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Article

Technical Efficiency in Ecuador's Dairy Farms: Evidences of the Pandemic Impact

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Abstract: The main point in the present article was the comparison of the Technical Efficiency (TE) in four years for milk production in Ecuador by the period 2018 – 2021, before and after the pandemic, and the determination of the factors related to the TE for the last year. The information from the official public database in the country were analyzed by the nonparametric technique called DEA including a bootstrap simulation. Once different variables were selected including aspects as livestock and labor, the TE with Variable Returns to Scale (VRS) with "output" orientation was calculated by each year and province. Among the provinces, statistically significant differences were found (P<0.1) for the TE means, and most of the efficient units were found throughout the Andean zone, in each year. Between the most important findings, it was important that the TE average after the beginning of the pandemic was statistically lower than the last 3 consecutive years under study (P<0.1) with 3% approximately of decrease, and the main factors related to this were multiple including labor characteristics, the field composition, and the supplies access during the pandemic. Finally, some implications for public policy were found around the gender in agriculture activities, the social security, and the difficulties in supplies access.

Keywords: DEA; COVID; labor; bootstrap; gender

1. Introduction

Milk production is the most important livestock activity in Ecuador [1]. Also, around 74% of the production's country is from the Andean zone, where their activities characterize with medium – low inputs use [2]. In general, dairy production is one of the most important economic activities in the country, and all the studies related to its industrial production try to generate substantial information for it [3]. On the other hand, it is known that the management activities in agriculture aim to improve the combination of inputs, and they imply a better economic performance in conditions of supplies access difficulties [4,5].

Since 2020, the impact of the pandemic in many farms around the world is related to agricultural inputs (materials, labor, transportation), daily production, and operations like agricultural supply chains and producers [6–9], and given the relationship efficiency-production factors, possibly all the elements related to the efficiency [10]. Actually, the use of parametric and non-parametric techniques for the Technical Efficiency (TE) calculations in dairy farms are common between the scientific literature related to management [11], animal welfare, animal productivity, and agricultural efficiency [12,13], or pasture access [14]. For example, Kelly et al. [4], reports results for efficiency in relation to scale and size, grazing and feeding on dairy farms in Ireland; Cabrera et al. [15] evaluates the TE of dairy farms with the use of several variables as cows, feed, capital, crop, and others. Indeed, from the non-parametric techniques, the Data Envelopment Analysis (DEA) is a frequently used methodology, and it analyzes dairy farms efficiency with relative success [16,17]. Actually, many variables are considered as important at the moment of the model determination: cows [18], labor force [18–20], lactating cows and grazing land available [19].

Ecuador's situation after the pandemic is not better comparing with the problems in some other countries. It is reported that in US and China, the disruption and difficulties of moving milk, or all the activities related to the supply chains including worker shortages [21] impacted on the agriculture, the labor, and the economy in general. Based on all above, the research objective was the comparison of the Technical Efficiency (TE) in Ecuador for the period 2018 – 2021, before and after the pandemic, and the determination of the factors related to the TE for the last year.

2. Materials and Methods

For TE calculations in each farm/unit based on the DEA model, and the factors related to TE, there were necessary three basic steps: (a) first off, all the units with complete information in the model variables were determined for each year, and based on the variables selected for the model; (b) second, using the DEA model with "output" orientation and with Variable Returns Scale (VRS) approach, during the period 2018 – 2021, all the technical efficiencies were found for each unit/farm, for each province in the country, and finally for each year; (c) finally, TE calculations for 2021 based on three ranges were found, and the statistical significance was evaluated by classifying the farms in efficiency ranges, and after that an Analysis of Variance (ANOVA) of models and parameters was performed together with the use of Tukey's HSD test, or Chi-Square and Fisher's Exact Test ($P<0.10$), depending on the type of variable evaluated.

2.1. Collection of information

The public data bases were provided by the "National Institute of Statistics and Census" (INEC) using the results from the survey called "Surface and Agricultural Continuous Production Survey" in the period 2018 – 2021 [22]. This survey is applied each year to a sample based on a specific methodology explained in: https://www.ecuadorencifras.gob.ec/documentos/web-inec/Estadisticas_agropecuarias/espac/espac_2022/Metodologia_ESPAC_2022.pdf. One of the most important characteristics of the survey was the use of the same methodology and variables in each year. Due to some ongoing corrections in to the 2022 database, we have considered the exclusion of 2022 database.

2.2. Farms location and selection

The data base provided by INEC included plenty information clustered by province, and it included in each year more than 20,000 farms. Also, for the DEA model, we included just farms with complete information in each variable included for the TE calculation. Based on that, the information of 10,988 different farms were used, and each year a similar number/percent of them was used: 2,370 in 2018 (21.6%), 2,987 in 2019 (27.2%), 2,713 in 2020 (24.7%), and 2,918 in 2021 (26.6%). Adding, the percent of farms around the Andean area is greater than 80% for each year. This last fact revealed the importance of the farms around the Ecuador's Andean zone [23].

In average, some Farm indicators revealed a possible impact of the pandemic for the year 2021. According with the Table 1, in general the Milk Production had a decrease over the time, but there was an important decreasing for the last year. Some important findings noted were the constant decrease of variables as the Farm Area (around a 50% of decreasing in 4 years in average), the Total Dairy Animal (around a 16% of decreasing), and the Milk Production (around 8% of decreasing). On the other hand, some variables were increasing until the pandemic year as the number of Workers, especially if they were men. Indeed, this last result could be related to the migration wave experienced in the country in the last years, and the fact that farms with more technology are more inclusive towards women in terms of employment [24].

Table 1. Farm characteristics in the years 2018-2021.

	2018		2019		2020		2021	
Variables for Farm Description	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Milk production/l×day	121.2	9	129.7	9.25	115.7	6.91	111.9	8.19
Farm Size/Ha	120.5	22.35	85.9	6.13	72.3	3.14	63.2	2.36
Total Dairy Animal/Units	51	1.68	51	1.69	49	1.54	43	1.33
Total Animals from Owner/Units	50	1.72	50	1.69	49	1.55	43	1.35
Grass Percent/%	91	0.12	92	0.11	90	0.13	90	0.11
Workers/Units	7	0.27	7	0.34	9	0.38	7	0.29
Men/Units	6	0.27	7	0.33	8	0.37	6	0.28
Women/Units	3	0.11	3	0.14	3	0.14	3	0.12
Natural Grass/m^2	3.1	0.23	3.6	0.29	5.9	1.86	3.8	0.33
Paramo/m^2	103	26.69	96.9	27.66	124.1	42.98	118.8	31.62

2.3. Mathematical model

It was used the Data Envelopment Analysis [25], based on n productive units (farms) which produce "y_i" units of an output but with "x_{ki}" units of the k-th input, being these in turn m inputs, the model with output orientation maximizes the latter (Equation 1; if the orientation were input, it would prioritize the minimization of input use; [26]. Given the fact that most of the farms produced milk in several areas in the country and they had it as the most important product, we used that variable as response in each model fitted with "output" orientation. Therefore, the equation to maximize would be:

$$\underset{\theta_j,\lambda_j}{Max\ \theta_i} \tag{1}$$

All this under certain conditions:

$$\sum_{j=1}^{n} \lambda_j y_j - \theta_i y_i \geq 0 \qquad \sum_{j=1}^{n} \lambda_j x_{kj} \leq x_{kj} \qquad \sum_{j=1}^{n} \lambda_j = 1 \qquad \lambda_j \geq 0; \tag{2}$$

$$k = 1, 2, \dots, m\ (inputs); j = 1, 2, \dots, n \text{ productive units}$$

The model proposed here is based on that of Charnes, Cooper and Rhodes [25], where θ_i is the proportional increase in output that can be realized for the i-th productive unit, λ_j corresponds to the use of the inputs. If the restriction $\sum_{j=1}^{n} \lambda_j = 1$ (Equations 2) was discarded, then constant returns to scale would be obtained. In addition, the level of the production frontier for the i-th farm, was calculated by Equation 3.

$$y_i^* = \sum_{j=1}^{n} \lambda_j y_j = \theta_i y_i \tag{3}$$

2.4. Analysis of the model, Parameter Assumptions, Variables, and restrictions

The determination of efficiency involves assuming two types of models: (a) the model under Constant Returns to Scale (CRS), known as the global technical efficiency; and (b) Variable Returns to Scale (VRS). Also, pure technical efficiency reflects deviations from the optimal frontier of each unit due to inefficient management [27]. In this work, VRS model have been used to determine the TE, assuming that the farms are not operating in an optimal scale [17].

The DEA model, at the time of identifying the variables -input(s) and/or output(s)- makes it necessary to choose the orientation under which this identification is established. First of all, the output approach, from a business point of view (production maximization), assumes that the farms use several production factors with the aim of providing a greater quantity of production, which is the opposite point of view from the input approach, where the farm try to minimize the use of the supplies in the production [7]. Under the output orientation, the calculations of the TE using just VRS are common in the scientific/specialized literature oriented to the dairy farms [10].

On the other hand, all the variables included in the database in the period 2018 - 2021 presented complete farm's information like: farm size, herd consistency, managerial variables, cow number, annual produced milk, or number of farm employees. Also, in all years were used the databases called: "Cattle", and "Employment". The variables selected for the determination of the DEA model are described in Table 2.

Table 2. Variables used from the database (2018-2021) for the DEA model.

Variable Description	Variables in Database
Total Animals from Owner	gl_k809
Total Dairy Animal	gl_k808
Dairy Cattle Property	gl_propleche
Worker Woman Total	eu_k1303
Milking Cows	gl_k807
Workers	eu_k1301
Man's Workers	eu_k1302
Workers Without Incomes (Total)	eu_k1305
Female Animals	gl_tothembras

For the calculation of technical efficiency with Bootstrap simulations, the R© program version 3.3.3 was used, together with the rDEA© package. Subsequently, SPSS software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) was used for statistical results analysis.

2.5. Factors identification

The identification of factors related to the TE used just the last database (2021). Basically, we classified TE by ranges only for the last year creating a new ordinal variable with 3 levels: Low = values from 0 up to 0.2, Medium = values from 0.2 up to 0.4, High = values greater than 0.4. Finally, all quantitative factors related with the new variable that had a statistically significant influence ($P<0.10$) were detected using Analysis of Variance (ANOVA) together with the use of Tukey's HSD test, and in the case of categorical variables the Chi-Square and Fisher's Exact Test ($P<0.10$) were used. Also, the 2021 public data base included a set of categorical variables related to the pandemic (called "Pandemic effects"), and all the variables were tested using Chi-Square and Fisher's Exact Test ($P<0.10$) again.

3. Results

This section was divided in two parts: (a) all the results related to the TE in general and divided by provinces; (b) all the statistically significant factors ($P<0.1$, ANOVA and Tukey test) related to the TE calculated in part (a).

3.1. Technical Efficiency according the DEA model, by and years and provinces

In general, the technical efficiency (VRS) during the period 2018 – 2021, shows values in the range of 18% - 27% in average (Figure 1).

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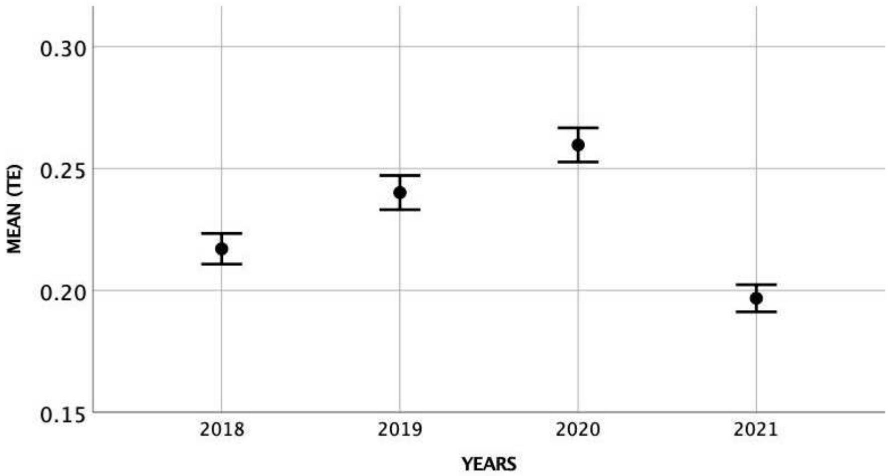

Figure 1. Mean and 95% confidence interval of the technical efficiency (VRS) of all the farms studied, during the period 2018 – 2021.

The evolution of the efficiency value clearly changed over the time, and it is easy to observe the effect of the pandemic. Its value was always higher between the first three years 2018 (0.22 ± 0.003), 2019 (0.24 ± 0.003), and 2020 (0.26 ± 0.003) before the pandemic (Table 3). However, TE for 2021 was atypically low for the year 2021 (0.20 ± 0.002) in addition to having a behavior different from the years described recently. Also, the TE in the last year was statistically different from the first three years (P<0.001, ANOVA Test, and Tukey Test). In general, TE decreased from all the period 2018-2020, which was notably accentuated in 2021 due to the pandemic, when the lowest values are observed for TE (Figure 1). Based on the results, it was possible to calculate around a 3% of decreasing in the average of the TE for the country.

Table 3. Technical efficiency (VRS) with *output* orientation, from 2018 to 2021, in the farms under study.

Year	Mean[1]	SE	Min	Median	Max
2018	0.22b	0.003	0.003	0.19	0.91
2019	0.24c	0.003	0.003	0.21	0.92
2020	0.26d	0.003	0.011	0.23	0.91
2021	0.20a	0.002	0.003	0.17	0.89
Total	0.23	0.001	0.003	0.20	0.92

[1] Different letters (a,b,c,d) indicate statistical significance using Tukey's test (α = 10%).

3.2. Main determinants of technical efficiency for the year 2021

According to Tables 4 and 5, the decrease in TE had several factors related to the decrease observed in the first year after the pandemic. Based on this information in 2021, there were different variables related to cattle management, farm conditions or even labour aspects that can be studied in more detail.

In general, for the last year, all the farms with higher TE characterized with higher values of (P<0.1, Tukey Test): Milk Production per day (436 ± 53.6), Cattle & Own Cattle (51 ± 5.6), Total Cows (29 ± 3.3), Milk from Cattle Owner (49 ± 5.6), Total Veal (12 ± 1.7), Calf (16 ± 1.8), Female Animals & Total Animals in reproduction (37 ± 4.1), Total Pregnant Animals (22 ± 2.9), Total Vaccinated Animals (49 ± 5.6), Milked Cows (24 ± 2.7), Milk Sold Yesterday (433 ± 54.7) and the last Week (3024 ± 358.2), Milk Processed in the Farm (207 ± 65.1), Insured Workers (3 ± 0.6), and Milk Total Production (436.32 ± 53.55).

On the other hand, all the farms with higher TE characterized with lower values of (P<0.1, Tukey Test): Men Workers (1.29 ± 0.2), Milked Cows No Owner (0.01 ± 0.01), Permanent Crops (1.68 ± 1.3), Grass Percent (85 ± 1.2).

Finally, most of the farms with higher TE (Table 5, 59.5%) considered the impact of the pandemic on the farm activities were important (P<0.1). Basically, the relationship between a high TE and a high impact was established.

Table 4. Others variables by technical efficiency by ranks.

	Technical Efficiency Ranges														
	0 ≤ TE ≤ 0.2					0.2 < TE ≤ 0.4					0.4 < TE				
Variables	**Mean**	**SE**	**Min**	**Median**	**Max**	**Mean**	**SE**	**Min**	**Median**	**Max**	**Mean**	**SE**	**Min**	**Median**	**Max**
Milk Production/day	71a	10.2	1	12	8,000	246b	22.9	4	40	7,692	436c	53.6	8	120	6,750
Cattle	29a	2.6	1	7	2,960	42b	3.2	1	10	1,100	51b	5.6	1	17	650
Own cattle	28a	2.6	1	7	2,960	42b	3.2	1	10	1,100	51b	5.6	1	17	650
Cows Total	14a	1.2	1	3	800	23b	1.8	1	5	600	29b	3.3	1	10	425
Milk from cattle owner	23a	1.7	1	6	819	40b	3.1	1	10	1100	49b	5.6	1	15	650
Men Workers	1.38b	0.1	1	1	159	1.21a	0.2	1	1	129	1.29a	0.2	1	2	27
Veal	6a	0.6	0	2	300	10b	0.9	1	3	300	12b	1.7	1	4	200
Calf	10a	0.9	1	3	400	13ab	1.1	1	4	263	16b	1.8	1	7	120
Female Animals in reproduction	16a	1.4	1	4	808	30b	2.5	1	6	690	37b	4.1	1	12	425
Total animals in reproduction	17a	1.5	1	4	838	30b	2.5	1	7	690	37b	4.1	1	13	425
Total pregnant animals	10a	1.0	1	2	450	19b	1.7	1	4	450	22b	2.9	1	6	285
Total vaccinated animals	30a	2.9	1	7	2,960	42ab	3.3	1	10	1,050	49b	5.6	1	17	650
Milked Cows	8a	0.6	1	2	328	18b	1.4	1	4	425	24c	2.7	1	9	338
Milked Cows, no owner	1b	0.2	0	0	15	0.2a	0.1	0	0	10	0.01a	0.01	0	0	0
Milk sold yesterday	102a	16.1	0	15	8,000	259b	24.5	1	40	7,350	433c	54.7	5	130	6,500
Milk processed in the farm	31a	5.9	1	14	1,680	48a	12.0	2	28	997	207b	65.1	3	50	822
Insured Workers	1a	0.2	0	0	352	2ab	.3	0	0	243	3b	0.6	0	0	102
Milk sold last week	689a	107.2	0	98	56,000	1,908b	240.4	0	280	153,200	3,024c	358.2	35	917	36,677
Permanent Crops	12.6a	6.9	.50	2	79	75.25b	74.8	0.50	75.25	150	1.68a	1.3	0.35	1.68	3
Milk Total Production (Liters)	71.65a	10.15	1	12	8,000	246.12b	22.85	4	40	7692	436.32c	53.55	8	120	6,750
Grass %	90c	0	5	90	100	87b	0	10	90	100	85a	1	30	90	100

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Table 5. Relations the ranks with the question: Does the pandemic impacted on the farm activities? (P<0.001, Fisher's exact Test).

			Technical Efficiency Ranges			
			0 ≤ TE ≤ 0.2	0.2 < TE ≤ 0.4	0.4 < TE	Total
Pandemic impacted on farm activities	Yes	Farms	759	493	122	1,374
		%	44.1%	50.5%	59.5%	47.3%
	No	Farms	963	483	83	1,529
		%	55.9%	49.5%	40.5%	52.7%
Total		Farms	1,722	976	205	2,903
		%	100%	100%	100%	100%

4. Discussion

The TE of dairy bovine farms determined through DEA under the conditions of Ecuador briefly coincided with the results achieved using the same technique by Torres et al. [23] in the Andean area, who found 39.2% as the efficiency average for the VRS rate. Obviously, this average is greater than the mean found here, but this results is not as encouraging as the results reported by Murova and Chidmi [28], Theodoridis et al. [5], and Parlakay et al. [29], on farms with better technological practices.

Also, the ranges used in the farm study showed a mid-set of various farms that should enhance the TE given that just 7% of them overcome the 40% barrier of efficiency, and the percentage is lower compared to the percentage found by Torres-Inga et al. [23]. In the previous paper, the TE farms close to 1 accounted for 0.59%, but in the present study this value was 0. This scenario, affected by different difficulties including the pandemic implies dissemination, persuasion, training, and encouragement to assume technology changes in the local production of milk.

In general, the TE means for different dairy farms with advance technology in the world, determined through different mathematic-statistics techniques as DEA, Stochastic Models, or Neural Network models is usually below 50% [23,30,31] despite of those farms better conditions. According with some authors, the negative impact of inefficient farms has been reduced by subsidy policies, such as in the US, and other dairy systems in South America's southern cone [30,32,33], and the use of specialized business technologies as online sales, less external-input practices, operation's business model transformations, and expanding marketing models during the pandemic [7,8]. However, before and after the pandemic, it seems to be that the trend moves in the positive direction toward an increase in bio-efficiency and/or as a palliative to cattle farmers household economies, still unattained in the realm of dairy systems [17,23,30,33], and the importance of the diversification, the sustainable logistic, and the exchange of knowledge and innovations among the farmers [9]. Adding, in Ecuador where the majority of farms are small, the TE could be explained for different factors as the employment [34], and it could derive in an "expected" transition from small farm operations with low inputs as the number of cows, to large commercial operations with sophisticated technology [21].

Moreover, the farms in group with TE greater than 40% showed better results than those other farms due to better production management (higher number of cows served), which led to an increase number of calving and milking cows, significant factors found in the study. Actually, this group characterized with elements as more milk production per cow, more milk production processed at farm, and more milk sold by the owner. Adequate breeding management and proper nutrition can ensure top indicators for reproduction, production, and cost-effectiveness of dairy herds [35].

5. Conclusions

Technical efficiency under VRS and "output" orientation has been generally described as low at the final of the time, and the pandemic period has impacted on by the year 2021. On average, overall efficiency has decreased at least 3% between 2018 to 2021, and this decrease was statistically significant.

Also, the findings in 2021 showed that some factors related to the more efficient groups were those with higher levels of Milk Production, Cattle, Total Cows, Veal, Calf, Animal in Reproduction, Pregnant Animals, Vaccinated Animals, Female Animals, Milked Cows. On the other hand, lower levels of factors related to the more efficient groups were those with less Men Workers, Milked Cows No Owner, Permanent Crops, and Grass Percent.

The TE found in the farms analysed in 2021 suggests that some of their findings could serve as a reference for the public policy after the pandemic. Indeed, Insured Workers, and the number of Men Workers were important variables to define an efficient group. So, there is a possibility that the women found less difficulty to maintain their position in the agricultural activities. However, this is a niche study proposed in this paper along the same lines of technical efficiency.

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Data Availability Statement: data supporting reported results can be found using the following links:

For years between 2018 – 2021: https://www.ecuadorencifras.gob.ec/informacion-de-anos-anteriores-espac/

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