Agrekon

Agricultural Economics Research, Policy and Practice in Southern Africa

ISSN: 0303-1853 (Print) 2078-0400 (Online) Journal homepage: www.tandfonline.com/journals/ragr20

Improving livelihoods of smallholder farmers through region specific strategies: a case study of South African sheep production

Yong Sebastian Nyam, Nicolette Matthews & Yonas Tesfamariam Bahta

AGREKON
2020, VOL. 59, NO. 1, 1–15
https://doi.org/10.1080/03031853.2019.1639205

Improving livelihoods of smallholder farmers through region specific strategies: a case study of South African sheep production

Yong Sebastian Nyam, Nicolette Matthews and Yonas Tesfamariam Bahta

Department of Agricultural Economics, University of the Free State, Bloemfontein, South Africa

ABSTRACT
The paper investigates if two groups of smallholder sheep farmers who farm using communal grazing land in the N8 development corridor of South Africa can be treated in a homogenous manner. Heterogeneous production environments should result in different production responses, which are unique to the production region. A better understanding of these unique responses could guide the development of improved strategies to increase smallholder livestock production in South Africa. A stochastic production frontier approach was used to evaluate two production districts before grouping the data and estimating the metafrontier. The metafrontier represents a homogenous benchmark for all producers. Results indicate that the two districts cannot be treated the same. Therefore a single production function and strategy cannot be used to improve productivity and efficiency of livestock production in both the districts. The conclusion is that the development of strategies to increase smallholder sheep producers, productivity and efficiency requires an understanding of the production, environmental and institutional factors that the farmers experience within that particular district. Considering the study areas used in the paper, attention to the more technical aspects of production and management can improve the farmers' productivity and efficiency.

KEYWORDS
Sheep production; stochastic metafrontier; technical efficiency; heterogeneous production environments

JEL CODES
c12; c14; c15; o4

1. Introduction

Livestock production holds great potential to alleviate household food insecurity and poverty in South Africa. The demand for livestock products is expected to increase in developing countries due to increasing population growth and increasing income levels, thereby creating a unique opportunity for livestock producers to sustainably increase livestock production systems as a means for reducing poverty and improving the management of the environment (McDermott et al. 2010). Growing demand for livestock provides an opportunity for livestock producers in less developed countries to increase production. This growth in agricultural production will have to take place in a way that affords smallholder farmers the opportunity to benefit from increased demand by applying environmentally sustainable production methods (Thornton 2010). Livestock is by far the largest agricultural sub-sector in South Africa, contributing an estimated 25–30% of the total agricultural output per year (Blignaut et al. 2014). Furthermore, the livestock industry employs approximately 5,00,000 people nationwide (South African Department of Agriculture, Forestry, & Fisheries [DAFF] 2012). Land used for agriculture comprises approximately 82.3% of the total land area of South

CONTACT Yonas Tesfamariam Bahta Yonas204@yahoo.com Department of Agricultural Economics, University of the Free State, P.O. Box 339, Internal box 58, Bloemfontein, 9300, South Africa
This article was originally published with errors, which have now been corrected in the online version. Please see Correction (http://dx.doi.org/10.1080/03031853.2020.1728996)

Africa, and approximately 68.6% of the agricultural land in South Africa is used for extensive livestock grazing (DAFF 2016). The Free State is the third largest sheep producing province in South Africa and produces approximately 20% of the sheep in the country (DAFF 2016). The N8 development corridor, within the Free State province, is suitable for sheep production and represents a major livestock production area in the province (Nyam 2017).

Sheep production plays a significant economic and socio-cultural role in the livelihoods of households in rural communities. The roles include food supply, a source of income, employment, manure for crop production, agricultural diversification and sustainable agricultural production (Bettencourt et al. 2013). Sheep production plays an essential role in the South African livestock industry, because it is a source of cash income and therefore contributes to smallholder farmers' livelihoods (Brundyna et al. 2005).

Despite the relative importance of livestock production in general and sheep production in particular, South Africa remains a net importer of sheep and sheep products, which means that local sheep consumption exceeds domestic production. This high expenditure on importing sheep products is of concern, because of its negative impact on the country's economic development. The amount South Africa spends importing sheep and sheep products also exerts pressure on the foreign currency reserves. Therefore, the South African government desires to reduce importation of sheep products by promoting domestic sheep production through productivity and efficiency-enhancement measures (DAFF 2016). Local sheep producers cannot compete with the prices of imported sheep products, and this often leads to the reduction of income and standards of living especially among smallholder farmers, given their reliance on sheep production for their livelihood.

Existing international studies, such as those by Perez, Gil, and Sierra (2007), Shomo et al. (2010), Furesi, Madau, and Pulina (2013), and Fathelrahman, Sherif, and Hoag (2014) focus on technical efficiency (TE) of sheep production. Some studies use surveys and fit a Cobb–Douglas production frontier function. Other studies investigate the efficiency of sheep farms using data envelopment analysis, sources of TE in sheep production, TE in the sheep industry, and the effect on important economic derivatives as well as associated risks of small ruminant production in arid areas.

In the African context, most of the studies concentrated on investigating the TE of crops, mango and wool production, agricultural productivity, determining the productivity gap among groundnut farmers, comparing TE of small farms, TE of crop and livestock and determinants of TE (D'Haese et al. 2001; Lema et al. 2012; Otieno, Hubbard, and Ruto 2012; Donkor and Owusu 2014; Bahta et al. 2015; Temoso, Villano, and Hadley 2015; Asekenye et al. 2016; Mensah and Brümmer 2016). Conradie and Piesse (2015) used data envelopment analysis to investigate productivity variations on sheep farms. They also studied which farm-level factors correlate with productivity, and investigated the most efficient sheep farming practices in the Western Cape Province, South Africa. None of these studies, however, assessed the TE of smallholder sheep farmers by accounting for technological variation or heterogeneous production environments. As a result, current knowledge on smallholder sheep production is insufficient to understand how smallholder sheep farmers in South Africa could improve their efficiency (farmers' decisions of resource allocation) and productivity based on an evidence-based analysis. Moreover, due to the lack of knowledge on smallholder sheep production, it is uncertain to what extent communal-grazing smallholder farmers experience production variations due to regional differences.

Heterogeneous production environments should result in different production responses, responses that are unique to the production region. A better understanding of these unique responses could guide the development of improved strategies to increase livestock production within the South African smallholder livestock sector. Efficiency estimation using stochastic frontier analysis (SFA) and data envelopment analysis often assumes homogeneous production technology for all decision-making units in that sector. However, for a variety of reasons, farmers in the same sector may be forced to operate under different production technologies or production environments, due to differences in climate, soil type and financial resources (Mensah and Brümmer 2016). The heterogeneous producers cannot be combined to fit a single frontier, because regional differences could bias results. Once separate frontiers have been fitted for the heterogeneous groups, the results cannot be used to make comparisons since the underlying technological assumptions are not the same.

Therefore, the aim of this paper is to investigate if two groups of smallholder sheep farmers who farm using communal grazing land in the N8 development corridor, Free State, can be treated in a homogenous manner. In other words, when developing a strategy to improve sheep production among these farmers, would a one size fits all approach be used, or would a region-specific strategy be more appropriate? This paper extends the standard estimation of production frontiers and inefficiency effects by fitting a metafrontier that can estimate a common benchmark, which can be used to make comparisons between heterogeneous groups of agricultural producers. The remainder of the paper is structured as follows. Section 2 discusses the study areas, the sampling procedure and data collected from both study areas. Section 3 discusses the procedures employed to conduct the analysis. While Section 4 discusses the results, starting with the hypothesis test, followed by the production frontiers, the metafrontier, the sources of inefficiency and the level of inefficiency and the technological gap ratio of the farmers. The last section, Section 5, draws some conclusions based on the results of the study.

2. Study area and data

2.1. Study area

This study was carried out in the N8 development corridor, Free State province of South Africa (Figure 1). The Free State province is located in the central part of South Africa and is one of nine administrative provinces. The Free State province is situated between latitude 26.6° S and 30.7° S and between longitude 24.3° E and 29.8° E and is the third largest province in South Africa. There are four district municipalities, (Xhariep, Lejweleputswa, Thabo Mofutsanyane and Fezile Dabi districts), and one metropolitan municipality (Mangaung Metro). The district municipalities (Thaba Nchu and Botshabelo) used for the study are located in Mangaung Metro. The main agricultural activities of the Free State include crop production and mixed livestock production. Livestock production is central to agriculture in the province and the study area. Livestock farmers, especially sheep farmers, practice intensively in those areas suitable for sheep production. The Free State is home to large farms that keep cattle for beef and dairy production, sheep and goats and, to a lesser extent, poultry and pigs. The Free State contributes 20% of sheep, 20% of beef and 40% of goats produced in South Africa (Maphalla and Salman 2012).

Figure 1. Map of the research area within the Mangaung metropolitan. Source: AfriGIS (Pty) Ltd. (2019).

The sheep farmers in the study area use free grazing on communal land to rear sheep flocks. Since the producers use a free grazing system that results in a decrease in the quality and quantity of grazing, farmers typically supplement pasture with purchased feeds and concentrates. The farmers tend to use cross-breeding of current breeds with breeds that are easier to manage (e.g., breeding a Merino ewe with a Van Rooy ram). The farmers are also of the opinion that crossbreeds are hardier (e.g., more resistance to parasites or diseases) and would, therefore, require less management and have less health-related issues. Some farmers think that indigenous sheep breeds are better adapted to the area and are less likely to experience health issues or heat stress during the hot summer months. Indigenous breeds are breeds that originate from South Africa and are therefore more hardy to the climatic changes experienced in South Africa, an example of an indigenous breed is the South African Meat Merino.

The health of the animals is a factor of some import to the farmers because the farmers do not have easy access to animal health services. The farmers in the study live in rural areas, are far from veterinary services, and in many cases lack own transport to travel to a veterinary. Extension officers, who have minimal or no training in animal health-related issues, provide veterinary or animal health-related services to the farmers. Sheep and sheep products are sold primarily within informal markets, although some farmers form sharing systems or take collective action to participate within formal markets.

2.2. Sources of data and sampling procedure

Data for this study were collected using structured questionnaires. A total of 217 farmers were interviewed, 157 farmers from Thaba Nchu and 60 farmers from Botshabelo. Respondents were smallholder sheep farmers in Thaba Nchu and Botshabelo along the N8 development corridor of the Free State Province of South Africa. These two districts were chosen, because of the number of livestock farmers, especially sheep farmers in the districts and the suitability of the areas for livestock production. The interviews were conducted during February 2016 regarding the production practices of 2015. Since some of the farmers were unable to communicate adequately in English, five interviewers were hired to conduct the interviews in the local language.

A proportionate stratified random sampling approach was used in Thaba Nchu. A complete list of all villages in Thaba Nchu was requested and obtained from the Department of Agriculture. Villages with the most sheep farmers were identified in the different areas and formed into groups. Seven farmers were chosen from each village in each sub-group, making a total of 21 farmers per subgroup, and therefore a total of 168 farmers were interviewed. Due to incomplete information from some respondents, only 157 responses were eligible (complete) for this study. A complete list of the villages with sheep farmers could not be obtained from the Department of Agriculture in Botshabelo. Therefore, a simple random sampling technique was used to select sheep farmers at random from two areas known for sheep farming. Sixty sheep farmers were selected at random and interviewed, and all their responses were eligible for the study.

The questionnaires were designed to capture relevant input-output data of smallholder sheep farmers. Questions included farmers' sheep production (sheep value in South African Rand (ZAR)), flock size (animals), size of grazing land (ha), amount of labour (hired and family labour in mandays), amount spent on animal health services (ZAR) and amount spent on feed (ZAR), operating and transportation costs, management practices or grazing systems (access to communal land or access to tenured land), and choice of breed. Other relevant information, such as socio-economic and institutional variables, were also captured. The socio-economic variables captured included age, gender, household size and education, while the institutional variables included extension services, veterinary services, access to credit, distance to the nearest market and land tenure systems.

The farmers within the study area do not always keep proper records of farming incomes and expenses. However, some of the information, especially price information and the information on the number of animals sold were obtained from the extension officers who keep some records on the farmers' production activities.

2.3. Production, Socio-economic, institutional characteristics and descriptive analysis

The description of the socio-economic, institutional characteristics and descriptive statistics for the variables used in this study and a t-test to test for significant differences between the two districts are presented in Table 1. Results for the average and standard deviations of the socio-economic and institutional characteristics indicates that there are no large differences between the two sheep producing districts. However, the t-test indicates that significant differences exist between the Thaba Nchu and Botshabelo farmers, especially with regards to the production variables. The Thaba Nchu farmers have, on average, slightly more years of farming experience (13 years) compared to Botshabelo farmers (11 years) (significantly different at 5%). The expectation is that farmers with more farming experience would be more efficient. What is interesting to note is that the farmers in Thaba Nchu shy away from cross-breeding and use predominantly indigenous sheep breeds ($p < .05$), which tend to be hardier (41%). The Botshabelo farmers are more inclined to use cross-breeding ($p < .000$) with 47% of the farmers cross-breeding their sheep flocks. Although the farmers do have some indigenous sheep breeds, it seems as if these farmers are less inclined to keep indigenous breeds.

Descriptive statistics for production variables (Table 1) indicate that farmers in Botshabelo produced on average more sheep (valued at ZAR 5 024 in 2015)[1] ($p < .000$) than farmers in Thaba Nchu (ZAR 2 972). Interesting to note is that although the number of maximum animals kept by the Thaba Nchu farmers (120 animals) is larger than that of the Botshabelo farmers ($p < .000$), the average number of animals are slightly more for the Botshabelo farmers (27 animals compared to 24 animals). The farmers in Botshabelo use on average 10 man-days per month more than farmers in Thaba Nchu (8 days compared to 18 days). The variation in man-days used is also greater for Botshabelo farmers (21 man-days) ($p < .000$).

The descriptive statistics for operating and transport expenses and animal-health cost all indicate a higher average cost ($p < .000$) and larger standard deviation for farmers in Thaba Nchu compared to farmers in Botshabelo. The cost of purchased feed is on average somewhat higher (ZAR 100) for Thaba Nchu farmers ($p < .000$), although the standard deviation of these farmers is lower (ZAR 26) compared to the Botshabelo farmers.

The *t*-test probability provided in Table 1, indicates that significant differences ($p < .000$) exist between the production inputs used and the output produced by the two farming districts. The descriptive statistics indicate that the Botshabelo farmers have on average larger flocks with larger land sizes and spend less on sheep production compared to Thaba Nchu sheep farmers. The expectation is therefore that the Botshobelo farmer should be more technically efficient compared to Thaba Nchu farmers.

3. Theoretical and analytical framework

3.1. The stochastic metafrontier model

The stochastic metafrontier model can estimate the efficiency of different production groups based on their distance from a common frontier (Battese and Rao 2002; Battese, Rao, and O'Donnell 2004; O'Donnell, Rao, and Battese 2008). Results on area-specific resource-use efficiencies can improve a farmer's ability to increase profits from production activities and thereby improve the farmer's livelihood. The stochastic frontier model is relevant to the study since the approach can identify the factors that affect a farmer's ability to use resources optimally, thereby reducing inefficiencies. Assuming that the metafrontier production function for the various regions of the N8 development corridor is known, the stochastic metafrontier model can be illustrated in Figure 2.

Production data are used to determine the individual production frontiers indicated by Production Frontier 1 and Production Frontier 2 in Figure 2. Each of these response functions is estimated

Table 1. Socio-economics, institutional characteristics and summary of statistics sheep producers in Thaba Nchu and Botshabelo study area.

Socio-economics and institutional characteristics				
Variables	Description	Thaba Nchu (N = 157)	Botshabelo (N = 60)	t-stat (prob)
Household size	Number of people in a household	4 (2)	3 (2)	0.464
Sheep loss	Number of sheep loss due to death or theft	11 (18)	13 (21)	0.094*
Sheep experiences	Years of sheep farming experience	13 (11.76)	11 (7.80)	0.037**
Education	Number of years formal education	6.57 (2.56)	6.17 (3.27)	0.194
Extension services	1 = Access to extension services and 0 otherwise	0.45 (0.50)	0.42 (0.50)	0.639
Veterinary services	1 = Access to veterinary services and 0 otherwise	0.33 (0.47)	0.42 (0.5)	0.127
Indigenous sheep breeds	1 = Farmers have indigenous sheep breeds and 0 = otherwise	0.41 (0.50)	0.27 (0.45)	0.037**
Cross-breeding	1 = Farmers use cross-breeding and 0 = otherwise	0.16 (0.37)	0.47 (0.50)	0.000***
Communal land	1 = farmer uses communal land and 0 otherwise	0.72 (0.45)	0.73 (0.45)	0.915

Descriptive/summary statistics							
	Thaba Nchu (N = 157)			Botshabelo (N = 60)			
	Mean	Min	Max	Mean	Min	Max	t-stat (prob)
Sheep output (R)	2972 (11,656)	340	129,600	5024 (6669)	340	26,000	0.000***
Flock size	24 (25)	2	120	27 (27)	2	106	0.000***
Purchased feed (R)	551 (756)	100	4000	541 (782)	100	4114	0.000***
Operating and transport expenses (R)	684 (1216)	90	14,300	466 (234)	100	1400	0.000***
Labour (man-days per month)	8 (13)	6	32	18 (21)	11	93	0.000***
Animal health cost (R)	1289 (1328)	150	8155	954 (776)	220	3500	0.000***

Note: Values in the brackets indicate standard deviations; Kgs = kilograms; R = rand and ha = hectare.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

separately and relate the production of each farmer to a common frontier, the production frontier, which represents the most efficient input-output production decision. Although comparisons between the farmers in a given production district, either district 1 or district 2, can be made, no comparison between the two districts is possible. A common benchmark is required to compare

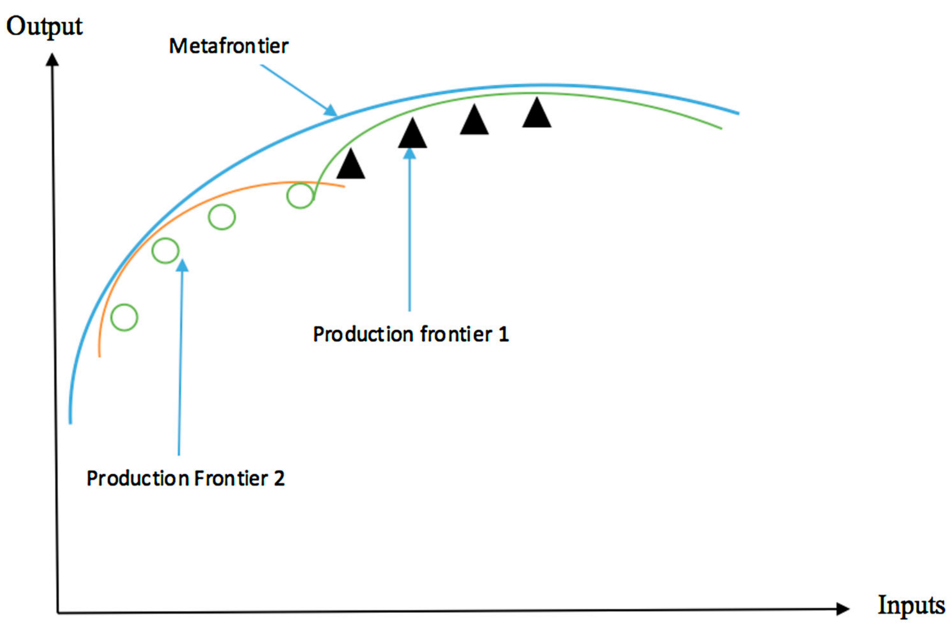

Figure 2. Metafrontier model and stochastic frontiers (Frontier 1 and Frontier 2) Source: Adapted from Mensah and Brümmer (2016)

production decisions made by farmers in district 1 to production decisions in district 2. The underlying assumption is that the farmers in district 1 and district 2 use different technology sets (actual technology and environmental factors such as weather and grazing conditions) to produce their output. As a result, the individual production frontiers are not comparable, but a common benchmark that allows for a heterogeneous technology set, such as a metafrontier, can be used to make comparisons. The metafrontier envelops the individual production frontier to ensure that no single farmer can outperform the common benchmark. The reader should note that comparisons are then made between the producers in the production districts and the common benchmark. The estimation of a metafrontier requires two steps. First, the individual frontiers for the two districts are fitted. During the second step, the results from the individual frontiers and the data are used to estimate the metafrontier.

3.1.1. Fitting the individual frontier

A Cobb Douglas stochastic frontier was estimated for every district using Equation (1). The choice of functional form was informed by literature and compared to other functional forms (e.g., linear, quadratic and transcendental). The Cobb Douglas form provided a better fit for the data. The stochastic frontier model was fitted using Frontier 4.1 software (Coelli 1996).

$$Y_i(w) = f(X_i(w), \beta(w))e^{V_i(w)-U_i(w)} \tag{1}$$

$$i = 1, 2, 3, \ldots, N; \quad w = 1, 2$$

where $Y_i(w)$ represents sheep output produced by the i-th sheep farm in the w-th district. $X_i(w)$ is a vector of the farm inputs used by the i-th sheep farm to produce sheep, while, $\beta(w)$ is the coefficients to be estimated. The farm inputs considered for the study are: the size of the sheep flock, animal health cost (cost of veterinary drugs used and services), feed cost, labour, and operating and transport cost (including electricity, fuel, and machinery). $V_i(w)$ is an independently and identically distributed random error term with zero mean and variance, $\sigma_v^2(0, \sigma_{v(w)}^2)$ (Battese and Broca 1997). $U_i(w)$ denotes the non-negative asymmetric component that measures technical inefficiency effects. The estimated inefficiency score ranges between 0 and 1, with scores of one (1) indicating that the farmer is 100% efficient in converting inputs into outputs. The efficiency scores estimated for the two districts can be used to compare a single producer to other producers in their district. However, no comparison can be made across districts, unless a common benchmark or metafrontier is known.

3.1.2. Fitting the metafrontier

Estimation of the metafrontier requires the use of an optimisation procedure that minimises the absolute deviation between the metafrontier and the individual frontiers for every sheep farmer (i). The optimisation model uses the data sets for the two districts (w) and the coefficients (β_w) estimated in Equation 1 to solve the linear programming problem given in Equation 2 subject to the constraint in Equation (3).

$$\min \sum_{i=1}^{I} |\ln f(X_i(w), \beta^*) - \ln f(X_i(w), \beta_w)| \tag{2}$$

$$\text{s.t.} \qquad \ln f(X_i(w), \beta^*) \geq \ln f(X_i(w), \beta_w) \tag{3}$$

where β^* is the vector of parameters of the metafrontier to be estimated, such that the output at the metafrontier is always greater or equal to the output from the individual districts. While In denotes the use of a logarithmic function and $f(X_i(w), \beta^*)$ shows that we are estimating output as a function of input use ($X_i(w)$) and the estimated β^* parameters. SHAZAM 11 was used to solve the linear programming model.

The group frontiers and metafrontier can be used to determine how producers compare with their peers in the same district and to make comparisons across districts. Comparisons across the heterogeneous districts require the estimation of a technology gap ratio (TGR). The TGR measures the rate of change of output for the production frontier for each district municipality relative to the potential output as defined by the metafrontier function, given by the available factor inputs (Battese and Rao 2002; Battese, Rao, and O'Donnell 2004). The TGR is calculated using Equation (4):

$$TGR_{iw} = \frac{f(X_i(w), \beta_w)}{f(X_i(w), \beta^*)} \tag{4}$$

The values of TGR range between zero (0) and one (1), where a value closer to one (1) indicates that the sheep farmer is operating closer to the metafrontier.

3.1.3. Explaining the variation in TE

Once technical efficiencies are determined, it is possible to regress socio-economic and institutional or production related factors against the TE score to determine the sources of variation. The sources of variation will indicate to the various stakeholders what the sources of inefficiency are and how farmers can change their production activities to improve resource-use efficiency. Typically, a linear regression technique such as OLS is used. The district TE levels and the factors that explain the variation in technical efficiencies are determined using a simultaneous equation approach in Frontier 4.1. The inefficiency model used is specified as:

$$U_i(w) = \varphi_0 + \sum_{i=1}^{9} \varphi_i Z_i(w) + \varepsilon \tag{5}$$

Where $U_i(w)$ represents the technical inefficiency of the ith sheep farm in each district municipality. $Z_i(w)$ is a vector of all explanatory variables associated with the inefficiency model. φ_0 represents the constant term and φ_i represents a vector of all the unknown parameters to be estimated, while ε represents the error term. The variables used to determine the sources of inefficiency are the use of indigenous sheep breeds, use of cross-breeding methods, sheep farming experience, use of communal land for grazing, level of education, household size[2], access to veterinary services, the number of sheep lost due to death or theft, and access to extension services.

3.2. Test of hypothesis

Hypothesis tests are necessary to determine the validity of the approach used, and therefore the results. Hypothesis testing was conducted first to determine if the variation in the technical inefficiencies are random (non-stochastic effect). And secondly, to determine the appropriateness of the use of a metafrontier using a generalised likelihood ratio test. Where the frontier results from a pooled model form the null hypothesis model and the combined effect of the Botshabelo and Thaba Nchu results form the alternative hypothesis model[3]. For more detail on generalised likelihood ratio tests refer to Coelli (1995).

4. Results and discussion

4.1. Results of hypothesis testing

The results of the hypothesis tests are presented in Table 2. The first null hypothesis ($H_0{:}\gamma = 0$), tests whether the inefficiency effects are random. Since the estimated statistic (17.2 and 23.7) is greater than the critical values (2.7) in the Kodde and Palm (1986) Chi-square table, H_0 is rejected. Since we reject the null hypothesis, we separate the production function from the inefficiency model, where we explain the farmer's level of inefficiency based on observed variables.

Table 2. Results of hypotheses test.

Null hypothesis	Location	Test statistic	Critical value[a]	Decision
$H_0{:}\gamma = 0$	Thaba Nchu	17.207	2.706	Reject H_0
	Botshabelo	23.736	2.706	Reject H_0
$H_0{:}\gamma_{Pool} = \gamma_{Thaba-Nchu} = \gamma_{Botshabelo}$		30.016	7.045	Reject H_0

The last hypothesis ($H_0{:}\gamma_{Pool} = \gamma_{Thaba-Nchu} = \gamma_{Botshabelo}$) was used to determine if a separate function should be fitted for Thaba Nchu and Botshabelo or if the data can be pooled to fit only one function. The underlying assumption of the test is that the two districts have the same technologies and therefore only a pooled function can be fitted. The estimated test statistic of 30 is greater than the critical value (7); therefore the null hypothesis is rejected. Results, therefore, indicate that the two districts use different technologies and therefore separate functions should be used to estimate the efficiencies for farmers in Thaba Nchu and Botshabelo.

4.2. Stochastic production frontier parameter estimate

The production parameter estimates for sheep production for the stochastic production functions and the metafrontier are presented in Table 3. The discussion of the results will focus on the stochastic production functions that were estimated for Thaba Nchu and Botshabelo, before moving to the discussion of the metafrontier.

The gamma parameter (γ) measures the total variation of output from the frontier that is attributed to technical inefficiency. The gamma values for Thaba Nchu and Botshabelo are 0.398 and 0.833, respectively, and are significant at 1%. The implication is that TE is a significant contributor to the total deviation of output. Although it should be mentioned that for Thaba Nchu, inefficiency contributes only to 39.8% of the variation in the dependent variable.

Table 3 shows that flock size (number of animals) has a positive and significant effect on output in Thaba Nchu and Botshabelo. The results indicate that sheep farmers who own larger flocks have a higher sheep output, possibly due to economies of scale. This result is in agreement with Otieno, Hubbard, and Ruto (2012) who found a positive correlation between beef herd size and beef output. For the Botshabelo farmers, labour is a significant input for sheep production since the use of labour significantly increases sheep output ($p < .1$). The data indicate that farmers in Botshabelo keep more livestock relative to the farmers in Thaba Nchu. Sheep production can be labour intensive, especially when livestock grazes on communal land. As a result, the use of labour could be more important in Botshabelo than in Thaba Nchu. Operating and transport cost also have a significantly ($p < .05$) positive influence on sheep output. The result initially seems counter-productive. However, the higher operating and transport cost is indicative of the farmer's ability or willingness to seek markets where inputs can be more easily obtained or where higher prices are obtained for sheep products. The results for Thaba Nchu does not show good relationships between sheep production and many of the explanatory variables. It could be that sheep production in the area is affected by factors that were not tested for during the study.

Not considering the significance levels for the variables in the production frontier, results for Thaba Nchu indicate that the producers have on average larger flock sizes, spend more on animal health, feed and labour. The farmers should also spend less on operating and transport costs. While the Botshabelo farmers must have on average larger flocks, spend more on labour, and operating and transport cost, while spending less on feed and animal health costs.

4.3. Metafrontier production function

The estimated parameters for the metafrontier model used to compare the two heterogeneous groups are presented in the last column of Table 3. Since the metafrontier is solved within a mathematical programming framework, it is not possible to estimate the significance of variables. Therefore, only the coefficients are presented in the last column of Table 3. All the coefficients have the expected positive sign, except for animal health cost and cost of feed, which show a negative sign. The positive effects imply that an increase in farm inputs will increase sheep output at the district level, and vice versa. The negative effects associated with the coefficients of animal health costs and cost of feed in the metafrontier estimation could indicate that the farmers are either using the wrong drugs or are miss-diagnosing diseases and therefore using the incorrect treatment. Also, farmers could be using insufficient levels of feed, which will affect the growth of the sheep and hence, sheep output.

4.4. Determinants of technical inefficiency in sheep production

The estimates of the determinants of technical inefficiency of sheep in the study areas are presented in Table 3. Since the dependent variable of the inefficiency model is the level of inefficiency, a positive sign would indicate that the independent variable results in increased levels of inefficiency. Independent variables with a negative coefficient would, therefore, increase producers efficiency level.

The results for the inefficiency model indicates that the factors that affect farmers' level of inefficiency are different for Thaba Nchu and Botshabelo. The factors that significantly affect the level of inefficiency in Thaba Nchu is the use of indigenous sheep breeds ($p < .05$), use of communal land ($p < .01$), and level of education ($p < .01$). Results indicate that the use of indigenous sheep breeds decreases the level of inefficiency, thereby increasing the level of efficiency. The negative effect or the use of indigenous sheep agrees with Otieno, Hubbard, and Ruto (2012), and Bahta and Hikuepi (2015) who found that indigenous cattle breeds reduce technical inefficiency in Kenya and Botswana respectively. This result is indeed as expected since indigenous sheep breeds are locally developed sheep breeds which are adapted to the region.

The use of communal land and inefficiency has a positive relationship, indicating that the use of communal land to graze sheep increases inefficiency. The result is expected since communal grazing land tends to be over-utilised due to the non-exclusive and indivisible nature of the grazing land.

Table 3. Stochastic production frontier parameters and parameter estimates for the metafrontier model and determinants of technical inefficiency in sheep production.

		Stochastic production frontier				
		Thaba Nchu		Botshabelo		Metafrontier
Variables		Coeff	prob	Coeff	prob	Coeff
Constant	β_0	7.043	0.000***	6.550	0.000***	6.485
Flock size	β_1	0.241	0.000***	0.309	0.016**	0.327
Animal health cost	β_2	0.103	0.169	−0.182	−0.289	−0.115
Feed cost	β_3	0.089	0.133	−0.053	−0.595	−0.068
Labour	β_4	0.037	0.759	0.310	0.084*	0.311
Operating and transport cost	β_5	−0.087	−0.316	0.357	0.041**	0.306
Inefficiency model						
Constant	δ_0	−1.292	−0.116	−5.199	−0.172	
Indigenous sheep	δ_1	−1.201	−0.038**	−1.190	−0.379	
Sheep experience	δ_2	0.016	0.160	0.129	0.103	
Cross-breeding method	δ_3	−0.211	−0.740	2.236	0.065*	
Communal land	δ_4	2.103	0.004***	2.971	0.136	
Educational level	δ_5	−0.215	−0.009**	−0.160	−0.221	
Household size	δ_6	0.080	0.372	0.417	0.050**	
Veterinary services	δ_7	−0.342	−0.691	−0.232	−0.756	
Sheep loss	δ_8	0.013	0.171	−0.069	−0.177	
Extension	δ_9	−0.416	0.569	−0.041	−0.956	
Diagnostic statistics						
Sigma square	σ^2	0.544	0.000***	1.260	0.068*	
Gamma	$\gamma = \frac{\sigma_u^2}{\sigma^2}$	0.398	0.004***	0.833	0.000***	
Likelihood function	LF	−142.567		−60.278		
Number of observations	N	157		60		

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Therefore, the grazing efforts required by animals are higher than for animals that graze on land not affected by over-utilisation. Education and inefficiency have a negative relationship, indicating that farmers with higher levels of education are more technically efficient. This result is expected since farmers with higher education levels are better able to interpret production information and make more informed decisions regarding sheep production.

On average, the Thaba Nchu farmers who wish to become more technically efficient use more indigenous sheep breeds, use cross-breeding methods and do not use communal land. Interesting to note is that the more efficient farmers show less sheep farming experience. The efficient farmers also have a higher education level, have smaller households, have access to veterinary services, lose less sheep to theft and diseases and have access to extension services.

The efficiency of sheep production in Botsahbelo is significantly affected by experience in sheep production ($p < .15$), use of cross-breeding methods ($p < .1$) and household size ($p < .1$). Interestingly, increased experience in sheep production results in increased inefficiency, and thereby decreases efficiency. Following the argument of Adhikari and Bjørndal (2009), this result was not as expected since older farmers tend to have more farming experience. However, it could also be argued that older, more experienced farmers are less inclined to adopt new or improved production technology or methods.

Results also indicate that the adoption of cross-breeding increases the inefficiency of sheep production. The implication is that farmers who adopt cross-breeding will have lower efficiency levels than their counterparts. Again the result is not expected. A possible explanation could be that farmers are choosing the breeds incorrectly, thus resulting in the expression of unwanted genes, e.g., slow-growing sheep or small sheep breeds. Therefore, the sheep output variable is reduced and thereby the TE. Household size ($p < .1$) is positively related to technical inefficiency, meaning that farmers with more people within the household tend to be less technically efficient. This result is similar to that found by Otieno, Hubbard, and Ruto (2012) and Mariano et al. (2010) who found that larger family size tended to increase inefficiency in agricultural productivity. These findings suggest that farmers with larger households tend to allocate most of their resources to the upbringing and education of their children, rather than investing in production.

On average, the Botshabelo farmers who wish to become more technically efficient use more indigenous sheep breeds, do not use cross-breeding methods and do not use communal land. Similar to the farmers in the Thaba Nchu district, more efficient farmers show less sheep experience. The efficient farmers also have a higher education level, have smaller households, have access to veterinary services and extension services. Results also show that farmers who lose more sheep tend to show higher levels of efficiency, this result is different than what is expected. A possible explanation could be that the current sheep flocks that the Bothsabelo farmers have are too large, thereby decreasing TE. However, it should be noted that the sheep loss variable is not significant to explain the variation in TE.

4.5. Technical efficiency scores

The summary statistics for the group TE, technological gap ratio (TGR) and TE relative to the metafrontier (TE_M) scores are presented in Table 4.

The results in Table 4 show that sheep farmers in Thaba Nchu and Botshabelo have an average TE score of 84.7% and 73%, respectively. However, TE scores are not sufficient enough to compare the different productions systems since different production frontiers are used in the estimation. The TGR shows that farmers in both production areas have an average TGR score of 56.5% and 94.8% for Thaba Nchu and Botshabelo, respectively. The TGR shows the average performance of each production district using the available technology compared to the metafrontier. The TGR of 0.565 for Thaba Nchu implies that, given the input vector, the maximum average output that can be produced by an average firm in Thaba Nchu is 56.5% of the output that is feasible using the metatechnology. While the TGR for an average farmer in Botshabelo is higher at 94.8%, meaning that the average

Table 4. Summary statistics for technical efficiency, technological gap ratio (TGR) and technical efficiency relative to the metafrontier (TE_M).

Statistics	Thaba Nchu			Botshabelo		
	TE	TGR	TE_M	TE	TGR	TE_M
Mean	0.847	0.565	0.478	0. 730	0.948	0.692
Minimum	0.217	0.167	0.105	0.083	0.851	0.083
Maximum	0.958	1.000	0.941	0.927	1.000	0.914
Std Dev	0.139	0.165	0.158	0.217	0.038	0.207
No of obs	157			60		

farmer in Botshabelo can produce 94.8% of the feasible metatechnology output using current average input levels. The implication is that Botshabelo farmers are producing closer to the metafrontier compared to farmers in Thaba Nchu.

The TE relative to the metafrontier (TE_M) score shows an average score of 47.8% and 69.2% for Thaba Nchu and Botshabelo, respectively. Thus, there is considerable scope for improving smallholder sheep farmers' production in Thaba Nchu and Botshabelo by up to 52.2% and 30.8%, respectively. The implication is that the technical efficiencies are low compared to the common benchmark (metafrontier), suggesting that policy response must be targeted at improving producers relative to a common benchmark.

Further, the results indicate that farmers in Botshabelo are performing better than farmers in Thaba Nchu. The above-estimated TE scores indicate that farmers in both districts are operating on different production frontiers and are performing differently with the available sheep technology. It is, therefore, necessary to design and implement different production strategies to suit the needs of each district to enhance the efficiency of the farmers.

5. Conclusion and recommendations

The paper applied an SFA and the metafrontier approach to determine if two groups of smallholder sheep farmers who farm using communal grazing land can be treated in a homogenous manner. In other words, should tailored approaches be developed for the smallholder sheep farmers based on the environmental factors they experience within a production region or district.

Results from the hypothesis test, (H_0:$\gamma_{Pool} = \gamma_{Thaba-Nchu} = \gamma_{Botshabelo}$), indicate that the two districts must be treated individually since the farmers in the districts do not experience the same environmental factors. As a result, evaluation of the producers' production and efficiency factors requires the use of two separate heterogeneous production response functions. Since two response function is needed, comparisons are only possible to a common benchmark or metafrontier.

The TE scores estimated show that that sheep farmers in Thaba Nchu and Botshabelo have an average TE score of 84.7% and 73%, respectively. Therefore, the Thaba Nchu farmers can increase their output level by 15.3% while using the same inputs, while the Botshabelo farmers can increase their sheep output by 23% while keeping inputs constant. Comparing the farmers to a common benchmark, the metafrontier, indicate that the Thaba Nchu sheep farmers can increase their sheep output by 52.2% using their current input level while the Botshabelo sheep farmers can increase their sheep output by 30.8% while keeping input levels constant. The result, therefore, indicates that although the two groups might seem to show similar levels of TE (relative to group frontiers) when comparing the districts to a common benchmark the groups shows larger efficiency differences (more than 20 percentage points). It is, therefore, possible to provide the Thaba Nchu farmers with incorrect guidelines should you base production advise on what the Botshabelo farmers are doing.

Results from the production response frontier indicate that factors that are significant for sheep production in the two districts are different. Flock size is the only significant factors that affect sheep output in the Thaba Nchu area. While flock size, labour, and operating and transport costs are significant factors that affect sheep output in the Botshebolo area. The results from the inefficiency model indicate that the factors that are significant to increase the level of TE are also different between the two districts. Use of indigenous sheep breeds, use of grazing land other than communal grazing and education levels are significant in explaining the variation of TE in the Thaba Nchu district. While cross-breeding and household size are significant to explaining variation in TE in the Botshabelo district. The conclusion is that the development of strategies to increase smallholder sheep producers productivity and efficiency requires an understanding of the production, environmental and institutional factors that the farmers experience within that particular district. Attention to the more technical aspects of production and management (i.e., the decision on flock size, use of indigenous breeds and use of cross-breeding) can improve the farmers' productivity and efficiency. Although extension services are not significant in the current study, it is advisable to use extension services to provide better guidance to farmers regarding the more technical aspects of production and management of sheep flocks.

Although inefficiencies exist in the two production regions, the technical inefficiency for Thaba Nchu is low with a gamma of 39.8%. Also, the overall models estimated for the two regions does not have a large number of significant variables. The study used variables typically included in productivity and efficiency studies. However, it is very likely that the variables that determine these farmers performance are atypical and has not yet been considered in the literature. It is therefore recommended that further research be conducted to determine the factors that can contribute or explain the smallholder farmers' productivity and efficiency. It is also recommended that future research investigate alternative study areas to identify more variables that can significantly contribute to the success of smallholder producers. Furthermore, it would also be very beneficial if future research could investigate the use of communal grazing versus the use of private grazing land. The expectation is that the variables that farmers deem significant or important for production would be different when they use communal land for production.

Notes

1. 1US$ = ZAR 13.12.
2. Labour (man-days) is used during the estimation of the stochastic production function to determine the relationship between labour used and the level of sheep output produced. Household size is included within the inefficiency model since it is expected that the size of the household can affect the level of efficiency. Whenever labour is provided by predominately household members, efficiency levels typically decrease when households are large (Mariano et al., 2010 and Otieno, Hubbard, and Ruto 2012).
3. $LR = -2[L(H0) - L(Ha)]$, where $L(H0)$ and $L(Ha)$ are the relevant log-likelihood values, and $L(Ha) = L(Botshabelo) + L(Thaba\ Nchu)$. See Rao, O'Donnell, and Battese (2003) and Villano, Boshrabadi, and Fleming (2010).

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Yong Sebastian Nyam http://orcid.org/0000-0001-7175-2873
Nicolette Matthews http://orcid.org/0000-0002-8975-9026
Yonas Tesfamariam Bahta http://orcid.org/0000-0002-3782-5597

References

Adhikari, C. B., and T. Bjørndal. 2009. Measuring the extent of technical inefficiency in Nepalese Agriculture using SDF and DEA models. Working Paper, No 28/09. Institute for Research in Economics and Business Administration. Bergen, Norway.

AfriGIS (Pty) Ltd. 2019. Free State municipality map. https://www.google.com/maps/place/Lejweleputswa/@-29.2060166,26.2508916,10z/data=!4m5!3m4!1s0x1e90f18049c54b5b:0xd8d7a5110dc3e562!8m2!3d-28.3991482!4d26.2304616 (accessed 8 July 2019).

Asekenye, C., B. E. Bravo-Ureta, M. Deom, N. Kidula, D. K. Okello, N. Okoko, and N. Puppala. 2016. Productivity gaps among groundnut farmers in Kenya and Uganda: A stochastic production frontier analysis. *African Journal of Agricultural and Resource Economics* 11 no. 2: 85–100.

Bahta, S., D. Baker, P. Malope, and K. Hikuepi. 2015. A metafrontier analysis of determinants of technical efficiency in beef farm types: An application to Botswana, International Conference of Agricultural Economists (ICAE), Milan, Italy, 8–14 August 2015.

Bahta, S., and K. Hikuepi. 2015. Measuring technical efficiency and technological gaps of beef farmers in three regions of Botswana: An application of meta-frontier approach. *International Farm Management Congress Proceedings* 1: 44–60.

Battese, G., and S. Broca. 1997. Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis* 8 no. 3: 395–414.

Battese, G. E., and D. S. P. Rao. 2002. Technology gap, efficiency and a stochastic function. *International Journal of Business and Economics* 1 no. 2: 1–7.

Battese, G. E., D. S. P. Rao, and C. O'Donnell. 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis* 2 no. 1: 91–103.

Bettencourt, E. M. V., M. Tilman, P. D. S. Henriques, V. Narciso, and M. L. S. Carvalho. 2013. The economic and sociocultural role of livestock in the wellbeing of rural communities of Timor-Leste. CEFAGE-UE working Paper 2013/01.

Blignaut, J. N., M. P. De Wit, J. Knot, S. Midgley, D. J. Crookes, S. Drimie, and N. P. Nkambule. 2014. Sustainable agriculture: A viable option for enhanced food and nutritional security and a sustainable productive resource base in South Africa: An investigation. Baseline Review. Prepared for the Development Bank Southern Africa, Pretoria: ASSET Research.

Brundyna, L., T. S. Brand, A. V. Ferreira, B. B. Aucamp, and A. Durand. 2005. The effect of frequency of supplementation on the production of South African Mutton Merino Ewes grazing wheat stubble. *South African Animal Science* 6 no. 1: 13–18.

Coelli, T. J. 1995. Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis. *Journal of Productivity Analysis* 6 no. 3: 247–68.

Coelli, T. J. 1996. A guide to FRONTIER Version 4.1c: A computer program for stochastic frontier production and cost function estimation, Centre for Efficiency and Productivity Analysis (CEPA). Working Paper No. 7/97, University of New England, Armidale. Australia.

Conradie, B., and J. Piesse. 2015. Productivity benchmarking of free-range sheep operations for Laingsburg. *South Africa. Agrekon* 54 no. 2: 1–17.

D'Haese, M., M. Calus, F. Kirsten, G. van Huylenbroeck, and F. Bostyn. 2001. Efficiency analysis of small-scale wool production in the former Transkei, South Africa. *Agrekon* 40 no. 4: 641–55.

Donkor, E., and V. Owusu. 2014. Effects of land tenure systems on resource-use productivity and efficiency in Ghana's Rice Industry. *African Journal of Agricultural and Resource Economics* 9 no. 4: 286–99.

Fathelrahman, E., S. Sherif, and D. L. K. Hoag. 2014. Small ruminant production system efficiency under Abu-Dhabi. *United Arab Emirates Arid Land Conditions. Agriculture* 4: 288–307.

Furesi, R., F. A. Madau, and P. Pulina. 2013. Technical efficiency in the Sheep Dairy Industry: An application of the Sardinian (Italy) sector. *Agriculture and Food Science* 1 no. 1: 1–11.

Google Maps. 2017. Free State maps. https://www.goggle.co.za/maps (accessed 20 November 2017).

Kodde, D., and F. C. Palm. 1986. Wald criteria for Jointly testing equality and inequality restrictions: Notes and comments. *Econometrica* 54 no. 5: 1243–48.

Lema, J., M. D'Haese, L. D'Haese, A. Frija, and S. Speelman. 2012. Comparing the technical efficiency of farms benefiting from different agricultural interventions in Kenya's Drylands. *Development Southern Africa* 29 no. 2: 287–301.

Maphalla, L. T., and M. V. Salman. 2012. Provincial Report on Education and Training for Agriculture and Rural Development, Free State Department of Agriculture, Forestry & Fisheries, Bloemfontein, South Africa.

Mariano, M. J., R. Villano, E. Fleming, and R. Acda. 2010. *Meta-frontier analysis of farm level efficiencies and environmental-technology gaps in Philippine rice farming*. Australian Agricultural and Resource Economics Society (AARES) 54th Annual Conference, Adelaide, Australia, 10-12 February.

McDermott, J. J., S. J. Staal, H. A. Freeman, M. Herrero, and J. A. Van de Steeg. 2010. Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science* 130 no. 1-3: 95–109.

Mensah, A., and B. Brümmer. 2016. Drivers of technical efficiency and technology gaps in Ghana's Mango production sector: A stochastic metafrontier approach. *African Journal of Agricultural and Resource Economics* 11 no. 2: 101–117.

Nyam, Y. S. 2017. Enhancing sheep farmers productivity in the N8 development corridor. MSc. Dissertation, University of the Free State, South Africa.

O'Donnell, C. J., D. S. P. Rao, and G. Battese. 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Journal of Empirical Economics* 34 no. 2: 231–55.

Otieno, D. J., L. Hubbard, and E. Ruto. 2012. Determinants of technical efficiency in Beef Cattle production in Kenya, International Association of Agricultural Economists (IAAE) Triennial Conference, Brazil 18–24 August, 2012.

Perez, J. P., J. M. Gil, and I. Sierra. 2007. Technical efficiency of meat sheep production systems in Spain. *Small Ruminant Research* 69 no. 1–3: 237–41.

Rao, D. S. P., C. J. O'Donnell, and E. Battese. 2003. Metafrontier functions for the study of inter-regional productivity differences. Working Paper No.WP01/2003. Centre for Efficiency and Productivity Analysis, School of Economics, The University of Queensland.

Shomo, F., M. Ahmed, K. Shideed, A. Aw-Hassan, and O. Erkan. 2010. Source of technical efficiency of sheep production system in dry area in Syria. *Small Ruminant Research* 91 no. 2-3: 160–69.

South Africa Department of Agriculture, Forestery & Fisheries (DAFF). 2012. Profile of livestock production in South Africa, Pretoria, South Africa.

South Africa Department of Agriculture, Forestery & Fisheries (DAFF). 2016. Profile of livestock production in South Africa, Pretoria, South Africa.

Temoso, O., R. A. Villano, and D. Hadley. 2015. Agricultural productivity, efficiency and growth in a semi-arid country: A case study of Botswana. *African Journal of Agricultural and Resource Economics* 10 no. 3: 196–206.

Thornton, P. K. 2010. Livestock production: Recent trends, future prospects. *Philosophical Transactions of the Royal Society* 365 no. 1554: 2853–67.

Villano, R., H. M. Boshrabadi, and E. Fleming. 2010. When is metafrontier analysis appropriate? An example of varietal differences in pistachio production in Iran. *Journal of Agricultural Science and Technology* 12 no. 4: 379–89.