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Technical Efficiency of Dairy Farms in *Sierra Andina* Using Neural Network Modeling

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ABSTRACT

The aim of this paper was to estimate the efficiency of milk production of 1 168 cases in Ecuadoran Sierra Sur Andina, with the implementation of a neural network model with multilayer perceptrons. These cases were collected from secondary samples provided by the Official Institute of National Statistics of Ecuador, in 2016. The variables chosen for the model were total milk production on the previous day (P), as dependent variable, and total cattle heads (CH), total laborers in the field (E), and total area attended by laborer (S), as independent variables. The data from individual cases and their impact on the dependent variable were used as the variable selection criteria. The average efficiency was 8.11%, from which the total efficient cases detected (>0.70) were 11 (0.9% of the sample). Later, the cases studied were classified into three groups, depending on the estimated efficiency: Group 1 (≤ 0.4 efficiency); Group 2 (>0.4-≤0.7 efficiency); and Group 3 (>0.7 efficiency). A comparison produced several statistical differences (P<0.01) for variables total milk production/year on the farm, total field laborers, farm size, total cows, total cattle heads, calvings, pregnant cows, and served cows.

Key words: *dairy bovines, production boundaries, multilayer perceptron, modeling*

INTRODUCTION

Milk production in the Ecuadoran Sierra accounts for approximately 77% of the total dairy production of the country (5.3 million liters daily) (ESPAC, 2016), with Azuay province as the second largest producer in Ecuador. In order to optimize resources, it is important to perform data analysis to determine the inefficiencies of production. In 2016, out of 100% of the dairy production cows in Sierra, 14% was located in the province of Pichincha (21% of all the Sierra production). In Azuay, the number of cows represents 17% of the national population, with only 14% of production. In other words, there are more milking cows in Azuay, but lower production, than in Pichincha.

Increasing milk production is important for the country, since the FAO recommendations on consumption of liter/inhabitant/year are being unmet, particularly due to the appearance of new markets for the local population (AGSO, 2016).

Several mathematical models have been designed, like deterministic linear regressions (Timmer 1971; Jiang, and Sharp, 2014), or non-parametric models, like envelop data analysis (Charnes, Cooper and Rhodes 1978; Cobo and Borroto, 2013; Flores, Herrera-Toscano, and Flores, 2014; and Gómez, 2016). The utilization of specific neural networks (Fernández, Hervás, García and Torres, 2011; Gallo, Contoa, Piermichele, and Antonazzoa, 2013) is being planned with a suitable methodology for data analysis.

The aim of this paper was to estimate the technical efficiency of dairy farms in the province of Azuay, through the application of a neural network model with multilayer perceptrons.

MATERIALS AND METHODS

Case location and selection

The cases studied were located in the province of Azuay, Central Ecuadoran Andes, coordinates 3 20´24´´S and 78 06´00´´W, 2 100 and 3 500 m above sea level. The average maximum and minimum temperatures of the area are 20.3 °C and 9.2 °C, respectively. The mean annual precipitation value is 878 mm.

The cases were provided by the Surface Survey and Continuous Agricultural Production, National Institute of Statistics and Census (INEC) (ESPAC, 2016).

In order to prevent the occurrence of atypical data, only productions below 300 L of milk daily were selected. The final number of cross-database cases analyzed from ESPAC (2016) was 1 168.

Mathematical model and selection of variables

Neural networks were utilized for nonparametric analysis, which has been thoroughly dealt with in the literature since the mid-80s (Santin, Delgado, and Valiño, 2004).

In this particular case, the variables chosen for the model were *total milk production on the previous day* (P), as output variable, whereas *total cattle heads* (CH), *total laborers in the field* (E), and *total area attended by laborer* (S), were the input variables.

Data normalization is normally used in relation to networks because the output variable requires transformation by activation. Furthermore, the database was partitioned (70%) for network training, whereas the other (30%) was used for testing, considering the efficiencies achieved on 399 farms in the graphic used and the comparisons made.

The estimations of total milk production from the previous day (P) on each farm were utilized to calculate efficiency (E, based on the neural network model), according to the methodology described by Athanassopoulos and Curram (1996), expressed by,

$$Efficiency = \frac{Y_i}{\hat{Y}_i + Max_i\ \varepsilon_i}$$

Where efficiency (E), is the ratio between the production observed and the estimate, plus the residue. Y_i corresponds to the production observed in each farm's sample. $\hat{Y}_i$ corresponds to the production estimated by the neural networks model for each farm, whereas $Max_i\ \varepsilon_i$ corresponds to the maximum positive residue of the residuals obtained by the difference between $Y_i - \hat{Y}_i$.

Later, the efficiency value determined for each farm was used for farm classification, according to the following criterion: group 1 = 0-0.4 efficiency, group 2 = 0.4-0.7, and group 3 = +0.7.

These three groups underwent analyses of variance (ANOVA) and Tukey's significant difference test (P<0.01) to determine the significant differences of total milk production/year on the farm, total field laborers, farm size, total cows, total cattle heads, calvings, pregnant cows, and served cows. SPSS (2015) was used for statistical analysis.

RESULTS AND DISCUSSION

The model determined an efficiency average of 0.26 ± 0.22. High variability was observed, which is common to all system studies. Most of the farms in the sample were below the efficiency mean (more than 55 %).

As shown in Fig 1, the model determined that 11 farms were > 0.7 efficient, a very low set value that requires further analysis to improve the results in this sector. Almost 75% of the farms showed efficiency below 0.7.

The groups determined were compared in Table 1. The results showed significant differences (P<0.01) in all the variables included in the model, as well as others used in the survey, but excluded from the estimation of the neural network. Overall, group 3 was characterized by a higher total milk production (P<0.01) after a year. There was a greater than normal use of supplies (P<0.01); the farm areas were statistically different (P<0.01); and the total production animals and cows were higher than the other groups (P<0.01). Besides, group 3 was observed to have more animals of their own, more animals for milk and breeding, as well as more vaccinated animals and Holstein individuals. Statistically speaking, this group had more milking cows (P<0.01). The number of milking cows on the efficient farms was higher (P<0.01) than on the inefficient farms.

The efficiency of dairy bovine farms determined through neural networks under the conditions of the Ecuadoran Andes coincided with the results achieved using data envelope analysis (DEA), by Torres, Guevara, Guevara, and Aguirre (2016), who found 39.2% as the efficiency average for the VRS rate. This result was, by far, not as encouraging as the results reported by Murova and Chidmi (2013), Theodoridis *et al.* (2012), and Parlakay, Semerci, and Çelik (2015), on farms with better technological practices.

The ranges used in the farm study showed a mid-set of various farms that might enhance production and overcome the 0.7 efficiency barrier, the same percentage was found by Torres-Inga, Guevara, Guevara, and Aguirre (2016), with different farm samples, and DEA in either work. In the previous paper, the efficient farms close to 1.0, accounted for 0.59%. This scenario implies dissemination, persuasion, training, and encouragement to assume technology changes in the local production of milk. In the provinces of Pichincha and Cotopaxi, the level of production is almost as twice as in the area included for this research, though similar studies that could elucidate the efficiency levels are inexistent (ESPAC, 2016).

The mean efficiency rate for important dairy systems in the world, determined through multivariate techniques, like DEA and hierarchical model analysis, and with variable integration, and/or the inclusion of stochastic or deterministic functions, is usually below 50% (Bravo-Ureta *et al.*, 2007; Jiang, and Sharp, 2014; Torres-Inga, Guevara, and Guevara and Aguirre, 2016).

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 (Bravo-Ureta *et al.*, 2007; Areal, Tiffin, and Balcombe, 2012; Comerón, 2012). Furthermore, it applies in the form of ration schemes within the European Union, which rule dairy production (D'Haese, Speelman, Alary, Tillard, and D'Haese, 2009; Carreño, Frank, and Viglizzo, 2012), and by low-cost production policies in Australia and New Zealand (Callow, Gobius, and Hetherington, 2005).

In the three cases, 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 (Bravo-Ureta *et al.*, 2007, Chang, and Mishra, 2011; Comerón, 2012; Torres-Inga, Guevara, Guevara, and Aguirre, 2016).

The high technical efficiency of the farms studied can also be explained by employment. Guevara *et al.* (2004), after carrying out a classification of dairy farms, found that a larger number of employees were able to improve the operational level and efficiency per hectare, per human labor unit, and per cow.

Moreover, the farms in group 3 showed better results than those in group 2 due to better production management (higher number of cows served), which led to an increased number of calvings and milking cows. Adequate breeding management and proper nutrition can ensure top indicators for reproduction, production, and cost-effectiveness of dairy herds (Inchaisri *et al.*, 2010).

CONCLUSIONS

The utilization of neural networks to perform analysis of technical efficiency in milk from bovines contributed to highly accurate results, which enabled adequate discrimination of the factors (variables included or not included in the model estimated) that helped determine why more efficient farms were classified that way by the model.

Similar studies will contribute to closer monitoring of production in this sector; they might help anticipate, regulate, and improve its future performance before any contribution and support of the state.

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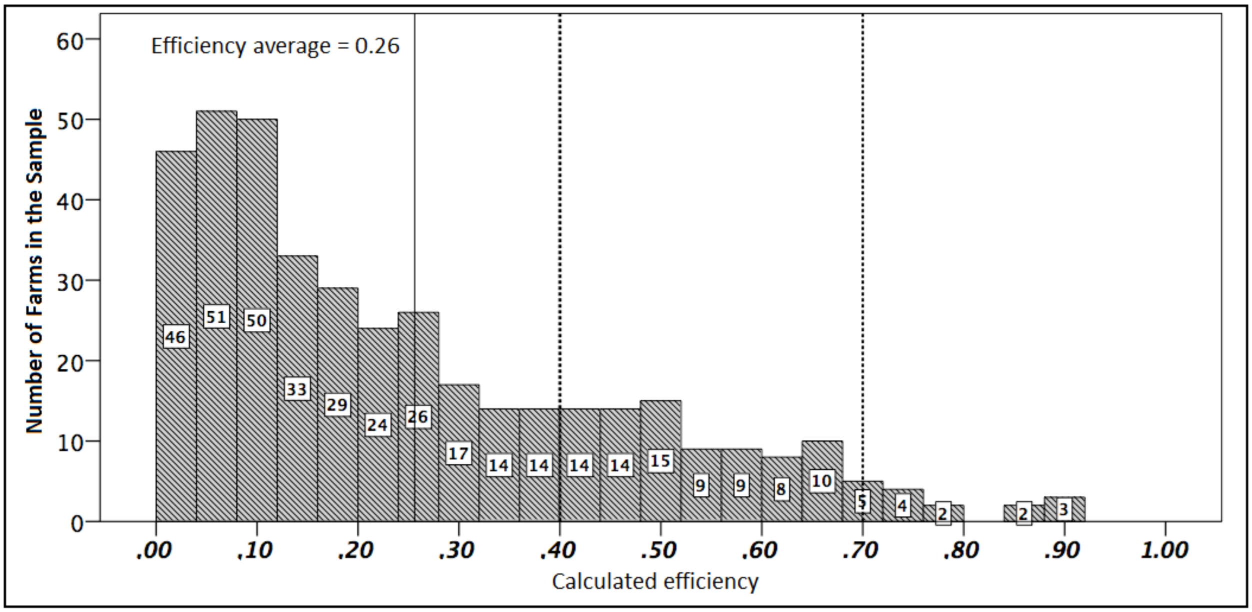

Fig. 1. Number of farms in terms of estimated efficiency, and groups per efficiency ranges: Group 1 (efficiency ≤ 0.4) Group 2 (efficiency > 0.4-≤ 0.7), and Group 3 (efficiency > 0.7

Table 1. Comparison of groups with different efficiency ranges

P[1] (kg)	Efficiency ranges*					
	(≤ 0.4)		(> 0.4 to ≤ 0.7)		(> 0.7)	
	Mean	SE	Mean	SE	Mean	SE
	18 558.8a	1 084.10	85 844.9b	3 605.53	161 136.8c	18 625.47
Permanent workers[2] (EMP; farms)	0a	0	1b	0	2c	1
Farm area (ha)	11.5a	0.49	20.9b	1.43	25.5b	2.2
Total cows (TC; CU[3])	9a	0	26b	1	34c	4
Total animals (farms)	20a	1	45b	2	60c	7
Calvings (farms)	6.2a	0.27	12.3b	1.16	27.9c	7.37
Pregnant cows (farms)	5.9a	0.30	13.5b	1.52	30.1c	7.10
Cows served (farms)	6.3a	0.33	15.8b	1.83	41.6c	10.32

[1]P: Total milk production per year.
[2]People employed 8 hours a day.
[3]CU: Cattle Units
* Unequal letters (a, b, c) mean significant differences (P<0.01), according to Tukey's test.