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ECONOMIC EFFICIENCY OF CATTLE PRODUCTION IN THE BRAZILIAN AMAZON

Marcos Antônio Souza dos Santos
Federal Rural University of Amazon, Brazil, Email: marcos.marituba@gmail.com

Antônio Cordeiro de Santana
Federal Rural University of Amazon, Brazil

Alfredo Kingo Oyama Homma
Embrapa Eastern Amazon, Brazil

Andréia Santana Bezerra
Federal Rural University of Amazon, Brazil

José de Brito Lourenço Júnior
Federal University of Pará, Brazil

Abstract

The article estimates a production function for cattle raising developed in the municipalities of the Brazilian Amazon, aiming to identify the influence of production factors on cattle production value. Municipal data on the gross value of cattle production, pasture areas, labor employed in livestock production, value of livestock investments, and access to technical assistance services were used. The model was statistically significant, and the production factors explained 84.54% of the changes in cattle production value. Land and capital factors contributed the most to the determination of production value. On the other hand, labor contributed the least. Cattle production shows increasing returns to scale, indicating the possibility of reducing average production costs by intensifying the use of the available production factors
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JEL Codes: *C20, D24, Q12*

1. Introduction

Cattle production systems involve a combination of several production factors that can be aggregated into three groups: land, represented by native and cultivated pasture areas; labor, composed of human resources that perform the various management practices in the production units; and capital, represented by machines, equipment, facilities, and technological innovations in the areas of genetics, health, and nutrition, among others.

In the Brazilian Amazon, cattle ranching is one of the most important economic activities and has strong representation in the use of production factors and the composition of agricultural production value. In 2015, beef and milk production accounted for 27.2% of regional agricultural production value, surpassing only the soybean crop, which contributed 34.4% (MAPA, 2016).

The regional herd is 84.2 million head, 39.1% of the national total, and the activity is responsible for the main form of land use in the region, approximately 63%, occupying an area of 47.98 million hectares (Almeida et al., 2016; INPE, 2016; IBGE, 2016a). Livestock also accounts for 42% of employed persons and 54.53% of the investment balance in the agricultural sector (IBGE, 2016b; BACEN, 2016).

The relationship between the use of these factors and the generation of products (meat, leather, and milk) can be determined by estimating a production function, one of the central elements of production theory. A production function is defined by the maximum product level that can be obtained for each combination of production factors used (Beattie & Taylor, 1985; Heathfield & Wibe, 1987; Rushton, 2009; Costa et al., 2015).

From the production function it is possible to define the production stage and indicators of technical and economic efficiency in the use of these factors, considering the current level of technology and management. In this paper, we estimate a Cobb-Douglas-type production function, a model that has already been employed in several studies on agricultural and forestry activities in Brazil (Oliveira & Marques, 2002; Soares, Silva & Lima, 2007; Strassburg, Oliveira, Piacenti & Piffer, 2014; Costa et al., 2015).

In the Brazilian Amazon, livestock production systems are associated with deforestation, soil degradation and burning, due to extensive and low-productivity production (Santana et al. 2011; Santana et al., 2016; Santos et al., 2017). Dairy farming, on the other hand, has great potential for sustainability of small production units, but there is no study on the economic efficiency of these production systems.

In this paper, the objective was to evaluate the influence of production factors (pasture, labor and capital) and access to technical assistance services on cattle production gross value in the Amazon and to determine the efficiency of allocation of these production factors.

2. Method

2.1. Study Area and Data Used

The database used in the study was obtained from the 2006 Agricultural Census of the Brazilian Institute of Geography and Statistics, published in 2012 (IBGE, 2016b). These data therefore reflect the technological level of cattle ranching in the first decade of the 21st century. Data from cattle production gross value, total pasture area, people employed in cattle ranching and investment value made in cattle raising were collected from 348 of the 775 municipalities that make up the Brazilian Amazon.

Municipalities were selected for production function estimation on the basis of the cattle farming technology index (ITPEC), estimated according to Santos et al. (2017). The technological levels of these 348 municipalities are classified as medium and high, and they also represent a high proportion of the regional livestock, accounting for 73% of pasture areas, 74% of herds and 78% of the regional cattle production value (MAPA, 2016; IBGE, 2016a, IBGE, 2016b).

2.2. Theoretical Model

Agricultural production is a biological and economic process that requires producers to be able to combine production factors in order to generate products for the consumer market. Cattle ranching involves the combination of factors such as land for pasture formation and herd feeding; labor for the execution of different herd management practices; and capital, composed of the infrastructure of machines, equipment, facilities, and technologies.

The analysis of this production process requires knowledge of quantitative relations between the production factors and the total product generated. This is possible through a production function that enables the mathematical specification of the various production possibilities for each level of factor use (Beattie & Taylor, 1985; Heathfield & Wibe, 1987; Rushton, 2009). Mathematically, the production function can be represented by:

$$Y = f(X_1, X_2, \dots, X_n) \quad (1)$$

Where Y is the dependent variable represented by total cattle production and Xi are the independent variables that correspond to the production factors.

From the production function, it is possible to determine the efficiency indicators in the allocation of factors in this economic activity. The first one is the average product of each factor that is calculated by dividing the total product (Y) by the respective quantity used of each input (Xi). Another indicator is the marginal product, which is obtained by the partial derivative of the production function in relation to factor Xi. It is also possible to determine the production's partial elasticity of each factor Xi from the division between the marginal product and the average product of the respective production factor (Debertin, 1986; Santana & Khan, 1990; Santana, 1992).

The production's partial elasticity value quantifies the variation of production caused by variations in the use of factors and allows us to indicate at what stage production is being performed, as well as the level of economic rationality of the production process. Therefore, if the partial elasticity coefficient is greater than 1, production is being performed at stage I, which corresponds to increasing average factor yields. If it is between zero and one, production is occurring in stage II, or the rational stage of production, corresponding to decreasing average yields. If the coefficient is negative, production is occurring in stage III, which means that the use of additional factor units causes a decline in total output due to the law of decreasing marginal yields. Therefore, from the perspective of economic efficiency, production must take place in stage II, as stages I and III are considered irrational.

Thus, we can analyze the degree of efficiency of producers in factor allocation and make suggestions to guide their decisions in order to combine factors with technology, increase productivity and economic efficiency of cattle production systems in the Brazilian Amazon.

2.3. Econometric Model

The general model of Cobb-Douglas production function used for the analysis of cattle ranching in the Amazon is specified below:

$$VBPB_t = AP_t^a L_t^b K_t^{c+dT} e_t \quad (2)$$

Where:

VBPBt = gross value of cattle production in Amazon municipalities, in thousands of R$;

Pt = total pasture area in Amazon municipalities, in hectares;

Lt = persons over 14 years of age employed in cattle ranching establishments in Amazon municipalities;

Kt = value of investments made in cattle ranching establishments in Amazon municipalities, in thousand R$;

Tt = access to technical assistance services by cattle-raising establishments in Amazon municipalities, in percentage;

A = efficiency parameter;
et = random error.

For the econometric estimation effect of equation parameters, the model was linearized by applying the natural logarithm (ln). Thus, the econometric model was as follows:

$$lnVBPB_t = lnA + alnP_t + blnL_t + clnK_t + dTlnKt + u_t \tag{3}$$

According to production theory, the parameters are expected to be positive and meet the following assumptions: (a) an increase (decrease) in pasture area tends to increase (reduce) the production value; (b) an increase (decrease) in employed labor tends to increase (reduce) the production value; (c) an increase (decrease) in capital tends to increase (reduce) the production value; and (d) the access to care services has a positive effect on the capital use and contributes to the increase in the production value.

The model was estimated by Ordinary Least Squares (Greene, 2003; Gujarati & Porter, 2008). Data were stored in a LibreOffice spreadsheet and later exported and analyzed in the Free Software Foundation's GNU Regression, Econometrics and Time-series Library (GRETL) (FSF, 2017). From the results obtained, the values of the average and marginal products, production's partial elasticities, returns to scale and the marginal rate of labor substitution by capital were determined.

The average product value of a production factor (VPMe) is given by the ratio between the cattle production gross value and the factor (pasture, employed persons, or capital). The function's partial derivative that is related to a specific factor gives the factor marginal product value (VPMg), *ceteris paribus*.

The partial elasticities of production are obtained from the ratio between relative changes in the cattle production gross value and factors. In other words, they measure the sensitivity of the production value in relation to changes in the level of factor utilization. Since the Cobb-Douglas function is expressed in logarithmic form, elasticities are given directly by the regression coefficients associated with each factor.

In Cobb-Douglas type production functions, the return-to-scale parameter (G) is given by the sum of partial elasticities of production of factors included in the production function. Thus, depending on the G values, increasing returns to scale (G > 1), constant (G = 1) or decreasing (G < 1) can be obtained.

Factors may exhibit substitution relations within production systems, and the most common relationship is the substitution of labor for capital. The indicator that evaluates this relationship is the marginal rate of labor substitution by capital, which indicates the amount of capital needed to compensate for the reduction of a job while keeping the quantity produced constant. It is obtained by dividing the value of labor marginal product and capital marginal product.

The formulas used to calculate the indicators are presented below:

a) Pasture average product value:

$$VPMeP_i = \frac{VBPB_i}{P_i} \tag{4}$$

b) Labor average product value:

$$VPMeL_i = \frac{VBPB_i}{L_i} \tag{5}$$

c) Capital average product value:

$$VPMeK_i = \frac{VBPB_i}{K_i} \tag{6}$$

d) Pasture marginal product value:

$$VPMgP_i = a \times \frac{VBPB_i}{P_i} \tag{7}$$

e) Labor marginal product value:

$$VPMgL_i = b \times \frac{VBPB_i}{L_i} \tag{8}$$

f) Capital marginal product value:

$$VPMgK_i = (c + dT) \times \frac{VBPB_i}{K_i} \tag{9}$$

g) Partial elasticities of pasture production, labor and capital: a, b and c

h) Returns to scale: G = a + b + (c + dT)

i) Marginal replacement rate between labor and capital:

$$TMSL, K = \frac{VPMgL_i}{VPMgK_i} \tag{10}$$

3. Results and Discussion

The econometric results of the beef cattle production function in the Amazon are presented in Table 1. The F test was significant at the 1% probability level and the coefficient of determination indicates that 84.54% of the total variation in the cattle production gross value occurred due to changes in independent variables. There was no serial correlation problem in the residues, since the data are of the cross-sectional type, which was confirmed by the Durbin-Watson test. White's heteroscedasticity test indicated that the residues are homoscedastic and linear combinations between the independent variables were not identified either, since the Inflationary Variance Factor of all independent variables was less than 10. The coefficients of independent variables showed signs consistent with the production theory and were significant at 1% by Student's t-test. These results validate the use of the model for the purpose of economic analysis.

Table 1. Adjustment results for the Cobb-Douglas production function of cattle ranching in the Brazilian Amazon

Variable	Coefficient	Standard Error	T-test
Constant	-0.1654^{ns}	0.3070	-0.5389
Pastures	0.3640*	0.0403	9.0336
Job	0.3014*	0.0527	5.7152
Capital	0.3340*	0.0421	7.9359
Interaction between capital and technical assistance	0.1039*	0.0284	3.6789
R-square	0.8454		
R-square adjusted	0.8436		
F test	468.8656*		
Durbin-Watson	2.0406		
White's test	54.73		

Source: Research data.

Note: (ns) not significant, (*) indicates significance at the 1% probability level.

Since the function was specified in logarithmic form, the estimated coefficients can be interpreted directly as partial elasticities of production. All coefficients were positive, significant and less than one, meeting the assumptions of production theory. Thus, percentage increases in the use of all factors imply a less than proportional increase in the cattle production gross value. Thus, these factors of production are being used in the production rational region (stage II).

The production elasticity of the land factor represented by pasture areas was 0.3640, indicating that a 10% increase in pasture areas would provide a 3.64% increase in the cattle production gross value in the Brazilian Amazon, *ceteris paribus*. Regarding the factor of labor production, it is observed that each percentage increase in the amount of labor implies an increase of 0.3014% in the production value and, in the case of capital, this increase is 0.3340%. These results indicate that producers, given the state of the art (level of knowledge and technology) are allocating factors in a technically efficient manner and thus contributing to maximize the production value. It remains to be seen, however, whether these utilization levels are achieving maximum economic efficiency.

The coefficient of the variable that expresses the interaction between capital and access to technical assistance services was positive and significant, confirming the hypothesis that technical assistance increases the capital efficiency and contributes to the increase in the production value. The capital production elasticity, considering access to care services, was 0.3585, which represents a 7.3% increase compared to the coefficient without the technical assistance effect (0.3340). A priori, this seems to be a small effect; however, it is justified by the fact that in the survey reference year only 23.57% of the livestock establishments in the municipalities surveyed received the provision of some technical assistance service. That is, in general terms, access to this service is still low, which limits the impact on the capital efficiency and production systems.

In the Cobb-Douglas production function, the partial elasticity coefficients also reflect the relative share of each factor in the livestock production gross value. Thus, it can be inferred that the largest relative participation is due to pasture areas (35.6%), followed by capital (35%) and, to a lesser extent, labor (29.4%). This distribution reflects well the technology level of cattle ranching in the Brazilian Amazon, which still depends heavily on the incorporation of new pasture areas.

In this regard, in 2006, the 348 municipalities analyzed constituted 74% of the cattle herd and 58.7% of accumulated deforestation, 414 thousand km^2. But as the pasture stocking rate is low, only 0.89 UA/ha/year of livestock extension maintenance depends on the deforestation dynamics. Thus, in 2015, the picture remained virtually unchanged, with these municipalities accounting for 72.7% of the herd and 57.6% of accumulated deforestation (IBGE, 2016b; INPE, 2016).

The returns to scale are obtained by summing the coefficients of the partial elasticities of variables. It is an indicator that measures the relationship between the increase in the use of all factors in the same proportion and the corresponding increase in the cattle production value. The coefficient value was 1.024, which represents increasing returns to scale, i.e., if the use of all factors is increased by 10%, combined with technical assistance, the cattle production value tends to increase by 10.24%, *ceteris paribus*.

This result indicates that average production costs tend to decrease as producers intensify their use of factors. This result is influenced by capital and its interaction with technical assistance services, because in highly commercial livestock, such as the municipalities analyzed, many of the inputs that make up the structure of production costs (seeds, salt, feed, vaccines, fertilizers, and correctives) are purchased off-site, and require more skilled labor and a range of machines, equipment, facilities, and improvements that require minimal scale to be efficient.

The average production in pasture areas was R$ 132.78/hectare/year (Table 2). Considering the arroba average price of R$ 45.22 in 2006, and a carcass yield of 50%, the average product corresponds to 5.87 arrobas of live cattle/hectare/year. The highest average product was obtained in Mato Grosso (6.61 arrobas/hectare/year) and the lowest in Amazonas (3.44 arrobas/hectare/year). The average product of capital invested in livestock was 4.71. In 110 municipalities, 32% of the total analyzed, this indicator was higher than the regional average. These municipalities are located in the states of Mato Grosso (37), Tocantins (37), Pará (13), Rondônia (11), Maranhão (9), and Acre (3).

Table 2. Efficiency Indicators of Cattle Ranching in the Brazilian Amazon

Indicator	Mean (R$)	Standard deviation (R$)	Coefficient of variation (%)
VPMe - Pastures	132.78	119.10	89.70
VPMe - Labor	4,837.35	4,597.82	95.05
VPMe - Capital	4.71	4.29	91.15
VPMg - Pastures	51.23	45.95	89.70
VPMg - Labor	1,266.90	1,204.17	95.05
VPMg - Capital	1.54	1.37	89.24

Source: Research data.

Regarding labor productivity, the average was R$ 4,837.35/year. Considering that the minimum wage in 2006 was R$ 350.00, this implies a remuneration of 1.15 minimum wage per person employed in livestock. Only 49 of the 348 municipalities analyzed (14%) had an average remuneration above two minimum wages. These municipalities are located in the states of Mato Grosso (16), Tocantins (13), Rondônia (8), Pará (7), and Maranhão (5). This low pay combined with the livestock work characteristics, which requires physical effort and exposes the worker to risks in the management of animals, in addition to rural migration and the predominance of informal relationships may explain the reduction in rural workforce in recent decades.

The results of marginal factor productivity indicate that each unit increase in pasture areas generates an additional value of R$ 51.23 in the livestock production gross value. In terms of live weight, this corresponds to 2.27 arrobas for each additional hectare of pasture. The state with the highest marginal productivity of pastures was Mato Grosso, with 2.55 arrobas/ha, followed by Pará (2.39 arrobas/ha), Rondônia (2.20 arrobas/ha), Tocantins (2.10 arrobas/ha), and Maranhão (1.93 arrobas/ha).

The average marginal labor productivity was R$ 1,266.90 for each additional livestock worker. Regarding capital, the highest marginal productivity was observed in the Tocantins, Pará, Maranhão, Mato Grosso, and Rondônia states, respectively, whose values were higher than the regional average of 1.54. That is, in these states each real invested in livestock generates an increase of over R$ 1.54 in the cattle production value.

The marginal rate of labor substitution for capital is given by the relationship between the marginal labor products and capital. Based on the data in Table 2, this amount was R$ 822.66, i.e., this is the amount of resources needed to replace a unit of labor in livestock, keeping the production level constant.

Table 2 also shows the coefficients of variation of the average and marginal products, and the values are high and above 89%. This indicates high heterogeneity in cattle production systems regarding the efficiency in the allocation of production factors and the high levels of uncertainty that may be associated with it.

4. Conclusion

The results of the work indicate that the estimated production function is adequate to evaluate the efficiency of production factors of cattle ranching in the Brazilian Amazon, and the variables included in the model explain 84.54% of the changes in the cattle production gross value.

The partial elasticity coefficients indicate that the factors are being used rationally, and access to technical assistance services positively influences capital efficiency. Pastures and capital were the factors that contributed the most to the production value, and the smallest factor was the labor factor. This result shows that livestock growth is still based on the expansion of pasture areas and, therefore, is associated with deforestation.

Cattle ranching shows increasing returns to scale, indicating that average production costs can be reduced by intensifying the use of available inputs and scaling up.

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