Economía Agraria y Recursos Naturales. ISSN: 1578-0732. e-ISSN: 2174-7350. Vol. 22,1. (2022). pp. 69-88

Rangeland cattle production in Uruguay: Single-output versus multi-output efficiency measures

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ABSTRACT: Rangeland cattle production is the largest agricultural sector of Uruguay. Ranches produce up to three products (beef, sheep-meat, and wool) usually combined into an equivalent meat (EM) index. The objective is to compare the empirical results from the estimation of a single output stochastic production frontier (SPF) and a multi-output stochastic ray frontier (SRF) to provide insights on the use of the EM index to evaluate ranches performance. Results show similar efficiency scores. The average level of TE is 0.769 for the SPF and 0.779 for the SRF. We cannot discard EM index as a simple measure of combined production.

Producción ganadera pastoril en Uruguay: medidas de eficiencia multiproducto versus uniproducto

RESUMEN: La producción ganadera es el principal sector económico del Uruguay. Los establecimientos producen hasta tres productos (carne vacuna, ovina y lana) usualmente reportados en un indicador de carne equivalente. El objetivo es comparar resultados empíricos de una estimación con frontera estocástica de producción (SPF) y una frontera estocástica de rayo multiproducto (SRF) para aportar información en el uso del indicador para evaluar el desempeño de los establecimientos. Las estimaciones de ET son muy similares, 0,769 (SPF) y 0,779 (SRF), indicando que no hay evidencia suficiente para no usar el indicador de carne equivalente para evaluar el desempeño de la ganadería.

KEYWORDS / *PALABRAS CLAVE*: Beef, production, rangeland cattle, stochastic production frontier, stochastic ray frontier / *carne, producción, ganadería, fronteras de producción estocásticas, fronteras de rayo estocásticas*.

JEL classification / *Clasificación JEL*: D24, Q10.

DOI: https://doi.org/10.7201/earn.2022.01.04

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Acknowledgement: The authors want to thank the Instituto Plan Agropecuario for making the data available for research purposes. García-Suárez and Pérez-Quesada share senior authorship.

Cite as: García-Suárez, F., Pérez-Quesada, G. & Molina, C. (2022). "Rangeland cattle production in Uruguay: single-output versus multi-output efficiency measures". *Economía Agraria y Recursos Naturales,* 22(1), 69-88. doi: https://doi.org/10.7201/earn.2022.01.04

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Received on November 2020. Accepted on January 2022.

1. Introduction

Rangeland cattle production is the largest agricultural sector of Uruguay. Based on natural pastures, grazing is usually done by cows and sheep resulting in three main products: beef, sheep meat, and wool. Ranching has shown a slow improvement in productivity over the last three decades. The combined production of beef, cattle and sheep (including meat and wool) has improved productivity by 1.7 % on average between 1981-2010 (Bervejillo *et al.,* 2011). A widely used index of the sector's performance is the equivalent meat produced by hectare (EM/ha). The evolution of EM/ha has undergone slow progress over the years, from 86 kg/ha in triennium 1994-1996 to 95 kg/ha in 2011-2013 (Bervejillo, 2019). Focusing on meat production, Aguirre (2018), reports values between 70.8 and 80.2 kg/ha over 8 years between 2010 and 2017 with a mean of 75 kg/ha.

The Equivalent meat (EM) index is a homogeneous productivity index of the rangeland cattle production that summarizes the production of cow meat, sheep meat, and wool. It allows for comparison between meat and wool production combined into a unique unit (INIA, 2018). The EM index has been used to compare ranches' performance as a simple tool to avoid differences in cow/sheep endowment. Ranching systems in Uruguay have combined cow/sheep grazing exploiting the complementation between species combining different endowment relations. Therefore, it is relevant to understand how grazing competition/complementation occurs on the energetic demand level.

The EM index, however, has been under scrutiny given the assumptions it makes to compare wool and meat are based on energy requirements (Oficialdegui, 1984), ignoring the complexity that different endowment relations of cow/sheep and races produce as output. The main objection is that cow/sheep grazing is a complementary rather than a competitive grazing behavior. Even though energy requirements are comparable, grazing occurs at different heights meaning different usage and not completely substitution between sheep meat and wool for beef meat. To some extent, there is a substitution effect between the two species but also a complement on grass usage. Moreover, the conversion factor used to obtain the index was estimated using data collected during the 1970 Uruguay Census of Agriculture. Hence, deep changes that have occurred in the production structure, both in the size of sheep flock and breed, are not captured by the factor. A deep discussion about synthetics indexes can be found in Álvarez (2013).

The objective of this study is to estimate the technical efficiency (TE) of cattle ranches and provide empirical evidence on whether it is appropriate to use the EM index to evaluate the performance of cattle ranches in Uruguay. To address the objective, we estimate two models: 1) a single output stochastic production frontier (SPF) model where different outputs (beef, sheep-meat, and wool) are combined using the EM index; and 2) a multi-output (beef, sheep-meat, and wool) stochastic ray frontier (SRF) model. We compare the technical efficiency scores obtained from the two models to contribute to the knowledge of ranches' efficiency performance and to better understand the relationship between the resources used in beef cattle production and the obtained output. The data used for empirical estimation is an unbalanced panel that is derived from yearly farm management records collected by ‘Instituto Plan Agropecuario’ (IPA). The data collected by IPA is widely used to calculate indicators of cattle sector performance across the country. We find that the average level of TE is 0.769 for the single output SPF and 0.779 for the multi-output SRF, suggesting that ranches can expand cattle production using the current level of inputs and technology. The comparison between the single output SPF and the multi-output SRF leads to very similar efficiency results. So even when the EM index simplifies the analysis, we cannot discard its use as a simple measure of combined production.

In general, efficiency studies are focused on unique output farms or single crop analysis. When multi-output is present, alternatives are non-parametric approaches as DEA or parametric approaches as output distance functions. The latter approach is not well-suited for cases in which some outputs present zero values (Henningsen *et al.,* 2015). The multi-output stochastic ray frontier offers an alternative to overcome this problem. There are two conditions to avoid the use of a metafrontier analysis to consider the multiple output environment in our study. First, we have a low number of ranches, limiting the tools to be applied to control for potential heterogeneity of the database. Second, we deal with some of the ranches having zero sheep production. Typically, a ranch combines beef cattle and sheep in a mixed grazing scheme, but some have abandoned the sheep production.

The SPF methodology has been widely applied to measuring technical efficiency in studies related to the agricultural sector (Coelli & Battese 1996). Most of the studies, however, have been focused on dairy farms, and only a few of them on beef cattle production. (e.g., Trestini, 2006; Qushim *et al.,* 2013; Gatti *et al.,* 2015). The stochastic ray production model has been applied more often in multi-output settings, such as healthcare, fisheries, oil and gas industries, and sawmilling (e.g., Löthgren, 2000; Fousekis 2002; Yin *et al.,* 2017; Managi *et al.,* 2006; Niquidet & Nelson 2010). To our knowledge, there are no previous studies which estimate cattle production efficiency using stochastic ray frontiers.

Our study contributes to the rangeland cattle production efficiency and productivity literature available in Uruguay because it applies the SPF methodology for panel data over ranches records in a way that has not been done previously. Moreover, we incorporate multi-outputs into the analysis of rangeland cattle production using the stochastic ray frontier approach. We also contribute to the analysis on cattle ranch performance done by public institutions and farmers organizations providing evidence on the use of the EM index.

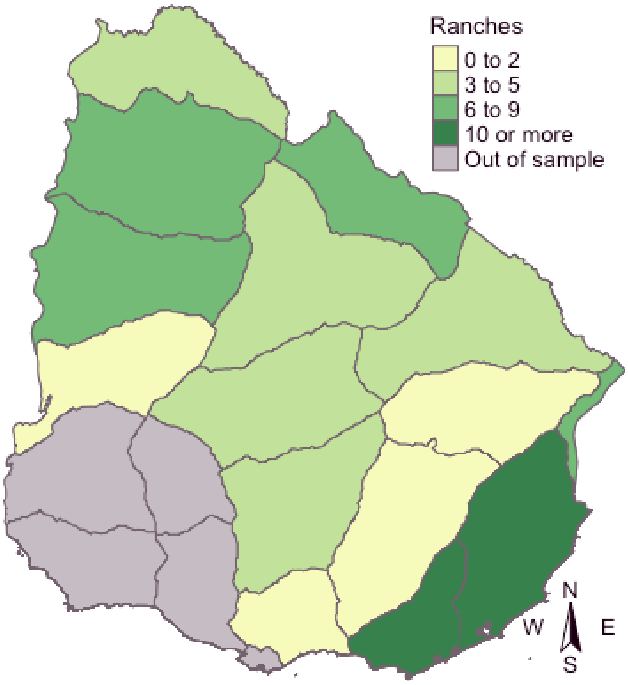
2. Methods

2.1. Data

The database available consists of an unbalanced panel of 70 farmers over 3 years, totaling 201 individual observations. Figure 1 shows the department locations of the ranches in our sample.

FIGURE 1

Department locations of the ranches in our sample



Source: Own elaboration.

Summary statistics of variables that describe the sector are presented in Table 1. Equivalent meat by hectare (EM/ha) assumes that the meat and wool production costs are based on the energy requirements for each animal. It is constructed as the sum of beef meat, sheep meat, and wool converted by a factor of 2.48. Therefore, this factor widely used in Uruguay, assumes that the production of a kilogram of wool requires the energy needed to produce 2.48 kilograms of meat[1]. All meat variables are constructed as:

Meat production = Total sales - Total purchases ± Stock difference

As Table 1 shows the ranches included in the database are heterogeneous. For example, the range of land in hectares runs from 79 to 10,497 ha. This results in different strategies of production that might explain differences in our estimation. Given that some ranches do not produce sheep, the minimum wool production is zero. The negative minimum value for ovine meat production is explained by a very negative year in terms of stock changes due to low lambing. Improved pastures reflect the percentage area with cultivated pastures or improved natural grass (exotic species or fertilization). The mean value of 16.7 % does not fully capture the high variation of improved pastures (from 0 to 99 %). This variable has the weakness of aggregating different types of practices that are not always fully comparable. In the last two columns of Table 1, we provide a comparison between the database and the country's level data. Even when the ranches considered in this study are a small sample to be representative of the national level, relative measures of endowment, improved pastures, and equivalent meat production by hectare show that on average ranches are not different from the national average. Based on these descriptive statistics we consider that our results are useful for the ranches performance discussion.

Stocking reflects the number of animals by hectare, bovine and ovine, by feed intake capacity relative to the necessary grass intake made by a pregnant cow weighing 480 kg. Each stocking category is measured relative to this pattern, and it is presented as units per hectare. Labor measures the number of equivalent workers to a 2,100 hour per year worker. Total expenditure is the sum of pasture, grain feed, and veterinary expenditures. Pasture expenditure reflects the yearly expenditure in improved pastures. Grain-feed accounts for the expenditure in grain for feeding cattle. Veterinary inputs represent the expenditure on veterinary products.

Improved pastures reflect the percentage of area that has some level of intervention. It ranges from fertilizer application to natural grassland to completely cultivated pastures. Most of the ranches have less than 40 % of the area under some type of improvement and there is not a clear and straight definition for each type of improvement. Therefore, improved pastures is a variable that is not a good fit explaining production differences.

Of the 70 ranches in the data set, there are 37 cow/calf producing systems characterized by a herd of cows and the main products are calf for finishing and cows for slaughter. There are 33 complete cycle systems in the data set that produce steers for industry from their calf production.

To measure efficiency, we must consider two weaknesses. First, the main input of the system, natural pasture, is not a marketable input but a natural resource making the efficiency estimation a difficult task. The second weakness comes from the lack

[1] EM/ha = bovine meat (kg)/ha + ovine meat (kg)/ha + wool (kg) x 2.48/ha.

of consistent and widely collected information on production input decisions. The IPA collects management information from cattle ranches and presents management indicators every year. However, ranchers' participation is voluntary and depends upon the presence of an agronomist processing data. Moreover, it is important to note that these ranchers do not have a special management system.

TABLE 1

Summary statistics of selected variables (n = 201)

Variables	Units	Mean	Std. Dev.	Min	Max	Units	Database Total*	Country Total*
Total EM	kg	104,949	128,226	8,505	934,233	000' ton	7.03	1232
Total ovine meat	kg	8,906	15,208	-1,838	104,970	000' ton	0.6	62
Total wool	kg	3,293	5,373	0	38,839	000' ton	0.2	28
Total bovine meat	kg	87,713	105,422	7,851	750,659	000' ton	5.9	1101
$\|\|y\|\|$	kg	88,790	106,175	7,856	756,000			
Labor	Eq. workers	3.3	2.9	0.3	20			na
Total expenditure	$	18,340	27,727	252	240,250			na
Bovine stock	UG	679	803	56	5,861			
Land	ha	1,077	1,365	79	10,497	000' ha	216.5	14123
EM/ha	kg/ha	99.5	27	26	178	kg/ha	99.5	87.2
Improved pastures	%	16.7	18.1	0	99.2	%	16.7	16.8
Stocking	UG/ha	0.83	0.14	0.52	1.31		0.83	0.69

* *Total average value in the database and at the country level for the three-year period, except for improved pastures presented as average values.*

Source: Own elaboration.

2.2. Empirical Model

The Stochastic Frontier Analysis (SFA) independently and simultaneously proposed by Aigner *et al.* (1977); Meeusen & van den Broeck (1977), is the underlying methodology of single output SPF and multi-output SRF. We introduce SRF to have measures of product response besides technical efficiency. The SPF is used as a benchmark for comparison using a widely traditional product index for cattle production in Uruguay.

Following Battese & Coelli (1992) and using a translog (TL) specification, the single output SPF model (Mod 1) is represented as:

$$\ln y_{it} = \beta_0 + \sum_{j=1}^{4} \beta_j \ln x_{jit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jk} \ln x_{jit} \ln x_{kit} + \lambda_1 d_{1it} + \lambda_2 d_{2it} + \lambda_3 t + v_{it} - u_{it} \quad [1]$$

where the sub-indexes *j* represents the *j-th* explanatory variable, *i-th* is a specific farm and *t* is the time period. The dependent variable y_{it} represents total equivalent meat in *kg*. The inputs included in the analysis are labor (LB), total veterinary, pasture, and grain-feed expenditure (EX), bovine stock (UG), and total land used for cattle production (LD). Given that the estimation is performed in levels, stocking is included as total bovine-cattle stock units and not in the traditional way of measuring carrying capacity. To consider differences in production systems we include a dummy variable d_{1it} that equals 1 if it is a complete cycle system, and an ordinal variable that accounts for the number of grazing fields, d_{2it}. The number of fields that the ranch is diving into defines the way stocking is managed. When the number of fields is low there is a tendency of continuous grazing that ultimately affects grass production, which in turn results in lower productivity. Finally, a tendency variable (*t*) is included to capture technological change. v_{it} is the random error assumed to be distributed independently and identically following $N(0, \sigma_v^2)$. The term is the non-negative random error that captures technical inefficiency.

The multi-output SRF was proposed by Löthgren (1997) to accommodate the cases where multi-output cannot be analyzed in a dual form and to handle zero values in the output quantities. According to Henningsen *et al.* (2015), the SRF proposed by Löthgren (1997) outperforms the approach presented in Coelli & Perelman (1996) in cases where zeros are present in some outputs.

The multi-output SRF model (Mod 2) is also defined as a TL function according to Löthgren (1997):

$$\ln\|y_{it}\| = \beta_0 + \sum_{j=1}^{4}\beta_j \ln x_{jit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4}\beta_{jk}\ln x_{jit}\ln x_{kit} + \sum_{m=1}^{2}\alpha_m\theta_{mit} + \frac{1}{2}\sum_{m=1}^{2}\sum_{l=1}^{2}\alpha_{ml}\theta_{mit}\,\theta_{lit} + \sum_{m=1}^{2}\sum_{j=1}^{4}\delta_{mj}\theta_{mit}\ln x_{jit} + \lambda_1 d_{1it} + \lambda_2 d_{2it} + \lambda_3 t + v_{it} - u_{it} \quad [2]$$

where $\| y_{it} \|$ is the Euclidean output norm for the *i-th* farm at time *t*. The output vector is defined by (y_1, y_2, y_3) where, y_1 is total ovine meat, y_2 is total wool, and y_3 total bovine meat. The explanatory variables used are the same as in the single output model, and d_{1it}, d_{2it}, and the tendency variables are also included. v_{it} is the random error assumed to be distributed independently and identically following $N(0, \sigma_v^2)$. The term u_{it} is the non-negative random error that captures technical inefficiency.

To calculate the polar coordinate angles (θ) we follow the formula proposed by Henningsen *et al.* (2017), which avoids the rounding errors of the recursive structure proposed by Löthgren (1997). The formula for θ's calculation is:

$$\theta_m(y) = arccos\left(\frac{y}{\sqrt{\sum_{j=m}^{M} y_j^2}}\right) \quad [3]$$

In both models (1 and 2), u_{it} follows a half-normal distribution N^{+} (0, σ_u^2). A more detailed analysis of inefficiency error term distributional forms can be found in Kumbhakar & Knox Lovell (2000). According to Battese & Coelli (1992), u_{it} is treated as time-variant depending on specific function as follows:

$$u_{it} = \eta_{it} u_i = \{exp[-\eta(t - T)]\} u_i$$

Inefficiency variation comes from the interaction between time and an unknown parameter (η). The sign of η defines the inefficiency variation. If η is positive this means that TE is increasing over time. If η is equal to zero, this means there is no change in efficiency; and if η is negative, TE decreases over time.

Kumbhakar *et al.* (2014) discuss that Battese & Coelli (1992) is a restrictive model since the inefficiency only varies over time following an exponential function. A more flexible model can be implemented if inefficiency is defined as a function of exogenous variables that explain the inefficiency variation (Battese & Coelli, 1995). Technical efficiency is associated with the role of management in the production process and the farmers' ability to use the inputs to obtain the maximum output. In our database, we have three dummy variables related to a farm's management capacity: if a farmer pays for veterinary or agronomic assistance, if a farmer is part of a group that may give him alternative support, and if a farmer uses gestation diagnosis techniques. We model the inefficiency term using these variables but none of them were significant.

Both Battese & Coelli (1992) and Battese & Coelli (1995) are models that mix inefficiency with specific firm effects (Kumbhakar *et al.,* 2014). Alternative approaches to surpass this limitation were proposed by Green (2005a; 2005b), considered as 'true-fixed' and 'true-random' effects models. Given the nature of our panel structure (unbalanced and short), these two models do not fit properly.

We use the maximum likelihood (ML) method to estimate the parameters in the single output SPF and the multi-output SRF. According to Battese & Corra (1977), the log-likelihood function is parameterized in terms of the variance ratio $\gamma = (\sigma_u^2)/\sigma^2$, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$. The variance ratio γ reflects which part of the total variance in the model is attributed to technical inefficiency variance. All the estimations were done using the package Frontier for R which provides ML estimates for the parameters.

To obtain an estimation of firm-specific technical inefficiencies, we follow the approach proposed by Jondrow *et al.* (1982). He used the mean or the mode of the conditional distribution (u_{it}/ϵ_{it}) where $\epsilon_{it} = v_{it} - u_{it}$ is the composed error. This idea was generalized to panel data models by Battese & Coelli (1988).

3. Results

Likelihood ratio tests were implemented to better understand the structure of production technology and the nature of technical inefficiency present in the two defined models, which share the same results. The test statistic LR = -2[ln($L(H_0)$-

$L(H_1))]$ where, $\ln(H_1)$ and $\ln(H_0)$ are the log-likelihood values under the alternative and the null hypothesis, respectively, follows the X^2 -distribution with degree of freedom equal to the number of restrictions imposed. To represent the frontier, we chose a Translog specification which is preferred over a Cobb-Douglas functional form for the two models defined. A likelihood ratio test (LR) was used to confirm which functional form fits the data significantly better. The null hypothesis that the restricted form of the Translog is suitable H_{01}: $\beta_{jk} = 0$, $j \leq k = 1 \ldots 4$, is rejected. The LR test results are presented in Table 2.

We also tested the varying nature of the model by looking at a ratio of variances. Under the null hypothesis (H_{02}: $\gamma = 0$ -no inefficiency) the test statistic follows a mixed X^2 -distribution (Coelli, 1995), and critical values can be obtained from Kodde & Palm (1986). The null hypothesis was rejected as the Table 2 shows. These results mean that both statistical noise and inefficiency are important for explaining deviations from the production frontier. Therefore, the stochastic production frontier and the stochastic ray frontier are more suitable than the OLS model.

TABLE 2

Likelihood ratio tests (5 %)

Null hypothesis	Test statistic	Critical value	Decision
Mod 1			
H_{01}: $\beta_{jk} = 0, j \leq k = 1 \ldots 4$	21.06	18.30	Reject
H_{02}: $\gamma = 0$	119.21	7.05	Reject
H_{03}: $\eta = 0$	18.91	3.84	Reject
H_{04}: $\lambda_3 = 0$	5.70	3.84	Reject
Mod 2			
H_{01}: $\beta_{jk} = 0, j \leq k = 1 \ldots 4$	53.71	32.70	Reject
H_{02}: $\gamma = 0$	108.19	7.05	Reject
H_{03}: $\eta = 0$	22.21	3.84	Reject
H_{04}: $\lambda_3 = 0$	6.07	3.84	Reject

Source: Own elaboration.

Since we have a 3-years panel structure, we tested the hypothesis of varying efficiency over time. That means testing u_{it} against u_i on the models. Given the LR test result, we rejected the null hypothesis of time-invariant inefficiency (H_{03}: $\eta = 0$).

Additionally, we tested neutral linear technological change using a LR test rejecting the null hypothesis of no technological change H_{04}: $\lambda_3 = 0$. Given the short and unbalanced panel data structure, the technical change appears to capture part of the variation of the data. Testing for non-constant, non-neutral technical change was not possible given the number of parameters involved and the length of the panel.

Table 3 includes estimates for the stochastic production frontier and stochastic ray frontier. We obtained an estimated γ equal to 0.931 and 0.941 in Mod 1 and Mod 2, respectively which confirms the importance of technical inefficiency in explaining deviations from the production frontier.

The two models exhibit differences if we consider the frontier's estimated coefficients. Mod 2 shows more significant coefficients and a larger log-likelihood value than Mod 1. There are 9 out of 18 significant variables in Mod 1 while in Mod 2 there are 18 significant variables out of 31 (Table 3). Regarding the labor variable, it is only significant in the interaction with total expenditure in Mod 1. Given the nature of the labor variable (total equivalent man workers), it is not surprising that it is not significant. This form of measuring labor does not capture differences in quality that can be better expressed in terms of labor expenditure. One might expect that better pay results in improved productivity or higher quality hiring.

The coefficient estimates of polar coordinate angle θ_2, θ_1^2 and most of the input-polar coordinate angle interaction variables are significant. Therefore, the output mix has effects on the frontier output norm for a given input vector.

The mean technical efficiency score is 0.769 and 0.779 for Model 1 and Mod 2, respectively. The difference is almost negligible, being the Pearson's product-moment correlation coefficient for technical efficiency scores equal to 0.957, and statistically significant. This result is consistent with the graphical relation between both TE estimates shown in Figure 2. Additionally, the difference between the mean technical efficiency scores is not significant (p-value = 0.5133).

Table 4 shows the summary statistics for TE estimates by year for both models. We can see that the statistics follow a decreasing trend in the two models, and mean TE reaches its maximum in the agricultural year 2013-2014. Therefore, the equivalent meat index is in some sense useful to compare ranch efficiency. Technical efficiency mean scores are in line with those obtained by Trestini (2006); Qushim *et al.* (2013) and are larger than those obtained by Gatti *et al.* (2015).

Technical change captured by the time trend results in a significant effect and shows a positive sign close to 5 % in both models. At the same time, the value of is negative equal to -0.254 and -0.251 in Mod 1 and Mod 2, respectively, meaning that technical efficiency is decreasing over time. This result explains that production measured as EM kg/ha is decreasing over the period, meaning that even when technical change appears to be positive, an increase in inefficiency offsets the improvement. Also, beef/cattle production based on natural pasture is largely dependent on net primary production (NPP), which is highly correlated with weather conditions. Figures 3 and 4 present the correlation between TE scores and equivalent meat by hectare by year for each model. As can be seen, the distribution of 2015/16 year values appear to be below the other two years showing consistency with the decreasing behavior of efficiency.

TABLE 3

Stochastic production frontier and stochastic ray frontier estimates

Variable	Mod 1 Coef.	Mod 1 Std. Err.	Mod 2 Coef.	Mod 2 Std. Err.
Intercept	6.981***	1.608	62.369***	24.021
LB	0.398	0.421	0.818	1.550
EX	-0.232	0.237	-2.597***	0.947
UG	3.097***	0.832	16.032***	4.009
LD	-2.248**	0.910	14.068***	4.074
θ_1			0.011	6.375
θ_2			-62.884**	32.023
LB^2	-0.053	0.107	-0.055	0.103
EX^2	-0.056	0.039	-0.079**	0.034
UG^2	0.624**	0.272	1.391***	0.496
LD^2	0.988***	0.310	1.642***	0.506
θ_1^2			-4.144**	2.032
θ_2^2			33.048	22.749
LB x EX	-0.085*	0.045	-0.021	0.043
LB x UG	0.201	0.130	0.273	0.178
LB x LD	-0.108	0.133	-0.254	0.188
LB x θ_1			-0.329	0.439
LB x θ_2			-0.032	1.114
EX x UG	-0.066	0.079	-0.274***	0.102
EX x LD	0.199**	0.083	0.392***	0.104
EX x θ_1			0.282	0.216
EX x θ_2			1.385**	0.704
UG x LD	-0.914***	0.253	-1.591***	0.462
UG x θ_1			2.456***	0.776
UG x θ_2			-9.713***	2.828
LD x θ_1			-2.334***	0.694
LD x θ_2			8.751***	2.640
θ_1 x θ_2			2.862	4.703
d_1	0.003	0.062	-0.009	0.061
d_2	-0.002	0.003	-0.002	0.003
Time trend	0.047**	0.020	0.046**	0.018
σ^2	0.217***	0.045	0.201***	0.038
γ	0.931***	0.018	0.941***	0.015
η	-0.254***	0.057	-0.251***	0.057
Mean TE	0.769		0.779	
LL-Value	62.22		80.10	

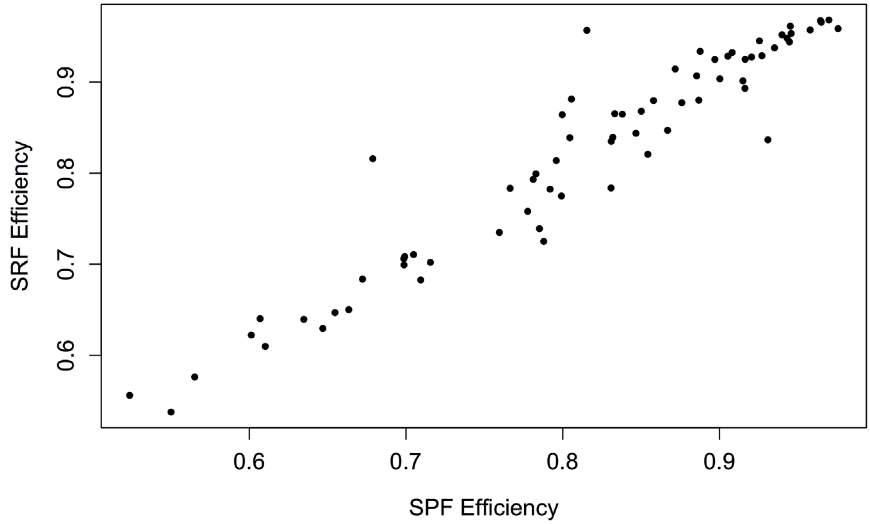
**** 1 % level of significance, ** 5 % level of significance, * 10 % level of significance.*

Source: Own elaboration.

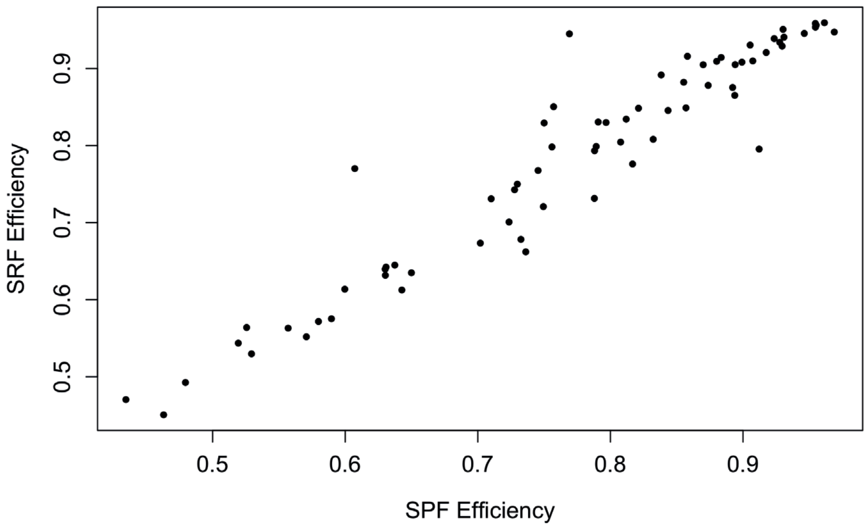
FIGURE 2

Technical efficiency scores for SPF and SRF; a) 2012/13, b) 2013/14, c) 2014/15

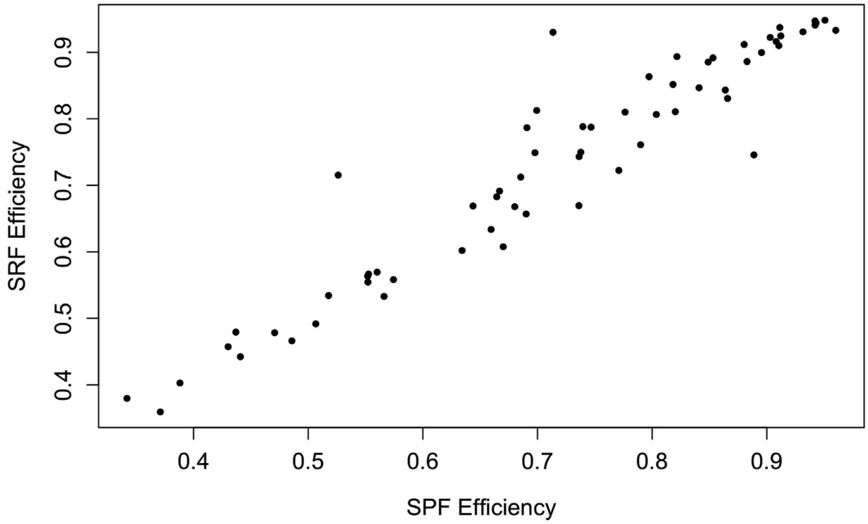
a) **2012/13**



b) **2013/14**



c) **2014/15**



Source: Own elaboration.

TABLE 4

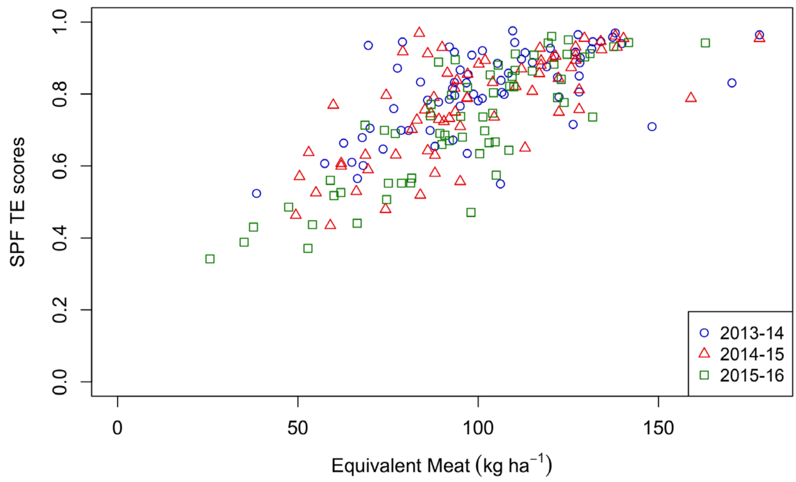
Summary statistics for technical efficiency estimates by year for models 1 and 2

Mod 1						
Year	Min	Q1	Median	Mean	Q3	Max
2013-14	0.524	0.716	0.832	0.813	0.915	0.976
2014-15	0.435	0.650	0.791	0.772	0.894	0.969
2015-16	0.342	0.570	0.736	0.717	0.865	0.960
Mod 2						
2013-14	0.538	0.725	0.844	0.820	0.928	0.968
2014-15	0.451	0.662	0.808	0.782	0.909	0.959
2015-16	0.359	0.586	0.750	0.730	0.889	0.948

Source: Own elaboration.

FIGURE 3

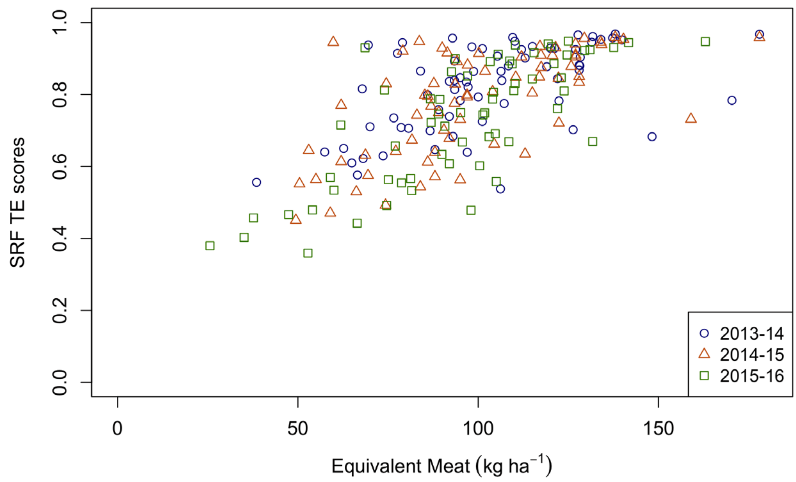
TE scores and equivalent meat (kg/ha) production by year for the single output SPF



Source: Own elaboration.

FIGURE 4

TE scores and equivalent meat (kg/ha) production by year for the multi-output SRF



Source: Own elaboration.

The output elasticity concerning the inputs and the polar coordinate angles are presented in Table 5. Of all input variables, the bovine stock has the highest effect on the dependent variable in each model. In Mod 1 bovine stock (UG) and land (LD) elasticities present the largest positive values. The elasticities mean that a 1 % increase in any of these variables results in an estimated increase in total equivalent meat of 0.507 % and 0.377 %, respectively. In Mod 2, bovine stock and land influence the Euclidean output norm. An increase of 1 % of these variables leads to an estimated increase in the output norm of 0.578 % and 0.309 %, respectively.

TABLE 5

Output elasticity with respect to the inputs and polar coordinate angles

Variable	Mod 1	Mod 2
LB	0.082	0.052
EX	0.070	0.088
UG	0.507	0.578
LD	0.377	0.309
θ_1	-	0.620
θ_2	-	3.919

Source: Own elaboration.

Considering polar coordinate elasticities $((\partial \ln(\|y\|))/(\partial \ln\theta_i))$, results show that for θ_1 is equal to 0.620, and for θ_2 is 3.919. The elasticity with respect to θ_1 represents the percentage change in the output norm with respect to a change in y_1 with fixed proportions of y_2 and y_3. The elasticity with respect to θ_2 represents the change in the output norm when y_1 remains constant. Unfortunately, there are no previous stochastic ray frontier studies in cattle system production to compare our results. Despite this, our elasticities results can be interpreted as in Niquidet & Nelson (2010); Yin *et al.* (2017). Being positive, both elasticity values reflect that changing the output mix from systems with wool-ovine orientation to meat-ovine orientation and more bovine specialized systems result in a higher output. The value of the elasticity with respect to θ_2 indicates that systems are highly responsive to reduced wool production in favor of bovine production with ovine meat being constant. These results are consistent with the bovine specialization of ranches in Uruguay over the last 20+ years and with the expansion of ovine meat specialization departing from multipurpose ovine breeds to meat-oriented breeds.

Since we have two types of ranches in the database (complete cycle vs cow/calf), it is interesting to analyze the efficiency scores by system type. The mean values of TE obtained from Mod 1 and Mod 2 are presented by type and year in

Table 6. On average, both systems show very similar efficiency results, which shows that ranchers choose the best system for the natural environment that they have available. Complete cycle systems are more associated with larger land size than cow/calf systems, but from an efficiency analysis, there are no differences between systems. Hence, the production system is not a significant determinant of efficiency performance.

TABLE 6

Mean value and standard deviation of technical efficiency estimates by production system and year

Mod 1 System	2013-14	2014-15	2015-16
Cow-calf	0.813 (0.124)	0.775 (0.149)	0.713 (0.177)
Complete cycle	0.812 (0.112)	0.769 (0.134)	0.722 (0.164)
Total	0.813 (0.117)	0.772 (0.142)	0.717 (0.170)
Mod 2 System	2013-14	2014-15	2015-16
Cow-calf	0.820 (0.127)	0.783 (0.152)	0.723 (0.181)
Complete cycle	0.820 (0.113)	0.780 (0.138)	0.738 (0.162)
Total	0.820 (0.119)	0.782 (0.144)	0.730 (0.171)

Standard deviation in parenthesis.

Source: Own elaboration.

4. Conclusion

This study estimated a single output SPF and a multi-output SRF to obtain and compare technical efficiency measures of ranches in Uruguay. Since the equivalent meat index has been under scrutiny because of how it is defined, we estimated a multi-output frontier allowing us to consider all outputs in an efficiency analysis. However, it is important to note that beef cattle production in Uruguay remains to be highly dependent on net primary production, which imposes limitations on stochastic production functions estimation due to limited use of external inputs.

We find that the average level of TE is 0.769 for the single output SPF and 0.779 for the multi-output SRF, suggesting that ranches can expand cattle production using the current level of inputs and production technology available. TE is decreasing among the period considered and it reaches the lowest score in the last year (0.717 and 0.730 for SPF and SRF, respectively). This might imply that the speed of technology adoption is at different speeds leading some ranches to fall behind over time as the standard deviation of the TE scores shows the opposite behavior. Both models show that production is more sensitive to bovine stock and land size rather than to cattle management expenditures or labor. The dispersion of efficiency scores shows that there is an opportunity for some firms to improve efficiency.

The comparison between the single output SPF and the multi-output SRF leads to very similar efficiency results. However, using an index to combine different products has some caveats since it does not allow us to capture the impacts of specialization. The stochastic ray frontier results indicate that specializing in meat production either beef or lamb over wool sheep breeds results in production improvements. Our results show that using the equivalent meat index does not reveal to be a problem *per se* to estimate efficiency. So even when it simplifies the analysis, we cannot discard its use as a simple measure of combined production.

As a final comment, to improve the results to draw public policy recommendations, the program that collects the data of ranch management should be reinforced. This reinforcement implies encouraging ranchers to remain in the program allowing for the construction of long-term panel structures. Moreover, the technical efficiency analysis could be improved including explanatory variables associated with the role of management in the production process.

References

Aguirre, E. (2018). "Evolución reciente de la productividad ganadera en Uruguay (2010-2017). Metodología y primeros resultados". *Anuario OPYPA 2018,* 457-470. Montevideo, Uruguay: Ministerio de Ganadería Agricultura y Pesca. Retrieved from: https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/sites/ministerio-ganaderia-agricultura-pesca/files/documentos/publicaciones/ProductividadGanadera.pdf

Aigner, D., Knox Lovell, C.A. & Schmidt, P. (1977). "Formulation and estimation of stochastic frontier production function models". *Journal of Econometrics,* 6(1), 21-37. https://dx.doi.org/10.1016/0304-4076(77)90052-5

Álvarez, J.E. (2013). "Ventajas y limitaciones del uso de indicadores sintéticos de productividad física de la ganadería en la comparación del desempeño productivo de los sistemas agrarios de Nueva Zelanda y Uruguay". Communication presented to *IX Jornadas de Investigación en Historia Económica, AUDHE,* Montevideo. Retrieved from: https://www.audhe.org.uy/images/stories/upload/Jornadas_nacionales/novenas2013/jorge%20alvarez_audhe_%202013_1.pdf

Battese, G.E. & Coelli, T.J. (1988). "Prediction of firm-level technical efficiencies with generalized frontier production function and panel data". *Journal of Economics,* 38(3), 387-399. https://dx.doi.org/10.1016/0304-4076(88)90053-X

Battese, G.E. & Coelli, T.J. (1992). "Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India". *Journal of Productivity Analysis,* 3, 153-169. https://dx.doi.org/10.1007/BF00158774

Battese, G.E. & Coelli, T.J. (1995). "A model for technical inefficiency effects in a stochastic frontier production function for panel data". *Empirical Economics,* 20, 325-332. https://dx.doi.org/10.1007/BF01205442

Battese, G.E. & Corra, G.S. (1977). "Estimation of a production frontier model: with application to the pastoral zone of eastern Australia". *Australian Journal of Agricultural Economics,* 21(3), 169-179. https://dx.doi.org/10.1111/j.1467-8489.1977.tb00204.x

Bervejillo, J.E. (2019). Inidcadores de la productividad ganadera. Estadísticas de OPYPA: Ministerio de Ganadería, Agricultura y Pesca. Not published. In person communication.

Bervejillo, J.E., Mila, F. & Bertamini, F. (2011). "El crecimiento de la productividad agropecuaria 1980-2010". *Anuario OPYPA.* Montevideo, Uruguay: Ministerio de Ganadería Agricultura y Pesca. Retrieved from: http://www2.mgap.gub.uy/OpypaPublicaciones/ANUARIOS/Anuario2014/pdf/estudios/E%20-%20Bervejillo%20Bertamini%20-%20Cambio%20tecnico%20y%20crecimiento%20dela%20productividad%20total%20del%20sector%20agrop.pdf

Bravo-Ureta, B.E. & Pinheiro, E. (1993). "Efficiency analysis of developing country agriculture: A review of the frontier function literature". *Agricultural and Resource Economics Review,* 22(1), 88-101. https://dx.doi.org/10.1017/S106828050000032

Bravo-Ureta, B.E., Solís, D. & Moreira, V.H. (2007). "Technical efficiency in farming: a meta-regression analysis". *Journal of Productivity Analysis,* 27, 57-72. https://dx.doi.org/10.1007/s11123-006-0025-3

Coelli, T. & Perelman, S. (1996). *Efficiency Measurement, Multiple-Output Technologies and Distance Functions: With Application to European Railways.* Working paper CREPP 96/05, University of Liege. Retrieved from: https://www.researchgate.net/publication/24125205_Efficiency_measurement_multiple-output_technologiess_and_distance_functions_with_application_to_European_Railways

Coelli, T.J. (1995). "Estimators and hypothesis tests for a stochastic frontier function: A montecarlo analysis". *Journal of Productivity Analysis,* 6, 247-268. https://dx.doi.org/10.1007/BF01076978

Coelli, T.J. & Battese, G.E. (1996, August). "Identification of factors which influence the technical inefficiency of Indian farmers". *Australian Journal of Agricultural Economics,* 40(2), 103-128. https://dx.doi.org/10.1111/j.1467-8489.1996.tb00558.x

Fousekis, P. (2002). “Distance vs. ray functions: An application to the inshore fishery of Greece”. *Marine Resource Economics,* 17(4), 251-267. https://dx.doi.org/10.1086/mre.17.4.42629369

Gatti, N., Lema, D. & Brescia, V. (2015). “A meta-frontier approach to measuring technical efficiency and technology gaps in beef cattle production in Argentina”. Communication presented to *International Conference of Agricultural Economists*. Milan, Italy.

Green, W. (2005a). “Fixed and random effects in stochastic frontier models”. *Journal of Productivity Analysis,* 23, 7-32. https://dx.doi.org/10.1007/s11123-004-8545-1

Green, W. (2005b). “Reconsidering heterogeneity in panel data estimators of the stochastic frontier model”. *Journal of Econometrics*, 126(2), 269-303. https://dx.doi.org/10.1016/j.jeconom.2004.05.003

Henningsen, A., Belín, M. & Henningsen, G. (2017). *New insights into the stochastic ray production frontier*. Technical Report 01, University of Copenhagen: Department of Food and Resource Economics (IFRO). Retrieved from: https://www.econstor.eu/handle/10419/204405

Henningsen, G., Henningsen, A. & Jensen, U. (2015). “A Monte Carlo study on multiple output stochastic frontiers: A comparison of two approaches”. *Journal of Productivity Analysis,* 44, 309-320. https://dx.doi.org/10.1007/s11123-014-0416-9

INIA. (2018). *Indicadores de productividad*. Ficha técnica, 43. Retrieved from: http://www.ainfo.inia.uy/digital/bitstream/item/12103/1/Ficha-tecnica-43-Indicadores-de-productividad.pdf

Jondrow, J., Konx Lovell, C.A., Materov, I.S. & Schmidt, P. (1982). “On the estimation of technical inefficiency in the stochastic frontier production function model”. *Journal of Econometrics,* 19(2-3), 233-238. https://dx.doi.org/10.1016/0304-4076(82)90004-5

Kodde, D.A. & Palm, F.C. (1986). “Wald criteria for jointly testing equality and inequality restrictions”. *Econometrica,* 54(5), 1243-1248. Retrieved from: https://www.jstor.org/stable/1912331?seq=1#metadata_info_tab_contents

Kumbhakar, S.C. & Knox Lovell, C.A. (2000). *Stochastic frontier analysis*. Cambridge: Cambridge University Press.

Kumbhakar, S.C., Line, G. & Hardker, J.B. (2014). “Technical efficiency in competing panel data models: A study of norwegian grain farming”. *Journal of Productivity Analysis,* 41, 321-337. https://dx.doi.org/10.1007/s11123-012-0303-1

Löthgren, M. (1997). “Generalized stochastic frontier production models”. *Economic Letters,* 57(3), 255-259. https://dx.doi.org/10.1016/S0165-1765(97)00246-2

Löthgren, M. (2000). “Specification and estimation of stochastic multiple-output production and technical inefficiency”. *Applied Economics,* 32(12), 1533-1540. https://dx.doi.org/10.1080/000368400418943

Managi, S., Opaluch, J.J., Jin, D. & Grigalunas, T.A. (2006). "Stochastic frontier analysis of total factor productivity in the offshore oil and gas industry". *Ecological Economics,* 60(1), 204-215. https://dx.doi.org/10.1016/j.ecolecon.2005.11.028

Meeusen, W. & van den Broeck, J. (1977). "Efficiency estimation from Cobb-Douglas production functions with composed error". *International Economic Review,* 18(2), 435-444. Retrieved from: https://www.jstor.org/stable/2525757?seq=1#metadata_info_tab_contents

Niquidet, K. & Nelson, H. (2010). "Sawmill production in the interior of British Columbia: A stochastic ray frontier approach". *Journal of Forest Economics,* 16(4), 257-267. https://dx.doi.org/10.1016/j.jfe.2010.04.001

Oficialdegui, R. (1984). "Carne equivalente: los riesgos de la simplificación". *SUL Boletín Técnico,* 13, 53-62. Retrieved from: http://www.ainfo.inia.uy/consulta/busca?b=ad&id=28874&biblioteca=vazio&busca=autoria:%22Oficialdegui,%20R.%22&qFacets=autoria:%22Oficialdegui,%20R.%22&sort=&paginacao=t&paginaAtual=1

Qushim, B., Gillespie, J. & Nehring, R. (2013). "Scale economies and economic performance in southeastern U.S. cow-calf production". Communication presented to *Southern Agricultural Economic Association (SAEA) Annual Meeting,* Orlando, Florida. https://dx.doi.org/10.22004/ag.econ.143009

Trestini, S. (2006). "Technical efficiency of Italian beef cattle production under a heteroscedastic non-neutral production frontier approach". Communication presented to *10th Joint Conference on Food, Agriculture and the Environment,* Duluth, Minnesota. https://dx.doi.org/10.22004/ag.econ.6683

Yin, X., Zhu, X., Zhou, H., Li, Z., Wang, A. & Liao, X. (2017) "Technical efficiency of carp polyculture production in Jiangsu, China: A ray stochastic frontier production approach". *Aquaculture Research,* 48(4), 1629-1637. https://dx.doi.org/10.1111/are.12998