Efficiency modeling, an important factor in the development of sheep and goat production in a semiarid region

Modelagem da eficiência, fator importante para o desenvolvimento da ovinocaprinocultura, dos produtores do Semiáridoc

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ABSTRACT
The paper aims to use the Data Envelopment Analysis (DEA) approach to evaluate the performance of sheep and goat production systems in the semi-arid region in Brazil. By applying a questionnaire with 127 variables, we obtained information from 254 producers in the municipality of Tauá - CE, with the input variables number of sheep and number of cattle, and the output variable of revenues from animal production. The DEA model with constant returns to scale (RCE) and variable returns to scale (RVE) and were used. The average technical efficiency measures of RCE and RVE models were 9.72% and 23.65% for all farmers. Only two and eight producers obtained efficiency equal to one (maximum) in RCE and RVE, respectively. Most producers operate in terms of increasing returns, and are inefficient. That is, the vast majority of producers are working below the optimum scale, which leads to the exclusion of producers.

Keyword: production system, constant returns, variable returns.

RESUMO

O artigo propõe a utilização da Análise Envoltória de Dados (DEA) para avaliar o desempenho de sistemas de ovinocaprinocultura no semiárido do Brasil. Por meio de questionário com 127 variáveis, foram coletadas informações de 254 produtores do município de Tauá - CE, as varáveis de *input* número de ovinos e número de bovinos, e a variável *output* receita com produção animal. Foi realizada a modelagem DEA de orientação produto com retornos constantes à escala (RCE), e com retornos variáveis à escala (RVE). As medidas de eficiência técnica médias dos modelos RCE e RVE foram 9,72% e 23,65%, no conjunto de todos os produtores. Apenas dois e oito produtores obtiveram eficiência igual a um (máxima) na modelagem RCE e RVE, respectivamente. Observamos que a grande maioria dos produtores operam na faixa de retorno crescente, e são ineficientes. Ou seja, a maioria dos produtores está trabalhando abaixo da escala ótima.

Palavra-chave: sistema de produção, retorno constante, retorno variável.

1 INTRODUCTION

Sheep and goat farming is important for the socio-economic development of the Brazilian Northeast region, due to the great potential of the species to adapt to the climatic conditions of the region. It plays a key role in the transformation of foraging plants into a source of feed protein with a high nutritional value. It also contributes to the generation of income and to the settlement of people in the countryside, as is the case of the semi-arid Brazilian Northeast (Souza et al., 2002).

The largest herds of sheep and goats in the country are in the Northeast region. The state of Ceará takes up 93% of the territory of the region and is the home of 2,316,625 sheep and 1,134,141 goats (IBGE, 2017). The municipality of Tauá is located in the southwest of the state of Ceará. It is 360 km away from Fortaleza, in the region called Sertão dos Inhamuns. In that territory, the size of the sheep herd is 285,305 heads and the size of the goat herd is 153,585 heads, which corresponds to 12.3% and 13.5% of the total herds in the state of Ceará, respectively. Tauá is the municipality with the largest herds of sheep and goats in the state: 133,000 and 68,000 heads, respectively (PPM/IBGE, 2017).

Although they do not manage sheep and goat farming as a single activity, the producers of Tauá consider both of them as their main activities, the ones on which the municipality is concentrated. Nevertheless, the breeding of sheep and goats is characterized by a low technical level, which partially accounts for the low productivity rate, as mentioned by Campos & Guimarães (2001) in relation to the state of Ceará. Some authors point out the traditionalism of the techniques adopted as responsible for the poor performance (Moreira Filho et al., 1985). Casimiro (1984) identifies the adverse climate and soil conditions, such as the low soil fertility rate, the inadequacy of the technologies available, the rainfall irregularities, the lack of financial resources and marketing organization, the archaic social relations of production, and the low levels of education as factors of obstacle to a better performance of the production activities.

Despite the challenges faced by the agricultural activity, Schuh (1996) understands that "agriculture plays a strategic role; it is fundamental in the economic development process. The key to the process is to remember that the basis for the agricultural development is technology". One of the first steps to be taken is to typify the production systems, in order to have an accurate understanding of the factors that influence the producers' decisions. An appropriate knowledge of the processes involved in the various systems is essential for the development of an analysis framework to apply in the research on agricultural systems (Dillon & Hardaker, 1994).

The conceptualization and the search for rigid efficiency measures involve the establishment of criteria to determine the best possible situation for the economic agents in the distribution of the goods produced. The search for technical efficiency (the lowest use of inputs), scale (the most appropriate production level), and allocation (the lowest cost and the highest revenue at market prices) is an essential component of the profitability strategies (Ferreira & Garcia, 2009). The modeling of agricultural systems by means of Data Envelopment Analysis (DEA) has evolved quickly and consistently, thanks to the method flexibility and the theoretical effort towards adapting the methodology to different production systems (Gomes, 2008; Emrouznejad & Yang, 2017).

The paper proposes to use the DEA approach to assess the performance of sheep and goat systems in semiarid regions. The knowledge of the production system efficiency is assumed to help increase the activity development and improve the technological and management processes, which will result in better productivity indices of the production chain as a whole.

2 MATERIAL AND METHODS

By means of a structured questionnaire with 127 variables (economic, social and zootechnical information), 324 producers of the municipality of Tauá-EC were interviewed. After removing the lost data, 254 producers remained for the analysis. The data was inserted in a spreadsheet, and exploratory statistics were estimated, in order to check data consistency, as described by Souza et al. (2014).

With the aim to establish production system typologies, Abreu et al. (2016), by means of multivariate factor analysis, found that the first two factors explained 80% of the total (co)variance of the information. By means of estimated factor loadings, these variables were maintained: number of sheep - QuantOv, number of cattle - QuanBov, total annual revenue from animal-origin products - Recprodoani, total annual revenue - RecT, and total annual agricultural revenue - RecTagro.

The Data Envelopment Analysis (DEA) was originally proposed by Charnes et al. (1978) as a methodology to assess the relative efficiency of homogeneous units that are autonomous in the decision-making process (Decision Making Units - DMU). DEA models are based on sample data (input and outputs) for different DMUs. The goal is to build a set of convex reference, and then classify the DMUs in either efficient or inefficient, by taking the surface formed as reference.

The model developed by Charnes et al. (1978) is called constant returns to scale (RCE). It was restructured by Banker et al. (1984), who developed another model, with the objective to enable the analysis in the case of variable returns to scale (VERS). The model to be used is formulated; its resolution calculates the production border as a data envelopment, and determines whether each DMU is on the efficient border or not. The use of the methodology does not require functional specification to relate the data, as it is a non-parametric technique. The methodology is based on linear programming, aimed at measuring the relative performance of organizational units with the presence of multiple inputs and relatively homogeneous outputs, which causes difficulty in comparisons. In a simple case, where the production process has only one input and only one output, efficiency may be defined as:

$$Efficiency = Output / Input$$

Organizations usually have a large number of outputs and inputs. This complexity may be incorporated in the efficiency measurement, by defining efficiency as:

Efficiency = Weighted Sum of Output / Weighted Sum of Input

This requires lot of weights that are difficult to estimate, particularly if a series of weights has to be applied to a large number of organizational units, with different characteristics. The problem may be solved by establishing that each individual unit may have its own value system and, consequently, define its own weight system (Cooper et al., 2006). The fundamental assumption of the DEA technique is that, if a given DMU is able to produce Y(A) output units by using X(A) input units, other DMUs will be able to do the same, as long as they are operating efficiently. Similarly, if another DMU is able to produce Y(B) output units by using X(B) inputs, other companies will be able to apply the same production process. If the two DMUs are efficient, they may be combined to form a compound DMU that uses a combination of inputs to produce a combination of outputs. If the compound DMU does not exist, it is called virtual DMU. The DEA methodology finds the best virtual DMU for each sample DMU. If the virtual DMU is better than the original DMU or produces more with the same number of inputs, or produces the same number with fewer inputs, the original DMU will be considered inefficient.

Charnes et al. (1978) proposed that the efficiency of j_0 unit may be evaluated by the solution of the following template:

$$Max\ h_0 = \frac{\sum_{r=1}^{t} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}} \qquad (\text{M1})$$

Subject to:

$$\frac{\sum_{r=1}^{t} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad j = 1, \ldots, n,$$

$u_r, v_i \geq \varepsilon, \quad \forall \quad r$ e $i,$

where:

y_{rj} = total outcomes r, originated from productive unit j;

x_{ij} = total outcomes i, originated from productive unit j;

u_r = weight given to input r;

v_i = weight given to output i;

n = number of productive units;

t = number of outputs;

m = number of inputs; and

ε = small positive number.

In the solution of this model, the efficiency of unit j_0 is maximized. The restriction is that the efficiency measures of all other productive units are below or equal to one. The key feature of the above model is that the weights u_r and v_i are treated as incognita and then chosen so that the efficiency of j_0 is maximized. If the efficiency of j_0 is equal to 1, it will be considered as efficient in relation to other productive units; otherwise, it is considered inefficient. If the unit is inefficient, the solution identifies corresponding efficient units, which in turn form a reference group (benchmark) for inefficient units.

The DEA model described above is a linear fractional model, but it may be converted in a linear programming, so that the linear programming methods may be applied. The model in the form of linear programming is shown below:

$$Max\ h_0 = \sum_{r=1}^{t} u_r y_{rj0} \qquad (M2)$$

subject to:

$$\sum_{i=1}^{m} v_i x_{ij0} = 1,$$

$$\sum_{r=1}^{t} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0,$$

$j = 1, \ldots, n,$

$-u_r \leq -\varepsilon,\ r = 1, \ldots, t,$

$-v_i \leq -\varepsilon,\ i = 1, \ldots, m.$

When the objective function is linearized, it is possible to identify that, during maximization, the ratio (relative magnitudes of the numerator and the denominator) is the important factor in the analysis, rather than its initial values. This way, in the model (M2), the denominator is equal to a constant (arbitrarily 1 in the notation), and the numerator is maximized. The model is applied to every unit, in order to obtain the efficiency measures one by one. The solution is computationally easier, as most restrictions are the same for different productive units.

In order to calculate the relative efficiency of a DMU, the dual problem is solved. This model may be described in case of constant returns to scale (CRS), according to Coelli (1996), as follows:

$$Min_{\ \theta,\lambda}\ \theta \qquad (M3)$$

subject to:

$$-y + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

where:

y = output of the model under analysis;

x = inpout of the model under analysis;

X = input matrix K x N;

Y = output matrix M x N;

θ = a scale that multiplies the input vectors;

λ = a vector of constant N x 1 that multiplies the input and output matrix; and

N = number of DMUs.

The dual model includes the relative efficiency analysis provided in cases where there are slacks or non-radial reductions in the inputs. For a DMU to be considered technically efficient, θ should be equal to one, and the slacks equal to zero. The linear problem must be solved N times in order to obtain the relative efficiency of each DMU for each iteration.

Banker et al. (1984) developed an important extension of the DEA model with constant returns to scale (CRS). The authors modified the linear program in such a way as to incorporate one restriction, the convexity (N1 ' □ = 1), thus enabling the analysis of variable returns to scale (VRS). The model is described as follows:

$$Min_{\ \theta,\lambda}\theta \qquad \text{(M4)}$$

subject to:

$$-y + Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$N1'\lambda = 1$$
$$\lambda \geq 0$$

where:

$N1$ = unitary vector.

The change enabled the decomposition of the technical efficiency into two: pure technical efficiency and scale efficiency. To this purpose, we must solve the linear problem by applying the two linear models (M3 and M4) described. If there is a difference between the two solutions in one particular DMU, it means that the DMU has scale inefficiency, and the inefficiency value is the ratio between the values found in models CRS and VRS.

The pure technical efficiency coincides with the solution to model VRS. The scale inefficiency originates from the production at a poor level of the scale. The optimal level of the scale is considered the result obtained in the comparison with the efficient firms (CRS = 1). The global technical efficiency is the product of the two efficiencies (pure technical and scale), and their measures match the CRS model.

The DEA model may have two guidelines, either by performing the optimization in the combination of inputs (input-oriented model) for the production of outputs, or by performing the optimization for the production of outputs (output-oriented model). Differences and details of the methodology may be seen in Cooper et al. (2006).

The inefficiency interpretation depends on whether the model is input- or output-oriented. In the first one, we may know the proportion of inputs that were transformed into outputs in the different DMUs. In the second one, we may infer the output increment in all efficient DMUs. An interesting indicator that aims to differentiate the inefficiency scale of a DMU may be calculated in order to check whether the DMU is operating with decreasing returns to scale (RNC) or in an area of increasing returns to scale (RND). To reach this goal, we must replace the restriction $N1'\lambda = 1$ with $N1'\lambda \leq 1$. This way, the impossibility of increasing revenues to scale is incorporated in the restrictions, if the new value obtained by performing the analysis is equal to the one obtained in the RVE model, which means that the DMU is operating in the sector of the decreasing revenues to scale. If the opposite occurs, it means that the DMU is operating in the sector of increasing revenues to scale. Of course the DMUs whose results of VRS and CRS models are an optimum scale and are not considered in this classification.

The data of each producer, surveyed *in loco*, were considered a DMU, with the input variables of number of sheep - QuantOv and number of cattle - QuanBov. The output variable was total annual revenue from animal-origin products - Recprodoani. The DEA model used was output-oriented constant returns the scale (CRS) and variable returns to scale (VRS), according to description by Cooper et al. (2006).

3 RESULTS AND DISCUSSION

Table 1 shows the producers' totals and percentages in relation to constant return (CRS) and variables (VRS), and the scale efficiency. Under the assumption of constant returns to scale, of the total sample of 254 producers, only 2 achieved maximum technical efficiency. The average level of technical inefficiency was 90.28%, output-oriented. This means that producers may be able to increase their revenue up to 90.28%, on average, with the best combination the production of sheep/cattle producers' production systems. In the VRS model, whose average technical efficiency measure was 23.65%, only 8 producers obtained an efficiency measure equal to one. In other words, they are efficiency models for group of producers analyzed. This means that, from among the 8 producers with technical efficiency equal to one, in the variable returns model, only 2 are equally efficient in the constant returns model.

The results was less efficient to observed by Dalgic et al (2018), at Isparta province in Turkey. They analyzed the technical efficiency of sheep farming using DEA. The data used were collected from 80 farmers using the stratified sampling method by means of a questionnaire. The technical efficiency of the sheep farming varied between 0.63 and 1.00. The mean efficiency of farms was calculated to be 0.41 and 0.48 for constant and variable returns to scale assumptions, respectively. It was found that out of 80 sheep farms, except for 5 farms (6.25%), the scale was below constant return to scale and 13 farms (16.25%) were below the variable return to the scale. The Scale Efficiency measure is obtained by the ratio between the technical efficiency measures of the constant returns and variable returns models. If the ratio is equal to one, the producer will be operating at an optimum scale. If it is lower than one, the producer will be technically inefficient, as they will not be operating at an optimum scale.

Table 1 – Number and percentages of producers in Tauá - CE, classified according to constant return (CRS) and variable return (VRS), and the scale efficiency

Efficiency	Numbers and Percentages of Producers		
	CRS	VRS	Scale Efficiency
E < 0,1	182 (71,65%)	85 (33,46%)	8 (3,15%)
0,1 ≤ E < 0,2	48 (18,90%)	66 (25,98%)	29 (11,42%)
0,2 ≤ E < 0,3	10 (3,94%)	30 (11,81%)	48 (18,90%)
0,3 ≤ E < 0,4	5 (1,97%)	33 (12,99%)	37 (14,57%)
0,4 ≤ E < 0,5	3 (1,18%)	12 (4,72%)	34 (13,39%)
0,5 ≤ E < 0,6	2 (0,79%)	5 (1,97%)	23 (9,06%)
0,6 ≤ E < 0,7	1 (0,39%)	7 (2,76%)	18 (7,09%)
0,7 ≤ E < 0,8	1 (0,39%)	2 (0,79%)	19 (7,48%)
0,8 ≤ E < 0,9	0	5 (1,96%)	16 (6,30%)
0,9 ≤ E < 1,0	0	1(0,39%)	18 (7,09%)
E = 1,0	2 (0,79%)	8 (3,14%)	4 (1,57%)
Total	254	254	254
Efficiency Measures			
Average	9,72	23,65	46,96
Standard deviation	12,92	23,10	26,37
Variation Coefficient	1,33	0,98	0,56

In order to determine whether the nature of the scale inefficiencies is due to the fact that the producer operates in terms of increasing returns or decreasing returns, the restriction of non-increasing returns to scale was imposed. If the value of the efficiency measure found in this model is equal to the value detected in the variable return model, then the producer is on the sector of decreasing return to scale, i.e., operating above the optimal scale. Otherwise, the producer is in the sector of increasing returns. Table 2 shows the result of the number of producers according to the return type.

Table 2 - Number and distribution of producers in Tauá - CE, according to the type of return.

Type of Return	Efficient	Inefficient	Total
Increasing	0	230	230
Constant	2	0	2
Decreasing	2	20	22
Total	4	250	254

It is clear that the vast majority of producers operate in the return sector, and are inefficient. In other words, 90% of the producers are working below optimum scale, using a lot of inputs and obtaining few outputs, which leads to the exclusion of producers as a consequence of lack of use of technology, market imperfections, and public policies that discriminate the small production. In order to increase efficiency and reach the optimum scale, it is necessary to increase production, but the increase must occur with balance between the amounts of input used and the volume of output.

This result is similar to that observed by Lakew et al. (2017) who in Ethiopia the production system and sheep management system in the study areas was characterized by mixed crop-livestock production system. Sheep play an important role in the livelihoods of people in the study area, and they have potential for greater contribution through better health management and genetic improvement.

On the other hand, this process of undertaking this research has underscored the benefits of interdisciplinary collaboration to assess technology and policy options. There is often a benefit to economic analyses of more detailed representation of the stock-flow-feedback dynamics found in all agricultural production and market systems. Applied biological scientists working collaboratively with economists to develop more appropriate systems oriented models often can provide both better policy answers and more robust learning processes (Parsons & Nicholson, 2017).

González & Fernández (2017) estimated Total Factor Productivity (TFP) and its components for sheep and goat farms in 37 Southern European regions, and concluded that the solution to inefficient systems is to design targeted policies that are able to diversify activities and reduce farms’ structural problems through techniques that allow increasing returns to scale, more efficient use of factors and technical modernisation.

According to Ferreira & Garrido (2009), technological progress is one of the few viable solutions to prevent inefficiency in production resulting from the attempt to increase production. Technology is knowledge created by research and developed by producers in the production system. According to Alves et al. (2012), few establishments were able to implement this organization, whether because they had specialized technical assistance, or because their managers were competent in the specialization. But it not the same with millions of establishments. It is the researchers' responsibility, in the case of family agriculture, together with technical assistance and rural extension, to organize the production systems, by observing the organization criterion of producers' understanding and profitability.

On the other hand, Silva e Costa (2014) emphasize that any proposal for restructuring economically smaller rural establishments in the semi-arid region, based on the adoption of technological packages, which do not take into account, for example, the soil salinization, the desertification of areas, the disappearance of native species, producers' formal education, etc., typical aspects of the Biome, will be technologically inadequate.

Despite the favorable conditions, sheep and goat production in the region is extensive, characterized by a poor diet, inadequate management and prophylaxis, resulting in low productivity, low off take rate and unsatisfactory financial results. This leads to the under development of the production chain. The activity is characterized by the prevalence of little organized production arrangements, unable to generate competitiveness for the agro-industrial sheep production system (Souza et al., 2014).

4 CONCLUSIONS

Most sheep and goat production systems in Tauá-CE present scale inefficiency and operate in the sector of increasing returns. There is ample room for the technological development of production systems. In parallel, public policies, adjusted to local peculiarities, should be developed for product organization and the technological development of the region.

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