Article

Productivity and technological change in the sugarcane agroindustry in Mexico

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Abstract

The sugarcane agroindustry in Mexico has an important share in employment and linkages in the economies of 267 municipalities in 15 states. The objective of this research was to analyze the total productivity of the factors, the technical efficiency and the technological change of the sugarcane mills of Mexico. The method used was the Malmquist index that measures changes in productivity over time and decomposes it into changes in efficiency and changes in technology under the assumptions of input orientation and constant returns to scale. The analysis used balanced panel data for the harvest period 2006/2007-2015/2016. The results show that at the level of decision-making units, the case of the El Dorado sugarcane mill in Sinaloa stands out, with an accumulative percentage change in its technical efficiency of 4.4%, in technical progress and innovation of 21.7% and a total factor productivity of 27%. The inverse situation occurs with the San Miguel del Naranjo sugarcane mill, whose accumulative percentage change in technical efficiency grew by -10.2%, technological progress and innovation by -0.3%, while total factor productivity was -10.4%. The general conclusion is that for 20 sugarcane mills that operated in the study period, productivity grew at negative rates, and for 30 it grew at positive rates.

Keywords: efficient frontier, Malmquist's index, technical efficiency, total factor productivity.

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Introduction

According to CONADESUCA (2017), in the 2016/2017 harvest, 777 078 ha were harvested, and 53 308 643 t of gross milled cane were obtained. There was a supply of 5 970 373 t of standard base sugar. The yield in the factory was 13.194% and in the field 68.6 t ha^{-1}. The approximate value of sugarcane, as well as that of sugar, reached US $2 271 million and US $3 781 million respectively in the 2016/2017 harvest, respectively. This economic benefit has a direct impact on 267 municipalities in 15 states of the country, where 15 million Mexicans live.

The 15 states where sugarcane is grown are: Campeche, Chiapas, Colima, Jalisco, Michoacán, Morelos, Nayarit, Oaxaca, Puebla, Quintana Roo, San Luis Potosí, Sinaloa, Tabasco, Tamaulipas and Veracruz, respectively. The country's sugarcane agroindustry has an installed capacity to industrialize more than 53 million tonnes, produce more than six million tonnes of sugar that guarantee the national supply and comply with international trade commitments. In macroeconomic terms, sugarcane contributed in 2016 with approximately 7% of the value of agricultural production. This context shows the importance of sugarcane agroindustry in the agricultural sector in particular and in the economy in general (SIAP-SAGARPA, 2018).

The cultivation of sugar cane has a standard, the Federal Law of Sustainable Development of Sugarcane (SAGARPA, 2005) and the National Sugarcane Program (PRONAC, SAGARPA-CONADESUCA, 2014) that regulate its operation and give guidelines for planning, modernization and improvement of competitiveness through research with a specific program for the agroindustry, operability, profitability and contribution to the promotion of manufacturing capacity for its milling; however, it presents challenges originated from the structural crises that agroindustry has suffered, both in Mexico and in the world, in several periods of the 20th century and the beginning of the 21st century, and that led to the expropriation of several sugarcane mills by the 2001/2006 administration.

The corollary of this situation are inefficient infrastructure and production technology, high production costs and little diversification in the use of byproducts obtained in sugarcane mills and distilleries, as well as the change in consumption patterns for health reasons and the appearance of substitutes for the products of the industry. In the field of engineering and operations research, the analysis of the productivity of a company or production unit is done in terms of the quotient of total output and the labor used in the production process or the total output per hour.

These quotients are simple measures of productivity and although they are the most common, it is possible to use other productivity measures depending on the field or productive sector. In the sugarcane agroindustry, tonnes of standard base sugar obtained per hectare are used as productivity measures. In the above context and under the persistent assertion that the sugarcane agroindustry suffers from a technological backwardness, it is of interest to quantitatively estimate the technical efficiency and technological change in each of the sugarcane mills currently operating over a period of at least 10 years.

In this way it will be possible to refute or properly argue the state of the situation of each of the sugarcane mills, as well as to evaluate the agroindustry globally in a short-term horizon. The objectives of this research were to evaluate the evolution of the productivity of the sugarcane agroindustry in Mexico in the harvest period 2006/2007-2015/2016 and to decompose the index of total factor productivity into the indices of change in technical efficiency and technological change using the Malmquist index. In the calculation of the Malmquist index, which represents total factor productivity, the analysis of enveloping data is used.

Models of analysis of enveloping data differ depending on the shape of the efficient frontier used. The two commonly used models are the called CCR model (Charnes *et al*., 1978) and the BCC model (Banker *et al*., 1984). These two variants of data envelopment analysis models differ because the former evaluates scale and inefficiencies simultaneously, while the latter exclusively evaluates technical inefficiency. In the present paper, the CCR approach was used, which assumes constant returns to scale of decision-making units (DMU), which is a conventional name in the analysis of enveloping data, commonly used in operations research.

In this research, the DMUs correspond to the sugarcane mills of Mexico. The CCR model assumes, as mentioned, constant returns to scale (CRS). Charnes *et al*. (1978) define efficiency as the maximum quotient of weighted output input and weighted inputs, subject to the fact that similar quotients for each decision-making unit are less than or equal to the unit. That is, the original approach of Charnes *et al*. (1978) for the model of the analysis of enveloping data was that of a fractional programming problem (Huguenin, 2012).

The technical efficiency of the decision-making unit k is maximized under two constraints. First, weights applied to the outputs and inputs of the company k cannot generate an efficiency score greater than 1 when applied to each company in the dataset. Mikulás *et al*. (2010) show how the fractional programming problem can be converted to one of linear programming, which is the usual way to solve the two models mentioned.

The calculation of the total factor productivity index was estimated with the Malmquist productivity index (MPI). This index measures productivity changes over time and can be decomposed into changes in efficiency and changes in technology with a nonparametric approach similar to the analysis of enveloping data. The decomposition of productivity into technical changes and from that, the recovery of efficiency requires the use of a contemporary version of the data and time variants of the technology in the period de study.

The geometric mean of the input-oriented Malmquist productivity index (MPI) is represented by the following expression: $MPI_I^G=\left(MPI_I^t MPI_I^{t+1}\right)^{1/2}=\left[\left(\frac{E_I^t(x^{t+1},y^{t+1})}{E_I^t(x^t,y^t)}\right)\left(\frac{E_I^{t+1}(x^{t+1},y^{t+1})}{E_I^{t+1}(x^t,y^t)}\right)\right]^{\frac{1}{2}}$. Where: I= denotes the orientation of the MPI model, in this case oriented to the input and *t*. This geometric mean of the input-oriented MPI model can be decomposed using the concept of input-oriented technical change (TECHCH) and input-oriented efficiency change (EFFCH) as shown in the following equation (Lee and Leem, 2010), $MPI_I^G=(EFFCH_I)(TECHCH_I^G)= =\left(\frac{E_I^{t+1}(x^{t+1},y^{t+1})}{E_I^t(x^t,y^t)}\right)\left[\left(\frac{E_I^t(x^t,y^t)}{E_I^{t+1}(x^t,y^t)}\right)\left(\frac{E_I^t(x^{t+1},y^{t+1})}{E_I^{t+1}(x^{t+1},y^{t+1})}\right)\right]^{\frac{1}{2}}$.

The first and second terms represent the change in efficiency and the change of technology respectively. The MPI given by the penultimate and last equations can be defined using the distance function of type DEA. That is, the components of MPI can be derived from the estimation of the distance functions defined in a frontier technology.

Färe *et al*. (1994) provided the formal derivation of MPI, and it is the most popular method among the various methods that have been developed to estimate a production technology (Thanassoulis, 2001; Coelli *et al*., 2005). By using the frontier generated with the DEA method either using constant return scales or variable return scales to estimate the distance functions in the last equation, the technical efficiency can be decomposed into components of scale efficiency and pure technical efficiency. According to Lee and Leem (2010), a change in scale efficiency (SECH) is obtained through the following expression: $\text{SECH}=\left[\frac{E_{vrs}^{t+1}(x^{t+1},y^{t+1})/E_{crs}^{t+1}(x^{t+1},y^{t+1})}{E_{vrs}^{t+1}(x^{t},y^{t})/E_{crs}^{t+1}(x^{t},y^{t})}\cdot\frac{E_{vrs}^{t}(x^{t+1},y^{t+1})/E_{crs}^{t}(x^{t+1},y^{t+1})}{E_{vrs}^{t}(x^{t},y^{t})/E_{crs}^{t}(x^{t},y^{t})}\right]^{\frac{1}{2}}$ and a change in pure efficiency (PECH) is obtained as: $\text{PECH}=\frac{E_{vrs}^{t+1}(x^{t+1},y^{t+1})}{E_{crs}^{t+1}(x^{t},y^{t})}$.

A balanced set of panel data was used in this research. A panel dataset consists of a time series for each cross-sectional member in the dataset. A panel data model is one that works with data in both dimensions and has a number of observations that are equivalent to the number of moments of time by the number of classes or cross-sectional identifiers. Also, the data panels are differentiated by the availability of information mainly in two types. Balanced panels are those in which all cross-sectional and time series observations are available.

The basic tools of the Malmquist productivity indices are the input and output distance functions, defined as the radial scaling of inputs and outputs, respectively. Malmquist (1953) defined the distance function as the radial contraction to an indifference curve, while Shepard (1970) defined the distance function in terms of a production function. The definition used in the research is the input distance function expounded with a high technical level in Färe and Grosskopt (2000).

In some investigations the parametric approach is used for this purpose, but whether one or the other approach is used, both (the parametric and the nonparametric) have their origin in few investigations that have developed the two methodologies, one of them by Färe *et al*. (1994), which compares productivity growth, technical progress and efficiency change of a sample of industrialized countries for the period 1979-1988. Farrell (1959) proposed a procedure for measuring technical efficiency in sugarcane mills.

Faret *et al*. (1994) enhance this proposal to separate the components of the changes in productivity and calculate the contribution of each of them: changes in technical efficiency and changes in technology over time. The measure of productivity growth is the geometric mean of two Malmquist productivity indices. That is, the distance functions of the Malmquist index components are calculated using nonparametric programming methods.

The Malmquist productivity index was introduced by Caves *et al*. (1982). Malmquist (1953) proposed to construct quantity indices as quotients of distance functions. Distance functions are representations of multiple input and output technology functions that require data only in input and output quantities. Consequently, the Malmquist index is a 'primordial' index of changes in productivity that, in contrast to the Törnqvist index, does not require costs or revenue sharing to add inputs and outputs, but is capable of measuring the total growth of factor productivity in a multiple production.

There are procedures that study the dynamics of the efficiency of companies at the firm level and the growth of total factor productivity (PTF) to evaluate their variations among decision-making units and over time for use in the appropriate development of policy responses to this sector in the economy (Raheman *et al*., 2009). In this case the nonparametric method of data envelopment analysis has been used to calculate the Malmquist TFP index with a panel dataset.

When there are several types of sugar farms in an economy and it is sought to calculate the total factor productivity for each of them, as well as to determine their levels of efficiency, the Malmquist index has also been used (Bushara and Moneim, 2016), since it allows the identification of which part of the change in the productivity of the firm or sector is due to the change in technical efficiency and which part due to the change in technology.

The Malmquist index uses the distance function, which has the advantage of allowing the description of a technology with multiple inputs and multiple outputs without the need to specify an objective function that reflects the behavior of the agents of production such as cost minimization or profit maximization. Technical progress in agriculture is invariably embodied in new inputs such as irrigation, high-yielding seed varieties, modern agricultural equipment and machinery, fertilizers, etc.

The use of modern inputs imposes the marginal productivity of land, labor and capital and induces the best use of these basic inputs, which is reflected in the greater cropping intensity, in technical progress, it would also capture the effect of proper timing, improvement of the quality of work, best management practices of the production unit, greater use of resources, such as terrestrial equipment, leading to a greater cropping intensity, changes in the pattern of cultivation in favor of high value-added crops.

The first represents new physical inputs, while the second represents scientific knowledge. Therefore, technical progress in agriculture captures the growth in production associated with both. In the sugar industry, it is important to know the intertemporal and interstate variations in the levels of technical efficiency and scale efficiency, for them it is possible to use the Tobit regression with panel data (Kumar and Arora, 2012).

Materials and methods

According to CONADESUCA (2017), the bulk of the sugarcane agroindustry is in Veracruz with 18 sugarcane mills (35.3%), Jalisco with 6 (11.8%) and San Luis Potosí with 4 sugarcane mills (7.8%). These three states have 54.9% of the sugarcane mills that operated in the study period. The main source of information to carry out the runs of the linear programming model for the calculations of the distance functions through the DEA was CONADESUCA (2017). The information used corresponds to a period of 10 years for the 50 decision-making units or sugarcane mills. So, there are 500 observations of balanced panel data.

That is, there are no lost values for any year for the 50 sugarcane mills. The variables used to process the linear programming model, calculate changes in efficiencies, technological change (regression), distance functions through the DEA and from these the index of total factor productivity via the Malmquist index are shown in Table 1. The third column defines whether this variable is an input or an output.

Table 1. Variables used in the research.

Variable	Units	Type
Sugar produced per hectare	Tonnes	Output
Filter cake	Tonnes	Output
Total energy consumed	Kw-h	Input
Haulage vehicles	Units	Input
Net milled cane	Tonnes	Input
Cutters	Day laborers	Input
Cutting fronts	Units	Input
Harvest time lost	Hours	Input

Adapted from CONADESUCA (2017).

The definition of the variables that were used to make the research operational is that described in CONADESUCA (2017). This definition has operational and practical purposes rather than theoretical purposes since each variable can be the subject of theoretical analysis in cane engineering as in Rein (2012). In the case of the total energy consumed, it is a variable not directly reported in the CONADESUCA statistics. Some sugarcane mills burn oil, bagasse and others buy electricity from the Federal Electricity Commission (CFE) to generate the power needed for cane milling. Using equivalence factors and conversion factors between energy units, oil, electricity purchased from the CFE and bagasse were converted to a common energy unit (kW-h).

Results and discussion

As mentioned, the results presented correspond to panel data for a period of 10 years. The model was processed using Coelli's (1996) DEAP 2.1 software. The model finally included two outputs and six inputs. The DEA model is input-oriented with constant returns to scale. The descriptive statistics of the variables used in the research are shown in Table 2, for the 10-year study period for the 50 sugarcane mills that were included in the study.

Table 2. Descriptive statistics of the variables used.

Variable	Average	Maximum value	Minimum value	Standard deviation
Sugar produced per hectare	8.26	16.54	1.86	2.71
Filter cake	134 153	480 421	11 027	87 408
Total energy consumed	573 740	1 884 582	87 691	295 193
Haulage vehicles	308	3071	13	265
Net milled cane	929 659	2 570 587	122 682	481 133
Cutters	1 348	4 368	24	820
Cutting fronts	26	173	2	23
Harvest time lost	742	2 081	66	349

The description of the units of the variables is as given in Table 1. Adapted from CONADESUCA (2017).

In this way, the measures of percentage change in the indices of efficiency, innovation and technological change and in the total factor productivity were obtained. The use of the total factor productivity index made it possible to identify two groups of sugarcane mills. The first group corresponds to those for whom the aforementioned index turns out to be positive and consists of 28 sugarcane mills. These are shown in Table 3 and are sorted from highest to lowest total factor productivity index. If the measure of percentage change in the case of technological change is negative, it will be a technological regression and the sugarcane mills in which there is such a regression are shown in Table 3.

Table 3. Measures of accumulative percentage change in the components of total factor productivity.

No.	Mill	Change in efficiency (%)	Change in innovation and technological change (%)	Change in total factor productivity (%)
1	El Dorado	4.4	21.7	27
2	El Carmen	8.3	2.8	11.3
3	Pujiltic (Cia. La Fé)	5.6	3	8.7
4	El Potrero	3.9	4.3	8.4
5	Central Motzorongo	4	3.2	7.3
6	El Modelo	0.6	5.4	6
7	Constancia	4.5	1.3	5.9
8	Tres Valles	5.2	0.5	5.8
9	El Refugio	5.3	0.3	5.7
10	El Molino	0.7	4.3	5
11	San José de Abajo	4.1	0.1	4.2
12	Central Progreso	3.4	0.6	4
13	San Cristóbal	3.3	0.4	3.7
14	Santa Clara	-1	4.6	3.5

No.	Mill	Change in efficiency (%)	Change in innovation and technological change (%)	Change in total factor productivity (%)
15	Huixtla	0	3.1	3.1
16	Plan de Ayala	5.7	-2.4	3.1
17	La Gloria	1.1	1.9	3
18	El Mante	2.7	0.2	2.9
19	Lázaro Cárdenas	0	2.4	2.4
20	Tamazula	0	2.4	2.4
21	Central Casasano	0	2.1	2.1
22	Pedernales	-1.4	3.4	2
23	Melchor Ocampo	0	1.5	1.5
24	Bellavista	-0.1	1.2	1.1
25	Alianza Popular	0.5	0.5	1
26	San Francisco Ameca	-1.7	2.6	0.9
27	Adolfo López Mateos	2.9	-2.2	0.7
28	Santa Rosalía	0.9	-0.2	0.7
29	José María Morelos	-2	2.5	0.5

In the first group, the two sugarcane mills with the highest percentage change in the total factor productivity index are El Dorado with 27% and El Carmen with 11.3%, El Dorado is in Sinaloa and El Carmen in Veracruz. The contribution to the high percentage of change in total factor productivity in El Dorado is on the side of technological progress and innovation (21.7%); that is, by leaps from the production frontier over time. In the case of the El Carmen sugar mill, the greatest contribution to total factor productivity was the improvement of efficiency over time (8.3%).

In contrast to the above, and as shown in Table 4, several sugarcane mills recorded in the study period not only an increase in their technical inefficiency, but also a technological regression. The most obvious cases are the sugarcane mills of San Miguel del Naranjo and Plan de San Luis. In the case of San Miguel del Naranjo, its inefficiency increased by 10.2% and a technological regression (more than progress) of 0.3%; therefore, the total factor productivity decreased by 10.4%; that is, in the study period, the production (sugar per hectare and filter cake) that could have been obtained with the inputs used in the production process was not obtained.

In the case of the Plan de San Luis sugarcane mill, its inefficiency over 10 years increased by 8% with a technological progress (regression) of 1.2%. From the analysis of the results of the Malmquist index of total factor productivity, it is observed that 24 sugarcane mills are above the efficient frontier, three are above it and 25 below the efficient frontier.

Table 4. Measures of accumulative percentage change in the components of total factor productivity.

No.	Sugarcane mill	Change in efficiency (%)	Change in innovation and technological change (%)	Change in total factor productivity (%)
1	Atencingo	-8.1	8.5	-0.3
2	San Rafael de Pucté	-0.6	0.1	-0.5
3	Cuatotolapam (CIASA)	-0.7	0.2	-0.6
4	Mahuixtlán	-1.3	0.6	-0.7
5	El Higo	-2.2	1.3	-0.8
6	San Miguelito	-1	-0.2	-1.2
7	Tala (José Ma. Martínez)	-2.4	1	-1.4
8	Azsuremex	0	-1.9	-1.9
9	La Margarita	-3.8	1.8	-2.1
10	Quesería	-4.1	2.1	-2.1
11	La Joya	-3	0.6	-2.4
12	San Pedro	-2.9	-0.2	-3.1
13	Aarón Sáenz Garza	-1.8	-1.4	-3.2
14	Puga	0	-3.6	-3.6
15	Pánuco	-4.8	-0.2	-5
16	Emiliano Zapata	-4.2	-2.4	-6.6
17	San Nicolás	-7.2	0.6	-6.7
18	Presidente Benito Juárez	-6.6	-1	-7.6
19	Central La Providencia	-7.9	-0.1	-7.9
20	Plan de San Luis	-8	-1.2	-9.1
21	San Miguel del Naranjo	-10.2	-0.3	-10.4

Performance of sugarcane agroindustry

Analogously to the case of the change in efficiency, technological progress and total factor productivity, it is possible to show how the sugarcane agroindustry performed in the different harvests during the study period. As in the case of sugarcane mill, the indicator is expressed as a measure of the accumulative percentage change as shown in Table 5. This table gives a complete picture of how total factor productivity, technical efficiency and technological change have performed over the study period. Some results contrast. Between the harvests 2010/2011-2011/2012, in the entire agroindustry there was an inefficiency of 15.4%. On the other hand, innovation and technological change grew 8.8%. So, the total factor productivity was -7.9% in the period between harvests.

Table 5. Total factor productivity between periods in the sugarcane agroindustry in Mexico.

Period between harvests	Change in efficiency (%)	Change in innovation and technological change (%)	Change in total factor productivity (%)
2006/2007-2007/2008	7.4	-3.6	3.5
2007/2008-2008/2009	-4.5	9.5	4.6
2008/2009-2009/2010	4.5	-7.1	-3
2009/2010-2010/2011	3.9	0.5	4.5
2010/2011-2011/2012	-15.4	8.8	-7.9
2011/2012-2012/2013	16.6	-10.1	4.8
2012/2013-2013/2014	-2.5	-2.1	-4.6
2013/2014-2014/2015	-3.2	5.7	2.3
2014/2015-2015/2016	-7.6	14	5.3

The change refers to the period between one harvest and the other, so, there are only nine periods and not 10 years. Source: own elaboration based on the runs of DEAP 2.1.

In order to compare and discuss the estimates obtained for the sugar agroindustry in Mexico, Table 6 presents the results of four countries that use panel data and a similar procedure to estimate the indices of total factor productivity and the two into which this indicator is decomposed (technical efficiency and technological progress).

Table 6. Changes in sugarcane productivity in several countries.

Region	Change in technical efficiency	Change in technical progress	Change in total factor productivity	Year of study	Orientation
China	1.002	0.88	0.894	2004-2013	Input
India	1.005	0.988	0.993	2004/2005- 2013/2014	Input
Mexico	0.995	1.014	1.01	2006/2007- 2015/2016	Input
Pakistan	0.992	1.008	0.999	1998-2007	Output
Sudan	1.002	1.125	1.127	1999-2007	Output

In the case of the evaluation of the change in productivity, technical efficiency and technological change in China (Yet *et al*., 2016), which uses panel data for a 10-year period of sugarcane agroindustry from the main four producing regions of that country, total factor productivity declined, as the average growth rate was -10.6% per year. This regression, according to Yet *et al*. (2016), was exclusively due to the technological regression of -12% per year, while technical efficiency grew on average by 0.2% per year.

For India, Singh (2016) calculated the indicators for the period 2004/2005 - 2013/2014 of 40 sugar companies. The findings of the above-mentioned research state that the growth rate of total factor productivity in the Indian sugar agroindustry was negative; that is, for the study period it was -0.7%. The decomposition of the index of total factor productivity shows that the negative growth rate of this indicator is due to technological regression, since its index for the Indian case had an average growth rate per negative year of 1.2%, while the rate of change in technical efficiency shows that it grew by 0.5%.

In the case of Pakistan, Raheman *et al*. (2009) calculated the three indicators that can be estimated with the Malmquist index for the sugarcane agroindustry in Pakistan for the period 1998-2007 of 20 sugarcane mills. For this country the total factor productivity index decreased by -0.1%, which is explained by the fact that technical efficiency decreased by -0.8% and the growth rate of technical progress was 0.8% per year.

In the case of Sudan, Bushara and Moneim (2016) calculated the three indicators derived from the Malmquist index, they were estimated for the sugarcane agroindustry for the period 1999-2007. The indices were calculated for four sugarcane mills. The growth rate of total factor productivity for this country was 12.7% per year, the growth rate of technical efficiency of 0.2% and the rate of technological change grew by 12.5% per year.

When comparing the average results obtained for Mexico, it is observed that for the three indices they are very similar with the other countries, except for China where the index of total factor productivity is very different, showing a technological delay. It should be noted that for China and India the indices are input-oriented, while for Pakistan and Sudan the indices were calculated with orientation to the output. Of the countries with which Mexico’s results are compared, with the exception of Sudan, the other three maintain a significant share in the world sugarcane production, remaining in the top eight in terms of production, area and yield.

Conclusions

It is concluded that according to the Malmquist index, the productivity of the factors of the sugarcane agroindustry in Mexico, on average in the period of analysis, has been above the efficient frontier of production. The index of total factor productivity on average for the 10-year period was 1.01. The analysis by periods of the indices of change in technical efficiency and technological change show that in eight of the nine periods these indices move in opposite directions; that is, in the same period there may be an improvement in efficiency (index greater than 1) but at the same time there may be a technological regression (index less than 1).

The exception is the fourth period corresponding to the period between harvests 2009/2010-2010/2011. El Dorado sugarcane mill stands out in the study period because its productive efficiency improved 4% and the technological change shows the incorporation of innovations since the analysis in terms of accumulative percentage change of the innovation and technological change index was 27% in the study period. Total factor productivity grew by 27%. The sugarcane mill with lowest performance was San Miguel del Naranjo, whose accumulative growth was negative for the three indices. Its efficiency was negative at 10.2%, it had a technological regression of 0.3% and its production was negative at 10.4%.

Plan de San Luis, Central la Providencia and Presidente Benito Juárez are also in this group of sugarcane mills. The results obtained for Mexico with four other countries show that the magnitudes of the indices for total factor productivity, technical efficiency and technological change are very similar, except for China in which case it is observed that the technological regression in the study period is 12% per year.

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