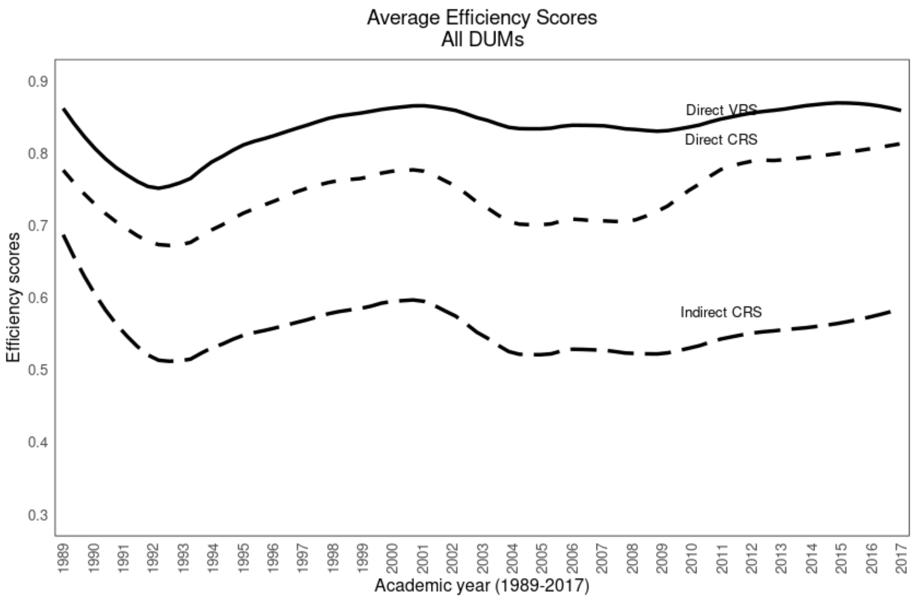


**Figure 7:** GAIN by cluster

This figure illustrates the evolution of the GAIN function values for each of the four clusters of Mexican state universities from 1989 to 2017. The GAIN Index, representing the potential efficiency improvement through better resource allocation, shows distinct patterns across clusters. Cluster 2 universities (solid line) demonstrate the best resource allocation practices with the lowest GAIN Index of 1.21 by 2017, indicating these institutions are operating closest to their optimal input combinations. In contrast, Cluster 4 universities (dotted line) exhibit the poorest allocation decisions with a substantial GAIN Index of 1.58, suggesting significant room for improvement without additional funding. Clusters 1 and 3 (short-dashed and long-dashed lines) fall between these extremes with values of 1.42 and 1.40 respectively.