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A Meta-Frontier Approach to Measuring Technical Efficiency and Technology Gaps in Beef Cattle Production in Argentina

Abstract

In this paper the stochastic metafrontier method is applied to estimate technical efficiency (TE) and metatechnology ratios (MTR), in beef cattle production for three distinct regions in Argentina. A deterministic stochastic metafrontier production function model is estimated that envelops the individual stochastic frontiers of the three regions. Our results show that firms from Pampean region, the most favored in terms of environment conditions, have an average (TE) of 53.7%, meanwhile for others regions the TE is around 58.9-66.97%. The average MTR for Pampean region is 96.8%, in contrast, the others regions have an average MTR of 42%. Our results suggest that, farms in the Pampean region could improve their performance through a better management using the available technologies and resources. In regions II and III the improvement of the productivity is likely to require additional investment in research to adapt and develop new technologies.

Keywords: beef cattle production, technical efficiency, metafrontier, Argentina

JEL codes: D24; O32; Q18

1. Introduction

In Argentina during the last 20 years soybean crop has been increasingly shifting cattle farms to marginal areas and an important issue in livestock production is how to increase production with an efficient use of available resources. Many agronomical and technical studies focus the attention on the description of indicators of beef cattle production (weaning rate, pregnancy rate, kg per hectare, steer/calf rate) and provide important information about production and technological levels. These studies remark the heterogeneity in technologies and variability of performance at a farm level. The typical questions that arise are: why productivity is so heterogeneous even within the same region? How do firms could increase productivity per hectare? Is it possible to increase total stocks? Is it possible to increase animal weight per head? In these studies, kilograms per hectare per year (kg/ha/year) are used to compare efficiency and the level of technology. Usually, production gaps are estimated by the difference between the average partial productivity (kg/ha/year) and its theoretical or experimental potential. However, these partial productivity measures do not consider the use of other factors of production (labor, capital, supplementary feed, etc.) or differences in technological efficiency (Cap, 1995; Cap and Trigo, 2006; Giancola *et al.*, 2014; Nemoz *et al.* 2014).

Bearing in mind that beef cattle production is characterized by its firm and regional heterogeneity[1] efficiency measures should attempt to consider these factors in order to provide an accurate assessment of relative productivity in the beef cattle production. The aim of this paper is to obtain estimates of the relative efficiency in beef cattle production for different regions of Argentina using the Stochastic Meta-Frontier (SMF) approach developed by Battese and Rao (2002), Battese et al. (2004) and O'Donnell et al. (2008).

The economic analysis of efficiency follows the seminal work of Farell (1957), who defined technical efficiency (TE) as the ability of a firm to produce maximum output from a given level of inputs under a given technology. Literature on TE of beef cattle farms is relatively limited; published research include Barnes (2008), Ceyhan and Hazneci (2010), Featherstone et al. (1997), Fleming et al. (2010), Hadley (2006) Rakipova et al. (2003) and Otieno et al. (2012). A few studies have used farm level data from different groups to compare technical efficiency (TE) and technology differences across groups. This is the motivation of the Meta-Frontier (MF) approach introduced by Battese and Rao (2002), refined by Battese et al. (2004) and then by O'Donnell et al. (2008). Chen and Song (2008) uses the Battese et al. (2004) procedure to estimate a MF for agriculture at a regional level for China. Moreira and Bravo-Ureta (2010) use the MF approach to

[1] Table 1 presents the average sales of beef by farm in kg/ha/year in the principal beef cattle productive regions of Argentina from the survey dataset.

estimate TE and metatechnology ratios for dairy farms in the southern cone. In one of the few studies using farm level data Otieno et al. (2012) estimates a stochastic metafrontier to investigate technical efficiency and technology gaps across three main beef cattle production systems in Kenya. Economic research on technical efficiency of livestock farms in Argentina is very limited. There are some studies estimating production efficiency using Stochastic Production Frontiers (SPF) for dairy farms, for example, Schilder and Bravo-Ureta (1993), Moreira and Bravo-Ureta (2006) and Gastaldi *et al* (2008). For beef cattle farms the evidence is very limited:, there are some papers using deterministic frontiers (Alvarez, 1999; Saldungaray, 2000; Gallacher, 2000) and less using stochastic frontiers (Galetto 2010). Using corrected OLS (COLS) Alvarez (1999) found a low level of efficiency in livestock farms in the Pampa's (60%) and also shows that there is no relationship between physical results (kg/ha) and economic efficiency. Gallacher (1994) and Gallacher *et al.* (1994) found that efficiency differentials are associated with the level of managerial ability of farmers. Galetto *et al.* (2010) estimates SPF and efficiency for livestock enterprises in the central region of the country, and shows a high variability among farms in production and technical efficiency with an important impact of the severe drought occurred during years 2008/09.

To estimate TE and technology gaps following the MF approach we use farm level data from a livestock technology survey conducted by the National Institute of Agricultural Technology (RIAN Technology Survey 2009/10). The database has a detailed description of the technology used in cattle production systems in Argentina from over 1,300 farms in eight provinces during the agricultural year 2009/10. The rest of the paper is organized as follows: section 2 presents the SMF methodological approach. Section 3 describes the data and the empirical models. Section 4 presents the results and main empirical findings. Finally, section IV presents the conclusions.

2. Methodological framework

Hayami (1969) and Hayami and Ruttan (1970, 1971) introduced the concept of meta-production function, defined as an envelope of traditional production functions , assuming that all producers of different groups (countries, regions, etc.) potentially have access to the same technology. Following this approach, Hellinghausen and Mundlak (1982) and Lau and Yotopoulos (1989) used the MF approach to compare aggregate agricultural productivity between countries. Battese and Rao (2002), Battese, Rao and O'Donnell (2004, 2008) consider the fact that technology could differ across regions and develop the SMF approach. This involves a Meta-Frontier estimation, which represents the envelope of all SPF for all groups or regions. The limits for groups can be differences in country geography, regional production environment or economic development of each area or region.

Figure 1 presents the single output (y) single input (x) case. The SPF´s define the MF represented by MM'. If the three groups represent the available technologies, then every SPF involves all combinations of inputs and outputs that can be produced by an individual firm. This would imply that the frontier is the convex function 1-B-3`. However, if groups are not exhaustive, there are other feasible combinations of inputs and outputs and it can be represented by the convex function MM '.

<Figure 1>

2.1. Stochastic Meta-Frontier Framework

Suppose that separate stochastic production frontier (SPF) models are defined for specific groups of firms in a given industry. If for the j-th group there is data for N_j firms then the stochastic frontier model can be written as (Meeusen and Van Den Broeck, 1977):

(1) $y_i = f(x_i, \beta) + \varepsilon_i$,

where y_i is the output for the i-th firm; x_i is the input vector and $\varepsilon_i = v_i - \mu_i$ is a random error. Assuming that the exponential of the production frontier is linear in the parameter vector β_j, then the technology can be represented by a suitable functional form (e.g., Cobb-Douglas (CD) or translog (TL)). Input and output data for firms in a j-th group can be used to obtain maximum-likelihood (ML) estimates of the unknown parameters of the frontier defined in Eq. 1.

Technical efficiency for the i-th firm associated with the j-th group with respect to its own frontier can then be computed estimating a SPF for each group:

(2) $y_i = e^{x_i^{\prime}\beta^j + v_i^j - \mu_i^j}$

Where v_i^j is a random error assumed to follow a normal distribution with mean zero and constant variance $\left(v_i^j \sim \text{iid } N(0, \sigma_v^2)\right)$; and μ_i it is a non-negative unobservable random error associated with the technical inefficiency of the i-th firm for a j-th group. As shown in Battese y Coelli (1992), the technical efficiency indicator for farm i for the j-th group is given by the ratio of the actual output to the output at the frontier such as in (3):

(3) $TE_i^j = \frac{y_i}{e^{x_i^{'}\beta^j + v_i^j}} = e^{-u_i^j}$

After the estimation of the individual SPF's it is necessary to verify if the various groups share the same technology. This can be done with a likelihood ratio test (LR), where L(H0) is the value of the loglikelihood function for a stochastic frontier estimated by pooling the data for all groups and L(HA) is the sum of the values of the log-likelihood functions from the individual SPF's[2]. The degrees of freedom for the Chi square statistic are the difference between the number of parameters estimated under HA and H0. If the null hypothesis that the stochastic frontier for the pooled data is rejected in favor of the individual frontiers (HA), then the data should not be pooled and in such case the MF is the appropriate framework to estimate and compare TE across groups or regions (Battese *et al* 2004).

The MF model is defined by Battese *et al* (2004) as a deterministic parametric frontier of specific functional form (e.g., Cobb Douglas or Translog) such that the predicted value for the MF is larger than or equal to the predicted value from the stochastic frontier for all firms and groups. The deterministic MF model for all firms in all groups can be expressed as follows:

(4) $Y_i^* = f(x_{1i}, x_{2i}, \dots, \beta^*) \equiv e^{x`_i\beta^*}$

where Y_i^* and β^* denote MF output and the vector of parameters for the MF model, respectively, provided the following condition holds for all j-groups (j = 1, 2,…, J):

(5) $x_i^` \beta^* \geq x_i^` \beta^j$

Therefore, to estimate the MF, the objective function to be minimized is the sum of the absolute deviations subject to equation (5). The linear programming (LP) problem to be solved can be written as:

(6) $\min_{\beta^*} \sum_{i=1}^{N} \left[lnf(x_{1i}, x_{2i}, \dots, x_{Ki}; \beta^*) - lnf\left(x_{1i}, x_{2i}, \dots, x_{Ki}; \hat{\beta}^j\right) \right]$

$s.a.: lnf(x_{1i}, x_{2i}, \dots, x_{Ki}; \beta^*) \geq lnf\left(x_{1i}, x_{2i}, \dots, x_{Ki}; \hat{\beta}^j\right)$

[2]The LR statistic is given by $\lambda = 2 \times [L(H_A) - L(H_0)]$, where $L(H_A)$ and $L(H_0)$ are the values of the likelihood function under the alternative and null hypotheses. The value of λ has a Chi-square distribution with the number of degrees of freedom equal to the number of restrictions imposed.

This problem is solved using the pooled dataset and thus includes all observations for all groups. Since $\hat{\beta}^j$, the vector of estimated coefficients for the stochastic frontier for each j-th group, and the input vectors are assumed to be fixed, the following equivalent form of the LP problem in Eq. 6 can be specified if the function $f(x_{1i}, x_{2i}, \dots, x_{ki}; \beta^*$ is log-linear in the parameters:

$$(7)\ \min_{\beta^*} \bar{x}\beta^*$$

$$x_i^{`}\beta^* \geq x_i^{`}\beta^j$$

Once the LP problem in Eq. 6 is solved, TE with respect to the MF (TE*) can be estimated for each observation in the data set. The difference between TE* (TE with respect to the MF) and TE_j (TE with respect to a group/country frontier from Eq. 3) for a given firm is due to a gap between the individual group frontier and the meta-frontier. This gap, called the Technology Gap Ratio (TGRj) by Battese *et al*. (2004) is defined as the difference (or gap) in the technology available to a given j-th group relative to the technology available to all groups/regions under analysis. In this paper we use the O'Donnell, Rao and Battese (2008) concept of Meta-Technology Ratio (MTR). The MTR identifies the ratio of the output for the frontier production function for each region relative to the potential output that is defined by the metafrontier function, given the observed inputs. The MTR definition indicates that ''increases in the metatechnology ratio imply a decrease in the gap between the group frontier and the metafrontier'' (O'Donnell et al. 2008, p. 236). The MTR takes the value of between 0 and 1, where 1 indicates no gap between the farm in a particular region and the metafrontier. The mathematical expression for $\widehat{TE}_i^*$, which is computed from the MF, can be expressed as:

$$(8)\ \widehat{TE}_i^* = \widehat{TE}_i^j \times \widehat{MTR}_i^j$$

where it is the TE_i^j of the i-th firm with respect to the j-th group frontier as defined by Eq. 3.

The expression for $\widehat{MTR}_i^J$ proposed by Battese and Rao (2002), Battese et al. (2004) and O'Donnell *et al.* (2008) is:

$$(9)\ \widehat{MTR}_i^j = \frac{e^{x_i^{'}\beta^j}}{e^{x_i^{'}\beta^*}} = \frac{\widehat{TE}_i^*}{\widehat{TE}_i^j}$$

where $e^{x_i^{'}\beta^j}$ is the deterministic component of Eq. 2 and $e^{x_i^{'}\beta^*}$ is defined in Eq. 4.

From figure 2, consider a firm from group 2 that produce at the input-output combination represented by point A. If MF is MM´, hence, an example of TE* could be:

$TE^*(A) = OC/OF = 0.6$

This (assumed) value of 0.6 indicates that the firm is using 60% of the available technology (the MF). The ET (ET^2) with respect to group 2 frontier could be calculated as:

$ET^2 (A) = OC/OD = 0.74$

This implies that the firm is producing at 74% of the potential output, with an x(A) input vector and group 2 technology. Finally, the MTR will be:

$MTR^2(A) = ET^*(A)/ ET^2 (A) = (OC/OF) / (OC/OD) = OD/OF = 0.60/0.74 = 0.81$

Given the input vector, the maximum potential output for a firm from group 2 is 81%. Thus, the technology gap (1-MTR) is 19%.

3. Data and Empirical Models

The study uses farm level data from a livestock technological survey conducted by the National Agricultural Information Network of the National Institute of Agricultural Technology (RIAN - INTA). This survey has information about farms activities from July 1, 2009 to June 30, 2010. The surveyed farms are located in six provinces along the three main cattle beef regions: the Pampean (central) region, the North Central region and North East region. The used database contains 1,083 observations[3] from the provinces of Buenos Aires and La Pampa in the Pampean region; provinces of Chaco and Santiago del Estero in the North Central region and provinces of Corrientes and Misiones in the North East region (see Figure 2).

The empirical application has four steps. First, we perform an estimation of one SPF for each region[4]. Second, we estimate one SPF for the whole data set (pooled). Third, we compare the individual SPF´s with the pooled frontier to test whether the technology differs between regions (LR test). Finally, we perform the calculation of the MF using the estimates from individual SPF´s.

3.1 *Empirical estimation*

First, the parameters of the stochastic frontiers for the three regions were estimated using the Cobb-Douglas (CD) specification:

[3] Some 200 observations were eliminated due to missing or non reliable data.
[4] The aggregation in three regions considers agronomic and environmental aspects: soil characteristics, climate, rainfall, etc.

(10) $Y_i = \alpha_0 + \sum_{k=1}^{4} \beta_k^j x_{ki} + \beta_d^j z_d + v_i^j\text{-}u_i^j$,

where the i and j refers to farms and regions, respectively and all variables are in natural logarithms. The dependent variable (Y_i) is the log of total sales of beef in kilograms (live kilos); x_{ki} is a vector of inputs and includes: T_i, the log of cattle area in hectares, L_i (labor) measured as the log of number of employees, K_i the stock of cattle (herd size) measured as the log of number of heads and A_i is the farm area allocated to crops measured in log of hectares. Z_d is a dummy variable to control farms that are specialized as cow-calf operators. Z_d is equal to one for cow calf operators, and zero otherwise.

Alternatively, a translog specification (TL) was estimated considering the same dependent and explanatory variables as for the CD specification:

(11) $Y_i = \alpha_0 + \sum_{k=1}^{4} \beta_k^j x_{ki} + \frac{1}{2}\sum_{k=1}^{4}\sum_{l=1}^{4} \beta_{kl}^j x_{ki} \times x_{li} + \beta^j z_d + v_i^j - u_i^j$,

In the TL specification variables T_i, L_i K_i and A_i are expressed as deviations from their sample geometric means. This transformation is simply a convenient change in units of measurement because it allows a direct interpretation of the first order translog parameters as the input-output elasticities evaluated at the sample means and is useful for comparison with estimates of the CD specification (Coelli *et al.,* 2003).

Finally, the results from the selected specifications (CD and TL) are used to estimate the MF parameters by solving the LP problem of Eq. 6. In addition, its standard deviations are obtained using bootstrap. Table 2 presents the descriptive statistics of the variables used in the econometric estimation. The output variable is total sales of beef in kilograms (live kilo) as a proxy of total production. The explanatory variables include quantitative approaches to three production factors: land, labor and capital. A dummy variable is introduced to control the case of specialized cow-calf operators were the proxy variable for production (sales in kg) could be biased downwards.

<Table 2>

4. Results and Discussion

This section describes the results of the estimation of the regional frontiers and associated TE measures. First, the SPF results and specification tests are analyzed for regions and for the pooled data. Second, TE measures are discussed for the six regions and then the TE and MTR measures with respect to the MF are examined.

4.1. Production frontiers estimates and specification tests by region and for the pooled data

Table 3 presents the SPF´s estimated coefficients by region. These are: Buenos Aires and La Pampa (I), Chaco and Santiago del Estero (II) and Corrientes and Misiones (III). Then, the pooled stochastic frontier is presented in Table 4. The Cobb-Douglas (CD) and Translog (TL) estimates results are presented in order to determine the most appropriate specification for the data under analysis. We performed a log-likelihood ratio (LR) test for model selection; the results are presented in Table 5[5].

The first-order coefficients have the expected sign and are in general statistically significant. Land and cattle stock estimated parameters are significant in most regional frontiers, while labor parameter is not significant. A Wald test was performed to contrast the constant returns to scale (CRS) hypothesis and we found that the CRS hypothesis cannot be rejected in all regions[6]. This is consistent with other econometric estimates for cattle farm production in Argentina including Gallacher (1994), Gallacher *et al.* (1994), Alvarez (1999), Gallacher (1999) y Saldungaray (2000).

<Table 3>

Table 4 shows the estimates for the pooled sample TL model and the linear programming estimates for the MF. The econometric model exhibits highly significant first-order parameter estimates and they are similar with those obtained in both the individual region and pooled models.

<Table 4>

Finally, we perform an LR test to examine the null hypothesis that the three regions share the same technology. If this is the case, regions share the same production frontier (i.e., no significant difference between the single region frontiers), then there would be no reason for estimating the pooled MF production model. The value of the LR statistic is 167.09 (32 df), which implies that the null hypothesis is strongly rejected. Hence, this result suggests that the stochastic frontiers for cattle

[5] The parameters of the stochastic frontiers were obtained using the frontier command in STATA version 12 software, while the metafrontier was estimated in SHAZAM version 7 software following codes adapted from O'Donnell et al. (2008).

[6] In Table 3 FC refers to the Function Coefficient that is the sum of the coefficients associated to factors land, labor and capital. The Wald test contrasts the hypothesis that FC is equal to one.

farms in the three regions are different and that any efficiency comparison across these three sub-samples should be undertaken with respect to the MF instead of the pooled stochastic frontier.

4.2. Metatechnology ratio (MTR) and technical efficiency (TE) analysis

The values of the MTR and the TE measures for the SPF and with respect to the MF are summarized in Table 6. A higher (lower) MTR value implies a smaller (larger) technology gap between the individual frontier and the MF. A MTR value of 100% is equivalent to a point where a regional frontier coincides with the MF.

The average estimated MTR for region I is 96%, ranging from a minimum of 41.7% to a maximum of 100%; the average estimated MTR for region II is 41.2%, and ranges from a minimum of 16.7% to a maximum of 64.8%; and the average estimated MTR for region III is 41.5%, and goes from 12.6% to 100%. The highest MTR average is for the Pampean region (96%) which means that these farmers are closer to the MF than farmers in regions II and III (41%). This may be related to the fact that farmers in regions II and III have less access to technology and also to the fact that the environmental conditions in these regions are harsher relative to the Pampean region. Villano et al. (2008) found similar performance of average MTRs relative to the environment in their research on regional productivity in the Australian wool industry.

The average TE measure in region I (pampean) is 53%, an estimate similar to what Alvarez (1999) has found for farms located in the west of Buenos Aires province (60%). Furthermore, from regions II and III, TE is higher, around 59% and 67%.

<Table 6>

Figure 2 presents the geographical distribution of average TE and MTR by county (department) in each province/region. We observe that the TE distribution is heterogeneous within regions II and III with varying average values by department. In contrast, the MTR is clearly intense in region I where the SPF is very close to the MF.

<Figure 2>

These results have an important policy implication related to the opportunities to close the productivity gap by increasing TE in beef cattle production. In the short run TE is expected to be responsive to targeted training and managerial programs which in the Pampean region can be implemented without new investments in technologies. In other words, the farms in the Pampean region could improve their performance through a better management using the available technologies and resources. But at the same time this region is, on average, close to the MF and to move forward is likely to require additional investments to develop and implement new technologies.

Farms from regions II to III are closer to their individual production frontiers operating with a higher TE, but they are far away from the MF and could improve their performance imitating prevailing agricultural practices at Buenos Aires and La Pampa. In these regions the movement towards the MF is likely to require additional investment in local research to adapt technologies and to develop new technologies applicable to local conditions. So, it is necessary to follow a strategy that shifts the local frontier approaching the MF. In the case of beef cattle production, pasture and grazing management together with animal genetics are important research areas suitable for both adaptive and original research and with important potential impacts on productivity (INTA, 2014).

5. Summary and conclusions

The objective of this paper was to analyze the relative efficiency (TE) for beef cattle farms in Argentina using the Stochastic Meta-Frontier (SMF). This paper applies the MF approach to a large database of livestock enterprises located in three different regions of Argentina using a single-output/multi-input technology. The data set is a cross section that contains 1,083 observations from a livestock technological survey conducted by the National Institute of Agricultural Technology (INTA) in year 2009-10. The surveyed farms are located in six provinces along the three main cattle beef regions: the Pampean (central) region, the North Central region and North East region.

First, TE measures were obtained from Stochastic Production Frontier (SPF) models estimated separately for each region and then pooled for all three regions. Second, an MF model was estimated with the pooled data using linear programming following O'Donnell et al. (2008). Alternative specifications using the Cobb-Douglas (CD) and translog (TL) functional forms were evaluated and the inefficiency error term was obtained. We perform several statistical tests to obtain the best model for the data under analysis and we select the TL as the most appropriate functional form. The null hypothesis that the beef cattle farms from the three regions share the same production frontier is rejected, which implies that the production frontier estimated from the pooled data is not an adequate specification to compare TE across regions. In its place, the TE comparisons need to be made with respect to an envelope function for the three individual regional frontiers: the MF. Thus, there are two kinds of frontiers estimated in this paper: the individual country frontiers and the MF. The difference or gap between the individual regional frontier and the MF is defined as the Metatechnology Ratio (MTR).

The value of MTR can be interpreted as a proxy for the technology gap, considering the potential efficiency of the best available technology available. At the most productive region the average MTR is 96.8 %, while in the other regions is close to 41%. Figure 3 summarizes and compares the findings in terms of ET and RMT for different productive regions. These results are relevant to understand what could be the potential sources of productivity improvements. At region I the technology gap (1-RMT), is very low (3.2%) and better productivity indicators could be achieved by managerial improvements. In the other two regions the efficiency is higher, but the technology gap is important (39%). In these cases, productivity gains should arise from new a technology that expands the production frontier towards the MF.

The results related to TE shows that the Pampean region, the most favored in terms of environment conditions, have an average TE of 53.7%, whereas in the other regions we found an average TE from 58.9% to 66.9%. These measures are more complete than partial productivity ratios (kg/ha/year) because multiple inputs and efficiency comparisons are under consideration. Some inefficiency of Buenos Aires and La Pampa farms may be explained by the increasing competition between agriculture and livestock. Mixed farming (livestock-crops) is frequent in this region and farmer´s allocation of time and managerial skills could be shifting to the more profitable activities related to crop farming, considering livestock as a secondary activity.

Our results suggest that, farms in the Pampean region could improve their performance through a better management using the available technologies and resources. In regions II and III the improvement of the productivity is likely to require additional investment in research to adapt and develop new technologies (genetics, pasture and grazing management). All estimated frontier models exhibit constant returns to scale (RTS), implying that on average beef cattle farms in the three regions are operating at an optimal size, which further suggests that larger farms do not have advantages related to lower average costs. This result is important because the adoption of new technologies or improvements in managerial abilities will benefit farmers independently of their size.

Finally, as O'Donnell et al. (2008) remarks, the estimation of the technological gap between SPF and MF can be useful to design public policies and programs that promote innovation, investment and technological change because they measure the potential improvement in performance resulting from changes in the production environment by investing in physical, financial and human capital.

6. References

Aigner, D., C. K. Lovell y P. Schmidt (1977), Formulation and estimation of stochastic frontier production function models, *Journal of* Econometrics 6(1): 21−37.

Alvarez, A, y Del Corral, J. (2010), Identifying different technologies using a latent class model: extensive versus intensive dairy farms, *European Review of Agricultural Economics* 37(2): 231-250.

Alvarez, R. M. (1999), Análisis de la productividad y la eficiencia en sistemas mixtos pampeanos, Tesis de Maestría en Economía Agraria, Universidad de Buenos Aires, Buenos Aires.

Battese G. E. y 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.

Battese G. E., Malik, S. J. y Broca, S. (1993), Production functions for wheat farmers in selected districts of Pakistan: an application of a stochastic frontier production function with time-varying inefficiency effects, *Pak Dev Rev* 32: 233–268.

Battese, G. E. y Coelli, T. J. (1995), A Model of Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, *Empirical Economics* 20: 325-332.

Battese G. E. y D. S. Prasada Rao (2002), Technology gap, efficiency, and a stochastic metafrontier function, *International Journal of Business Economics* 1:87–93.

Battese G. E., D. S. Prasada Rao y O'Donnell, C. J. (2004), A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies, *Journal of Productivity Analysis* 21:91–103.

Bravo-Ureta B., Schilder E. (1993), Análisis de la Eficiencia Técnica Mediante Funciones Estocásticas de Fronteras: El Caso de la Cuenca Lechera Central Argentina. *Annual Meeting of Argentine Agricultural Economist Society*. Cordoba, Argentina, 1993.

Cap, E. J. (1995). Argentina: The sustainable growth potential of the production possibilities frontier in the agricultural sector - an outlook. National Institute of Agricultural Technology. Buenos Aires, Argentina.

Trigo, E. J., & Cap, E. J. (2006). Ten years of genetically modified crops in Argentine agriculture. National Institute of Agricultural Technology. Buenos Aires, Argentina.

Ceyhan, V., Hazneci, K., 2010. Economic efficiency of cattle-fattening farms in Amasya province, Turkey. Journal of Animal and Veterinary Advances 9(1), 60-69.

Chen Z, Song S (2008), Efficiency and technology gap in China's agriculture: a regional meta-frontier analysis. *China Economics Review* 19:287–296.

Coelli, T., Estache, A., Perelman, S. y Trujillo, L. (2003), *A Primer on Efficiency Measurement for Utilities and Transport Regulators*, The World Bank, Washington DC, Estados Unidos.

Farrell M. J. (1957), The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society*. Series A General, Part III:253-290.

Featherstone, A., Langemeier, M., Ismet, M., 1997. A nonparametric analysis of efficacy for a sample of Kansas beef cow farms. Journal of Agricultural and Applied Economics 29(1), 175-184.

Fleming, E., Fleming, P., Griffith, G., Johnston, D., 2010. Measuring beef cattle efficiency in Australian feedlots: applying technical efficiency and productivity analysis methods. Australasian Agribusiness Review 18(4), 43-65.

Gallacher, M. (1994), The management factor in developing-country agriculture: Argentina, *Agricultural Systems*, Volume 47, Issue 1, 1995, Pages 25-38.

Gallacher M., Goetz, S. J. y Debertin, D. L. (1994), Managerial form, ownership and efficiency: a case of study of Argentina agriculture, *Agricultural Economics* 11:289-299.

Gallacher, M (1999), Human Capital and Production Efficiency: Argentine Agriculture, *CEMA Working Papers:* Serie Documentos de Trabajo. 158, Universidad del CEMA.

Galetto, A. (2010), Análisis de la eficiencia técnico-económica y modelos de organización en sistemas de producción de carne del centro-norte de la provincia de Santa Fe, no publicado, Universidad Tecnológica Nacional (UTN) – Facultad regional Rafaela.

Gastaldi, L. B., Galetto, A. y Lema, D. (2007), Lechería en áreas con restricciones edáficas y climáticas. Eficiencia técnica y potencial productivo. *Reunión Anual de la Asociación Argentina de Economía Agraria*. Mendoza, Argentina.

Giancola S. I., Calvo S., Roggero, P., Andreu, M., Carranza, A.O, Kuszta, J. S., Salvador, M. L., Di Giano, S. And Da Riva, M. (2014), Causas que afectan la adopción de tecnología en la cría bovina en el Departamento Patiño, Formosa: enfoque cualitativo. *Estudios socioeconómicos de la adopción de tecnología 7*. National Institute of Agricultural Technology. Buenos Aires, Argentina.

Hadley, D., 2006. Patterns in technical efficiency and technical change at the farm-level in England and Wales, 1982-2002. Journal of Agricultural Economics 57(1), 81-100.

Hayami Y. (1969), Sources of agricultural productivity gap among selected countries, *American Journal of Agricultural Economics* 51:564–575.

Hayami Y. y V.W. Ruttan (1970), Agricultural productivity differences among countries, *American Economic Review* 60:895–911

Hayami Y. y V. W. Ruttan (1971), *Agricultural development: an international perspective*. John Hopkins University Press, Baltimore.

Instituto Nacional de Tecnología Agropecuaria (2008), Perfil Tecnológico del Sector Primario. Available at: http://www.inta.gov.ar/ies/info/cuales.htm

Instituto Nacional de Tecnología Agropecuaria (2010), Encuesta ganadera, bovinos para carne RIAN 2009/10. http://rian.inta.gov.ar/encuestas/

Instituto Nacional de Tecnología Agropecuaria (2014), *Avances en Raigrás Red de Evaluación de Cultivares de Raigrás*. Editor: Daniel Méndez. Buenos Aires, Argentina.

Lau L y Yotopoulos P. (1989). The Meta-Production Function Approach to Technological Change in World Agriculture. *Journal of Development Economics* 31:241-269.

Meeusen, W. y van den Broeck, J. (1977), Efficiency estimation from Cobb–Douglas production functions with composed error, *International Economic Review* 18(2): 435−444.

Moreira V. H. y Bravo-Ureta B. E. (2010), Technical efficiency and metatechnology ratios for dairy farms in three southern cone countries: a stochastic meta-frontier model, *Journal of Productivity Analysis* 33:33-45.

Mundlak, Y. y Hellinghausen, R. (1982), The Intercountry Agricultural Production Function: Another View. American Journal of Agricultural Economics 64(4): 664-672.

Mundlak, Y. (2000), *Agriculture and Economic Growth*. Cambridge, MA, Harvard University Press.

Nemoz J. P., Giancola, S. I., Bruno M. S., De La Vega, M. B., Calvo, S., Di Giano S. and Rabaglio, M. D. (2013), Causas que afectan la adopción de tecnología en la ganadería bovina para carne de la Cuenca del Salado: enfoque cualitativo. *Estudios socioeconómicos de la adopción de tecnología 5*. National Institute of Agricultural Technology. Buenos Aires, Argentina.

O'Donnell C J., D. S. Prasada Rao y G. E. Battese (2008), Metafrontier frameworks for the study of firm-level efficiencies and technology ratios, *Empirical Economics* 34:231–255.

Otieno, D. J., Hubbard, L and Ruto, E. (2012) Determinants of technical efficiency in beef cattle production in Kenya. International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguacu, Brazil, 18-24 August, 2012.

Rakipova, A. N., Gillespie, J. M., Franke, D. E., 2003. Determinants of technical efficiency in Louisiana beef cattle production. Journal of American Society of Farm Managers and Rural Appraisers (ASFMRA) 99-107.

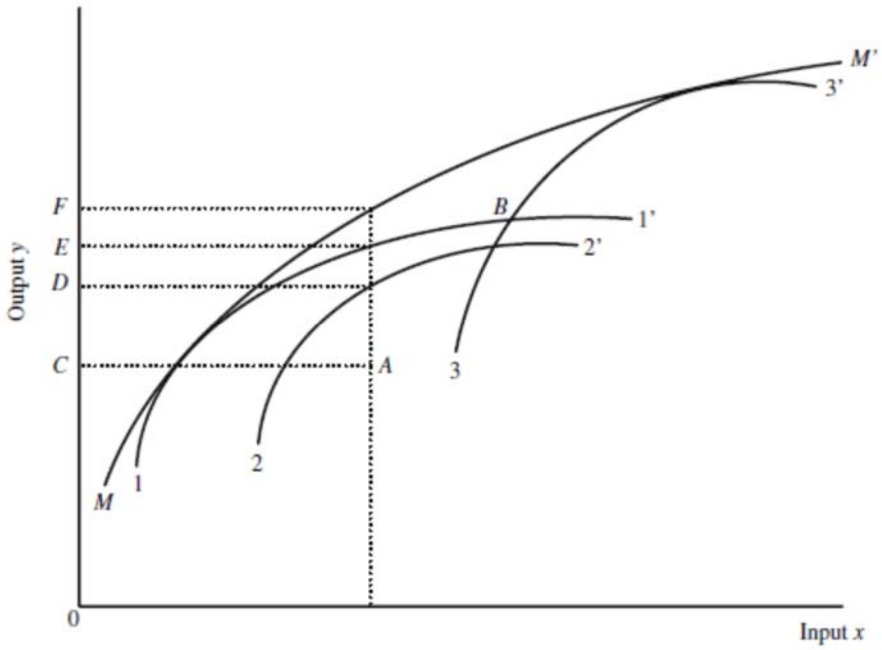
Saldungaray, M. C. (2000), "Adopción de Tecnologías en Empresas Rurales del Partido de Bahía Blanca", Tesis Magister en Economía Agraria y Administración Rural, *Universidad Nacional del Sur*.

Shazam (1993). *The Econometrics Computer Program*. User´s Reference Manual Version 7.0. Kenneth J. White. Mc Graw Hill.

Villano, R., Fleming, E. and Fleming, P. (2008), Measuring Regional Productivity Differences in the Australian Wool Industry: A Metafrontier Approach, No 6036, 2008 Conference (52nd), February 5-8, 2008, Canberra, Australia, Australian Agricultural and Resource Economics Society.

Tables and Figures

Figure 1. Metafrontier (MF) and Stochastic Production Frontiers (SPF).



Source: *Metafrontier frameworks for the study of firm-level efficiencies and technology ratios*, O´Donnell, Rao y Battese (2008).

Table 1. Average Production (sales) kg/ha/year by Region.

Regions	N	Mean	Sd.	Min	Max
I. Buenos Aires & La Pampa (Pampean)	639	98.4	71.1	3.0	298.8
II. Chaco & Santiago del Estero (North Central)	316	57.3	50.1	3.4	278.1
III. Corrientes & Misiones (North East)	128	54.7	45.2	4.3	274.7
Total	1,083	81.2	66.1	3.0	298.8

Table 2. Variables Definition and Descriptive Statistics by Region.

Variable	Definition	Units					
I. Buenos Aires & La Pampa			**n**	**mean**	**sd**	**min**	**max**
Yi	Beef sales	Kg	639	126,452	177,905	1,201	1,546,001
Ti	Cattle area	Hectares	639	1,865	3,408	47	43,062
Li	Labor	# of workers	639	5	6	1	115
Ki	Herd size	# of heads	639	1,091	1,457	32	14,891
Ai	Crops area	hectares	639	533	849	1	5,127
Z_d	Specialization in cow calf	Dummy =1 if cow calf	639	0.17	0.37	0	1
II. Chaco & Santiago del Estero			**n**	**mean**	**sd**	**min**	**max**
Yi	Beef sales	Kg	316	66,901	104,007	1,411	984,001
Ti	Cattle area	Hectares	316	1,544	2,151	21	16,501
Li	Labor	# of workers	316	5	7	1	94
Ki	Herd size	# of heads	316	934	1,537	17	14,851
Ai	Crops area	hectares	316	406	756	1	9,001
Z_d	Specialization in cow calf	Dummy =1 if cow calf	316	0.39	0.49	0	1
III. Corrientes & Misiones			**n**	**mean**	**sd**	**min**	**max**
Yi	Beef sales	Kg	128	72,363	124,392	1,201	925,251
Ti	Cattle area	Hectares	128	1,825	3,815	41	34,222
Li	Labor	# of workers	128	6	5	1	26
Ki	Herd size	# of heads	128	1,332	2,887	11	27,139
Ai	Crops area	hectares	128	518	1,214	1	7,001
Z_d	Specialization in cow calf	Dummy =1 if cow calf	128	0.30	0.46	0	1

Table 3. Cobb-Douglas (CD) and translog (TL) production frontiers by region.

	Buenos Aires & La Pampa (I)				Chaco & Santiago del Estero (II)				Corrientes & Misiones (III)			
	CD-I		TL-I		CD-II		TL-II		CD-III		TL-III	
	Coeff.	std. error	Coeff.	std. error	Coeff.	std. error	Coeff.	std. error	Coeff.	std. error	Coeff.	std. error
Constant	5.925***	(0.206)	11.90***	(0.0538)	5.484***	(0.314)	11.02***	(0.172)	5.095***	(0.473)	11.13***	(0.165)
T_i	0.229***	(0.0368)	0.203***	(0.0503)	0.116**	(0.0578)	0.124**	(0.0611)	0.594***	(0.0959)	0.497***	(0.105)
L_i	0.110**	(0.0551)	0.112*	(0.0586)	0.0822	(0.0686)	0.0779	(0.0771)	0.0958	(0.109)	0.122	(0.123)
K_i	0.619***	(0.0416)	0.689***	(0.0550)	0.729***	(0.0636)	0.725***	(0.0703)	0.262**	(0.108)	0.412***	(0.121)
A_i	0.0517***	(0.0194)	0.0413**	(0.0204)	0.0159	(0.0193)	0.0101	(0.0234)	0.0368	(0.0384)	0.0475	(0.0354)
T^2			-0.0110	(0.0243)			-0.0225	(0.0624)			0.0136	(0.0896)
L^2			-0.112**	(0.0451)			-0.0108	(0.0784)			0.0198	(0.112)
A^2			-0.00750	(0.00702)			-0.00569	(0.00732)			-0.0173	(0.0133)
K^2			0.106***	(0.0373)			0.0516	(0.0719)			0.161***	(0.0534)
L_i*A_i			0.0650*	(0.0377)			0.0534	(0.0388)			-0.109	(0.0722)
T_i*A_i			0.00595	(0.0244)			0.0469*	(0.0282)			0.0567	(0.0442)
K_i*A_i			-0.0184	(0.0321)			-0.0436	(0.0311)			0.0340	(0.0692)
T_i*L_i			0.105	(0.0658)			0.272**	(0.107)			0.326**	(0.163)
T_i*K_i			-0.0889*	(0.0521)			-0.0545	(0.112)			-0.247**	(0.120)
L_i*K_i			-0.109	(0.0811)			-0.242*	(0.128)			-0.358**	(0.176)
Z_d	-0.349***	(0.0707)	-0.297***	(0.0726)	-0.315***	(0.0766)	-0.290***	(0.0774)	-0.455***	(0.147)	-0.492***	(0.138)
FC ($\beta_1+\beta_2+\beta_3$)	0.96		1.05		0.93		0.93		0.95		1.03	
Wald Test χ^2 ($\beta_1+\beta_2+\beta_3=1$)	0.03		1.73		1.14		0.98		0.10		1.71	
Returns to scale	Constant		Constant		Constant		Constant		Constant		Constant	
Log-Likelihood	-668.89		-653.52		-321.17		-313.58		-143.78		-135.33	

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

Table 4. Estimates for the pooled sample (PS) and the Meta-Frontier (MF).

	Pooled Sample (PS)		Meta-frontier (MF)	
	Coeff.	std. error	Coeff.	Std. error
Constant	11.67***	(0.0536)	11,90***	(0,041)
T_i	0.203***	(0.0353)	0,224***	(0,051)
L_i	0.046	(0.0437)	0,091	(0,047)
K_i	0.687***	(0.0407)	0,671***	(0,016)
A_i	0.0572***	(0.0140)	0,047	(0,027)
T_i^2	-0.002	(0.0220)	0,028	(0,042)
L_i^2	-0.112***	(0.0362)	-0,073***	(0,005)
A_i^2	0.127***	(0.0266)	-0,004	(0,032)
K_i^2	-0.006	(0.00445)	0,132***	(0,028)
$L_i x A_i$	0.0442*	(0.0236)	0,041*	(0,020)
$T_i x A_i$	0.0122	(0.0169)	0,029	(0,024)
$K_i x A_i$	-0.003	(0.0215)	-0,037	(0,063)
$T_i x L_i$	0.179***	(0.0538)	-0,026	(0,049)
$T_i x K_i$	-0.155***	(0.0430)	-0,152**	(0,071)
$L_i x K_i$	-0.125**	(0.0620)	-0,045	(0,057)
Zd	-0.406	(0.0506)	-0,296***	(0,037)
FC	0.93			
Wald Test ($b_1+b_2+b_3=1$)	0.05			
Return to Scale	Constant			
LLF	-1185.99			

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

Table 5. Specifications tests

Null Hypothesis: CD nested in TL	Chi2	Chi2 0.9 value (*df*)	Decision	Choice
Buenos Aires & La Pampa (I)	30.74		Reject H0	TL
Chaco & Santiago del Estero (II)	15.17		Do not Reject H0	CD
Corrientes & Misiones (III)	16.90		Reject H0	TL
Pooled Sample	67.34	15.98 (10)	Reject H0	TL
Null Hypothesis: regions share technology				
Pooled sample vs. sum of individual log-likelihood	167.09	41.42 (32)	Reject H0	Meta-frontier

Table 6. Metatechnology ratio (MTR) and technical efficiency (TE) for selected production frontier models

	Mean	Sd	Min	Max
Metatechnology Ratio (MTR)				
Buenos Aires & La Pampa	0.968	0.061	0.417	1.000
Chaco & Santiago del Estero	0.412	0.071	0.167	0.648
Corrientes & Misiones	0.415	0.138	0.126	1.000
Technical Efficiency (TE & TE*)				
Buenos Aires & La Pampa				
TE from SPF (TL)	0.537	0.200	0.038	0.923
TE from MF (TE*)	0.521	0.198	0.038	0.893
Chaco & Santiago del Estero				
TE from SPF (TL)	0.669	0.106	0.295	0.868
TE from MF (TE*)	0.276	0.065	0.097	0.501
Corrientes & Misiones				
TE from SPF (TL)	0.589	0.156	0.133	0.880
TE from MF (TE*)	0.244	0.104	0.038	0.721
Pooled Sample				
TL	0.582	0.182	0.038	0.923
MF*	0.417	0.203	0.038	0.893

TE*: TE measured with respect to the meta-frontier (MF)

TL: calculated from the TL model

RMT: Metatechnology ratio estimated following equation (9).

Figure 2. Geographical distribution of Technical Efficiency (TE) and Meta-technology Ratios (MTR).