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Article

Identification of the sugar mills with the highest relative technical efficiency in Mexico

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Abstract

In 2021, Mexico ranked sixth worldwide in sugarcane production with 2.9% and internally, this grass is grown in 16 states. In the 2021-2022 harvest, the sugarcane agribusiness employed 182 512 producers and in 2022, it generated 5% of the value of agricultural production. The work aimed to estimate the relative efficiency under constant and variable returns to scale of the 47 sugar mills that operated during the 2021-2022 harvest in the 16 states where sugarcane is produced in order to identify the most efficient mills in the sugarcane agribusiness. The methodology used was the super-efficiency slack-based model of input-oriented data envelopment analysis. In the results, 29 mills were identified as the most efficient. The five best performing mills were Zapoapita, San Cristóbal, Tres Valles, Benito Juárez, and Calipam and the three with the lowest performance were San Miguelito (0.937), Bellavista (0.919) and Constancia (0.905). It was concluded that the method used made it possible to identify the most efficient decision-making units and to support the design of programs that promote the best productive practices and management of those units with lower performance.

Keywords:

agricultural policy, data envelopment analysis, linear programming, slacks, super-efficiency model.

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Introduction

In Mexico's primary sector, sugarcane cultivation is carried out in 16 states and 267 municipalities, occupying an area of 912 968 ha industrialized in 49 mills (CONADESUCA, 2022). In terms of employment, if we consider the sugarcane suppliers of the 49 sugar mills that operated in the 2021-2022 harvest, 188 512 direct jobs were created among the producers themselves, 25 thousand jobs among permanent, temporary, and casual employees in the sugar mills themselves in addition to 72.9 thousand cane cutters (CNIAA, 2022).

In this research, the approach used to determine the relative efficiency of decision-making units, in this case sugar mills, is a non-parametric approach and therefore does not require the specification of a functional form or assumptions about the normality of the variables to be used; it is possible to use the methodology of data envelopment analysis in its variant of the super-efficiency model in order to determine which are the most efficient sugar mills among the 47 selected for the study (Simar and Wilson, 2000; Hollingsworth and Smith, 2003; CONADESUCA, 2024).

The approach of data envelopment analysis (DEA) has been widely used to analyze technical efficiency, economies and returns to scale, productivity, and technological change over time in a wide variety of areas since its introduction by Charnes *et al*. (1978); however, its use in agriculture has been very scarce in the vast majority of countries, including Mexico.

In a study by Escobedo and Valdivia (2019), using the conventional DEA and a dataset of 50 observations for the 2015-2016 harvest, they identified that all the mills that are efficient, the respective indicator was equal to one; nevertheless, among the efficient mills, there will be some that are more efficient than others in practice. Santiago *et al*. (2021) also used the DEA to calculate the Malmquist productivity index and estimate the total factor productivity, technical efficiency, and technological change of the sugarcane mills in Mexico over time for the 2006-2007-2015-2016 harvest period. In their results, they found that the El Dorado sugar mill in Sinaloa during the entire study period registered an increase of 4.4% in its technical efficiency, of 21.7% in its technical progress and innovation, and of 27% in total factor productivity.

In this framework, the objective of this research is to estimate the relative efficiency indicators under constant and variable returns to scale of the sugar mills that operated during the 2021-2022 harvest through the super-efficiency model of the data envelopment analysis to effectively identify the most efficient mills in the sugarcane agribusiness in Mexico.

Materials and methods

The material used for the estimation of the data envelopment analysis model was secondary statistical information on sugarcane from the 2021-2022 harvest obtained from UNC-CNPR (2022). The software used to perform the analysis was Cran-R Benchmarking. The method used to estimate the relative efficiency of the mills is data envelopment analysis (DEA) (Rincón *et al*., 2016; Bogetoft and Otto, 2024).

Nonetheless, in the case of the two conventional models of the DEA, that is the DEA with constant returns to scale and the DEA with variable returns to scale, when estimating the relative efficiencies of the decision-making units (DMUs), they do not discriminate between all those units that are completely efficient, so the relative efficiency indicator in all cases will be equal to one (Tone, 2002).

In this way, the method used to identify the most efficient mills in the sugarcane agribusiness during the 2021-2922 harvest was the super-efficiency model, which is a variant of the two conventional models of data envelopment analysis, which estimates efficiency indicators greater than one for those decision-making units that, in conventional models, can only take a value equal to one if they are completely efficient; therefore, if there are a significant number of mills whose efficiency is 100%, it is not possible to identify among them which are effectively the most efficient, a situation that does not occur in the super-efficiency model, which does allow it to be done.

The theoretical model estimated using the available sugarcane database is the input-oriented non-radial super-efficiency slack-based (SSB-I) theoretical model of the DEA. The linear programming expressions of the super-efficiency model can be found in Tone (2002). The variables used in the research are shown in (Table 1).

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Table 1. Definition of the study variables.

Variable	Description	Units	Item
Sutops	Standard base sugar total production	(t)	Output
Cachaça	Cachaça obtained from milling	(t)	Output
Bagob	Bagasse obtained from milling	(t)	Output
Inare	Industrialized area	(ha)	Input
Vehtr	Vehicles for transporting cane from field to sugar mill	Units	Input
Ramica	Raw milled cane	(t)	Input
Labor	Labor	People	Input
Elecc	Electricity consumption	Megawatt	Input
Totfu	Total diesel in cane lifting and transport	(hL)	Input
Stegen	Steam generated	(t)	Input

Based on UNC-CNPR (2022); Debernardi *et al*. (2018).

With regard to the variables used, it is necessary to point out the following singularities. The total amount of diesel for transporting cane from the field to the mill was imputed based on Debernardi *et al*. (2018), who estimated this parameter to be 14 mills. For the remaining 33 mills, the arithmetic average of the aforementioned study was used, which had a value of 2.45 L t^{-1} of cane transported. In this way, the multiplication of this constant by the raw milled cane produced the estimate of the total diesel for the transport and lifting of sugarcane in the 2021-2022 harvest.

Results and discussion

Table 2 presents the descriptive statistics of the variables used in the empirically applied methodology. The definition of the variables corresponds to the one presented in Table 1.

Table 2. Descriptive statistics of the analysis variables.

Variable	Mean	Standard deviation	Minimum value	Maximum value
Sutops	125 456.9	69 645.2	12 232	289 823
Inare	16 184.3	9 847.2	1 519	47 300
Labor	5 119.1	2 836.2	732	16 291
Vehtr	336.1	315.9	48	1 947
Stegen	599 958.1	343 362.8	63 840	1 489 192
Elecc	25 972.7	32 889.4	1 745	222 473
Diese	26 819.8	14 373.9	3 168	67 363
Sutops	125 456.9	69 645.2	12 232	289 823
Cacha	42 479.1	24 382.6	5 466	122 760
Bagob	319 205.6	184 246.9	37 789	87 963

Based on UNC-CNPR (2022).

When applying the data envelopment analysis with constant returns to scale with input orientation, it is found that the relative efficiency of a significant proportion of such decision-making units is equal to the unit. This situation is observed in Table 3.

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Table 3. Relative efficiency results with conventional DEA models.

Conventional DEA model	Num. of mills with relative efficiency		Total mills
	Less than one	Equal to one	
With constant returns to scale	26	21	47
With variable returns to scale	18	29	47

Based on Cran R Benchmarking runs.

In the case of the DEA model with constant returns to scale, the average relative technical efficiency was 97.6% and the lowest was 90.1%, which corresponded to the Constancia mill. In the case of the model with variable returns to scale, the average relative technical efficiency was 98.6% and the lowest was 90.47%, which also corresponded to the Constancia mill. As has been pointed out, a disadvantage of the two conventional models of the DEA is that, if a significant proportion of the decision-making units show that their efficiency is 100%, this fact did not provide criteria on the design of differentiated support policies for those mills whose relative efficiency is low or to know which mills are the ones that carry out the best production practices, which can be the reference for the design of public policies to support the income of suppliers of sugarcane material or a support policy according to the size and scale of operation of the sugar mills.

However, as Tone (2002) points out, empirical research has shown that, in industries that produce a homogeneous good, in this case standard sugar, even when the decision-making units operate at the same scale, they will do so at different levels of relative technical efficiency. Within the framework of the methodology of data envelopment analysis itself, one of its variants that allows identifying which mills are in practice the most efficient is the super-efficiency slack-based model (SBM) (Petersen, 1993; Tone, 2002; Chen, 2004). This model made it possible to identify and classify the most productive sugar mills since the technical efficiency indicator of the most efficient mills will be greater than the unit.

Technical efficiency with constant returns to scale

The results of the super-efficiency model obtained with the runs of the Cran-R Benchmarking package are those presented in Table 4.

Table 4. Relative efficiency of sugar mills under constant returns to scale.

	Mill	Technical efficiency with CRS		Mill	Technical efficiency with CRS
1	Benito Juárez	6.116	1	Calipam	0.997
2	El Higo	1.667	2	San Cristóbal	0.988
3	Santa Clara	1.32	3	Cuatotolapan	0.987
4	El Mante	1.288	4	San José de Abajo	0.985
5	Melchor Ocampo	1.19	5	Adolfo López Mateos	0.984
6	El Refugio	1.176	6	San Miguel	0.983
7	Emiliano Zapata	1.16	7	Lázaro Cárdenas	0.983
8	Casasano	1.146	8	La Providencia	0.98
9	Quesería	1.143	9	Zapoapita	0.977
10	San Pedro	1.116	10	Progreso	0.976
11	El Carmen	1.094	11	Plan de San Luis	0.974
12	Atencingo	1.066	12	La Margarita	0.966

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	Mill	Technical efficiency with CRS		Mill	Technical efficiency with CRS
13	San Rafael	1.061	13	Alianza Popular	0.966
14	Eldorado	1.06	14	José María Morelos	0.965
15	Huixtla	1.06	15	Mahuixtlán	0.963
16	Tres Valles	1.057	16	Puga	0.962
17	Pujiltic	1.042	17	Pedernales	0.949
18	Tamazula	1.027	18	San Nicolás	0.939
19	La Gloria	1.016	19	El Potrero	0.939
20	El Modelo	1.012	20	Plan de Ayala	0.935
21	El Molino	1.01	21	Santa Rosalía	0.934
			22	Tala	0.92
			23	Motzorongo	0.916
			24	Bellavista	0.914
			25	San Miguelito	0.91
			26	Constancia	0.901

CRS= constant returns to scale. Based on Cran-R Benchmarking runs.

As can be seen in Table 4, the super-efficiency slack-based model of DEA does allow the identification of the mills that in practice are the best performing in the sugarcane agribusiness, unlike the results of the two conventional DEA models where, as can be seen in Table 3, only two groups of decision-making units are identified: the group of mills with efficiency equal to or less than one, both in the case of constant returns to scale and in the case of variable returns to scale.

In cases where the relative technical efficiency indicator is equal to the unit (21 and 29 mills, respectively) it is impossible to differentiate which are in practice the really efficient. This situation can be observed in Table 3, where it was found that, for the study harvest, the Benito Juárez, El Higo, Santa Clara, and El Mante mills were the most efficient and those with the poorest performance were Bellavista, San Miguelito and Constancia.

Technical efficiency with variable returns to scale

Analogous to the previous case, Table 5 shows the results of the super-efficiency model with variable returns to scale.

Table 5. elative efficiency of sugar mills under variable returns to scale.

	Mill	Technical efficiency with VRS		Mill	Technical efficiency with VRS
1	San Cristóbal	Infinite	1	San José de Abajo	0.997
2	Tres Valles	Infinite	2	Mahuixtlán	0.995
3	Zapoapita	Infinite	3	Cuatotolapan	0.991
4	Benito Juárez	8.566	4	San Miguel	0.988
5	Calipam	2.842	5	Progreso	0.986
6	Eldorado	2.402	6	Motzorongo	0.985
7	El Higo	2.221	7	La Providencia	0.981
8	San Pedro	1.572	8	José María Morelos	0.976
9	Pujiltic	1.348	9	La Margarita	0.974
10	Santa Clara	1.331	10	Tala	0.969
11	El Mante	1.291	11	Alianza Popular	0.967
12	Melchor Ocampo	1.273	12	Puga	0.965

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	Mill	Technical efficiency with VRS		Mill	Technical efficiency with VRS
13	El Refugio	1.203	13	Plan de Ayala	0.944
14	Atencingo	1.175	14	San Nicolás	0.942
15	Casasano	1.171	15	Santa Rosalía	0.938
16	Emiliano Zapata	1.16	16	San Miguelito	0.927
17	Queseria	1.16	17	Bellavista	0.919
18	El Carmen	1.106	18	Constancia	0.905
19	San Rafael	1.105			
20	Huixtla	1.089			
21	Lázaro Cárdenas	1.057			
22	Tamazula	1.055			
23	La Gloria	1.03			
24	Pedernales	1.021			
25	El Molino	1.018			
26	El Modelo	1.017			
27	El Potrero	1.007			
28	Plan de San Luis	1.003			
29	Adolfo López Mateos	1.001			

Based on the Cran-R runs.

Table 5 shows the two groups of mills identified once the assumption of constant returns to scale has been changed to that of variable returns to scale. The first corresponds to those mills whose efficiency indicator is greater than one and the second in which this indicator is less than one. However, as explained above, in the first group, it is possible to obtain a hierarchy of the mills that present the greatest technical efficiency.

The result indicates that, under variable returns to scale, the San Cristóbal, Tres Valles, Zapoapita, Benito Juárez, and Calipam mills are the best performers, that is, those that had the best relative technical efficiency in the 2021-2022 harvest for having had the best production practices and management of their production factors. In this scenario, the three mills with the lowest efficiency were San Miguelito, Bellavista, and Constancia, with an indicator of 0.927, 0.919, and 0.905, respectively.

The results of this research can be discussed in the light of other works that used the efficient production frontier methodology. Escobedo and Valdivia (2019) were the first to evaluate the relative technical efficiency of the sugarcane agribusiness for the 2015-2016 harvest under the assumption of constant returns to scale and input orientation. In their results, these authors found that the average relative technical efficiency of the agribusiness in the study harvest was 89%, without considering the mechanization of the sugarcane harvest, and it rose to 96.5% when considering the mechanization of the cutting and lifting of sugarcane. The research concluded that there was room for improvement in technical efficiency in agribusiness.

In their study, Santiago *et al*. (2021) applied the Malmquist productivity index for the 2006-2007-2015-2016 harvest period to a balanced panel dataset and a total of 50 mills. In their results, they found that, in the study period, in the El Dorado mill, the cumulative percentage change in its technical efficiency was 4.4%, in technical progress and innovation 21.7%, and a total productivity of the factors of 27%, whereas the opposite situation occurred for the San Miguel del Naranjo mill, whose cumulative percentage change in its technical efficiency was -10.2%, its technological progress and innovation grew by -0.3%, while total factor productivity was -10.4%. Valdivia *et al*. (2022) analyzed the relative efficiency and economies of scale of sugar mills for the 2010-2011 harvest. Their work indicates that, between 1996 and 2018, 10 sugar mills closed or stopped operating; that is, in a 19-year period, 16.4% of the milling infrastructure of the Mexican sugarcane agribusiness closed, which was due to inefficiencies in its productivity parameters.

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In their results, Valdivia *et al*. (2022) found that, out of 51 mills, 23 operated at an optimal scale, a second group of 9 mills operated with total efficiency, but with pure inefficiency and scale inefficiency, and a third group of 19 mills that operated with total inefficiency, pure inefficiency, and scale inefficiency. Regarding the nature of the yields, they identified 23 mills that operated with constant returns to scale, 29 with increasing returns to scale, and only two mills with decreasing returns to scale.

The main conclusion of the study is that the 29 mills with increasing returns to scale could improve their performance, if they expanded their size, production and factor productivity would increase more than proportionally. A particularity of Valdivia *et al*. (2022) results is that they also concluded that the Zapoapita mill (Pánuco) was the only one that was identified with both inefficiency of scale and decreasing returns to scale.

As can be seen in Escobedo and Valdivia (2019); Santiago *et al*. (2021); Valdivia *et al*. (2022), those mills that are relatively the most efficient in technical terms have been identified. Nevertheless, none of these studies makes a classification (ascending or descending) of which mills are the most productive in practice in the respective harvest or harvest period of the respective study; however, the information they provide is valuable because it helps to understand the performance of these complex production units in terms of their production practices and management of the factors of production at their disposal. Finally, according to Valdivia *et al*. (2022), during the 2010-2011 harvest season, this mill was inefficient and with decreasing returns to scale, which implied that, according to this research, it could have closed and stopped operating. Nonetheless, according to its indicators for the 2021-2022 harvest obtained in this study, this mill turned out to be one of the three with the highest performance, the other two being San Cristóbal and Tres Valles. The Zapoapita sugar mill was acquired by the Pantaleón Group of Guatemala in 2011.

Conclusions

Zapoapita, San Cristóbal, Tres Valles, Benito Juárez, and Calipam sugarcane mills were identified as the most efficient the 2021-2022 harvest, and those with the lowest performance were San Miguelito, Bellavista, and Constancia (whose average efficiency was 0.92). In this way, the evaluation of the relative technical efficiency of the sugarcane agribusiness mills in Mexico through the variant of the data envelopment analysis method, called the super-efficiency slack-based model, oriented to the input and with variable returns to scale, made it possible to identify which sugarcane mills were effectively the most efficient in the 2021-2022 harvest and thus overcome the disadvantage of the two conventional models of the data envelopment analysis methodology, which, under the assumptions of constant returns to scale and with an orientation to the input, identified 21 sugar mills with relative efficiency equal to one and 29 mills in the case of variable returns to scale, which did not allow, in practice, to distinguish which mills are effectively the most efficient. Under the same assumptions as above, it was found that a group of 16 had a scale efficiency greater than one, so it can be said that they can further improve their performance by identifying better productive and management practices.

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