JOURNAL OF AGRICULTURE & SOCIAL SCIENCES
ISSN Print: 1813–2235; ISSN Online: 1814–960X
06–3306/AWB/2008/04–3–95–100
http://www.fspublishers.org

Full Length Article

An Evaluation of Parametric and Non-Parametric Methods of Technical Efficiency Measurement: Application to Small Scale Food Crop Production in Nigeria

IGBEKELE A. AJIBEFUN[1]
Department of Agricultural Economics and Extension, Federal University of Technology, P.M.B. 704, Akure, Nigeria
Cirresponding author's e-mail: iajibefun@yahoo.com

ABSTRACT

Efficiency analysis remains an important issue in economic studies. The objective of this study is to compare the estimation ability of the parametric and non-parametric techniques of frontier models in technical efficiency analyses. For this study, Stochastic Frontier Production Function (SFPF), for parametric technique and the Data Envelopment Analysis (DEA), for non-parametric technique were estimated and compared. Results of analysis indicate that the sample farmers have varying level of technical efficiency, ranging from 0.22 to 0.87 for both techniques. Also the results for both parametric and non-parametric techniques showed that age and education level of sample farmers have significant influence on the level of technical efficiency. The estimated mean technical efficiency do not vary widely with the method used, though some differences in magnitude of individual technical efficiencies are noted for both techniques. Finally, a combination of the technical efficiency scores obtained from the two different methods is proposed as a better set of scores.

Key Words: Stochastic frontier; Data envelopment; Technical efficiency; Nigerian agriculture

INTRODUCTION

Efficiency is an important area of economic analysis that has attracted the attention of economists, especially in the last three decades. Methods of efficiency analysis are parametric methods involving the stochastic frontier production function and the non-parametric methods involving the data envelopment analysis. While parametric method includes production, cost, profit and perhaps revenue functions as alternative methods of describing the production technology and estimating efficiency, the non-parametric methodology involves mainly the use of linear programming techniques. Recently, applications involving parametric and non-parametric distance functions have started to appear in literature (Fare *et al.*, 1993; Lovell *et al.,* 1994; Grosskpof *et al.,* 1996; Coelli & Perelman, 1996). The majority of efficiency studies have been motivated by the desire to estimate the frontier production function and to calculate technical efficiencies. The principal advantage of frontier analysis is that it allows the possibility of calculating technical, allocative and economic efficiency of production. The case of Nigerian small-scale food crop farmers, which is considered in this paper, is a typical example of an industry in which inefficiency is assumed to be present in the production system. The aim of this study is to estimate, discuss and compare, using empirical example, some of the recent methods of efficiency analysis. The focus here is on two commonly used estimation methods:

1. Estimation of parametric frontier production function (Battese & Coelli, 1995 & 1998; Ajibefun *et al*., 2002).
2. Construction of a non-parametric piece-wise linear frontier using the linear programming methods (Fare *et al.,* 1993; Coelli & Perelman, 1996; Forsund & Hjalmarsson, 1997; Bardason & Vassdal, 1998).

The two methods have a range of advantages and disadvantages, which may influence the choice of methods in a particular application. The principal advantage of parametric frontier analysis, which is the Stochastic Frontier Production Function (SFPF), is that it allows the test of hypothesis concerning the goodness of fit of the model. However, the major disadvantage is that it requires specification of technology, which may be restrictive in most cases. Furthermore, the major advantage of the non-parametric frontier analysis, which is the Data Envelopment Analysis (DEA) is that it does not require the specification of a particular functional form for the technology. The main disadvantage is that it is not possible to estimate parameters for the model and hence impossible to test hypothesis concerning the performance of the model.

Majority of the applications of frontier methodology in efficiency analysis utilize only one of the above methods at a time to estimate the production function and technical efficiency of production. This paper tries to shed light on the sensitivity of empirical results to the selection of the

To cite this paper: Ajibefun, I.A., 2008. An evaluation of parametric and non-parametric methods of technical efficiency measurement: application to small scale food crop production in Nigeria. *J. Agri. Soc. Sci.,* 4: 95–100

estimation method. The primary avenue of comparison in this analysis will be to assess the sensitivity of technical efficiency predictions to the choice of estimation method.

While this paper is by no means the first to investigate the sensitivity of technical efficiency estimates to the method of estimation, (Aigner & Chu, 1968; Kopp & Smith, 1980; Ferrier & Lovell, 1990; Coelli & Perelman, 1996; Thiam & Bravo-Ureta, 2000). This study is significant in the sense that it appears to be the first comparative study of frontier estimation methodologies using agricultural data in the African setting.

Frontier modeling and technical efficiency. Technical efficiency is defined as the ability of a producer to produce maximum output from a given set of inputs. Most of the frontier models that have been developed, based on Farrell (1957) work, can be classified into two basic groups: parametric and non-parametric frontier models. While the two methods have some similarities, they have some differences that make some authors have preference for a particular method. For instance, while the programming approach is not stochastic and hence interprets noise as inefficiency, the econometric approach imposes parametric structure on both technology and the distribution of inefficiency, thereby susceptible to specification error. Given the stated differences of the two frontier methods, we consider it necessary in this study to compare the efficiency estimation ability of these methods, with empirical application to small scale food crop production data in Nigeria.

Measurement of technical efficiency is important for the following reasons: Firstly, it is success indicator of performance measure by which production units are evaluated. Secondly, measurement of causes of inefficiency makes it possible to explore the sources of efficiency differentials and elimination of causes of inefficiency. Finally identification of sources of inefficiency is essential to the institution of public and private policies designed to improve performance.

Giving the importance of frontier estimation and the rising interest in technical efficiency analysis, several models of frontiers have been developed. The idea of frontier estimation is to replace the classical approach of efficiency measurement, which is based on the ratio of output to a particular input (partial productivity measure). Dissatisfaction with the shortcomings of the classical approach has led economists to develop advanced econometric and linear programming method–the frontier methods. These two methods have in common the concept of a frontier. It implies that efficient producing units are those that operate on the production frontier, while inefficient producing units are those operating below the production frontier and the level of inefficiency is measured by the level of deviation from the frontier.

Theoretical Framework: Farrell Efficiency Measures

Input-orientated measures. The subject of efficiency measurement started with Farrell (1957). Farrell illustrated his ideas using two inputs X_1 and X_2 to produce output Y. Frontier technology can be reflected by the unit isoquant, in a two-dimensional plane with the input-output ratios as the vertical and horizontal axes such as SS' in Fig. 1.

Farrell proposed that efficiency of a producing unit consists of two components- technical efficiency, which reflects the ability of a firm to obtain maximum output from a given set of inputs and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportion, given their respective prices. The two measures then combine to provide a measure of total economic efficiency. If a given farm uses quantities of inputs, defined by the point *P*, to produce a unit of output, the technical inefficiency of that farm could be represented by the distance *QP*, which is the amount by which all inputs could be proportionally reduced without a reduction in output. The technical efficiency (TE) of a producing unit can then be measured by the ratio:

$$TE_I = OQ / OP \qquad (1)$$

If the input price ratio, represented by the line AA^1 is also known, allocative efficiency may also be calculated. The allocative efficiency (AE) of the farm operating at *P* is defined to be the ratio:

$$AE_I = OR / OQ. \qquad (2)$$

Output–orientated Measures.

The work of Farrell was subsequently adjusted and extended by a large number of authors. Aigner and Chu (1968) considered the estimation of a parametric frontier production function in input/output space. They specified a Cobb-Douglas production function for a sample of *N* producing units as:

$$Ln\,(y_i) = f\,(ln\,(X_i), \beta) - U_i, \;\; i = 1, 2, \text{-------}n \qquad (3)$$

Where y_i is the output of the i^{th} farm; f (.) is a linear function; and U_i is a non-negative variable representing inefficiency in production. This is an output-orientated measure as opposed to the input-orientated measure. It indicates the magnitude of the output of the *i*-th producing units relative to the output that could be produced by the fully efficient producing units using the same input vector.

In the figure, the distance *AB* represents technical inefficiency. That is the amount by which outputs could be increased without requiring extra inputs. Hence:

$$TE_0 = OA / OB \qquad (4)$$

If price information is available, then we can draw the iso-revenue line 'DD' and define the allocative efficiency to be:

$$AE_0 = OB / OC \qquad (5)$$

The stochastic frontier production function. The theoretical definition of a production function has been based on expressing the maximum amount of output obtainable from given input bundles. This is regarded as estimating average production function. This definition assumes that technical inefficiency is absent from the production function.

The idea of stochastic frontier production function can be illustrated with a producing unit using *n* inputs (X_1, X_2, ----- X_n) to produce output *y*. The stochastic frontier production function assumes the presence of technical inefficiency of production and is defined as:

$$Y_i = f(x_i, \beta) \exp(v_i - u_i) i = 1,2, ------, N \qquad (6)$$

Where *v* = random error associated with random factors not under the control of the producing unit. This model is such that the possible production Y_i is bounded above by the stochastic quantity, $f(x_i); exp(v_i)$, hence the term stochastic frontier.

The technical efficiency of an individual producing unit is defined in terms of the ratio of the observed output of the corresponding frontier output, given the available technology.

$$TE = Y_i / Y_i^*$$
$$= f(x_i; \beta) \exp(v_i - u_i) / f(x_i; \beta) \exp(v_i)$$
$$= \exp(u_i) \qquad (7)$$

Y_i is the observed output and Y^* is the frontier output. X_i is a vector of inputs in production while βs are parameters to be estimated, V_i is as defined earlier. For detailed discussion of modeling and estimation of the stochastic frontier production function, see Battese and Coelli (1995 & 1998).

For this study, both the parametric and non-parametric frontier models were estimated and results compared. For the parametric frontier model, the Cobb-Douglas frontier model was assumed to describe the production function of the farmers on which data were obtained. The model in which the determinants of efficiency are incorporated was estimated simultaneously with the Cobb-Douglas stochastic frontier model. The model is represented as:

$$\text{Ln } Y = f(x_i; \beta) \exp(v_i - u_i) \qquad (8)$$

Y, x_i, β, v_i and u_i are as defined earlier.

U_i which defines the inefficiency term is represented by:

$$\mu = f(z_s) \qquad (9)$$

Where z_s are vectors of the determinants of technical efficiency.

The non-parametric model (the Data Envelopment Analysis), which is the second part of the estimation procedure is discussed fully in the next section.

Data envelopment analysis (DEA). Data envelopment analysis (DEA) is the non-parametric mathematical programming approach to frontier estimation. In micro economic theory, the production function can be interpreted as forming the basis for a description of input-output relationships in a farm. Efficiency computations can be made relative to this frontier if it is known. The initial task is to determine, which of the set of decision–making units (DMUs), as represented by observed data, form an empirical production function envelopment surface.

Assuming that there are *n* DMUs to be evaluated, each DMU consumes varying amounts of *n* different inputs to produce *s* different outputs. The DEA model seeks to determine an envelopment surface. The envelopment surface is referred to as the efficiency frontier. DEA provides a comprehensive analysis of relative efficiency by evaluating each DMU and measuring its performance relative to an envelopment surface composed of other DMUs. Units that lie on the surface are deemed efficient, while units that do not lie on the surface are termed inefficient and the analysis provides a measure of their relative inefficiency.

DEA estimation. The DEA methodology of interest in this study is that of Fare *et al.* (1989). The method involves the use of linear envelopment frontier over the data points such that all observed points lie on or below the production frontier. Productivity is usually measured as a fraction of outputs over inputs. As long as there are but one input and one output, nothing much is wrong with such a simple method. In a multi- input-multi-output production technology, the simplicity of the method breaks down.

Let the input production possibility set be defined as *L(Y)* i.e., all combinations of input, *x,* that can produce a given output *Y*. similarly, an output production possibility set is defined as *P(X)* i.e., all combinations of outputs, *Y* that can be produced by a set of inputs, *X*. *L(Y)* consists of efficient production and inefficient production. For efficient production, it means some minimum combination of *X* that can produce *Y*. For inefficient production, it means any production where more than the minimum *X* is used to produce the given *Y*.

This concept of production possibility set is illustrated in Fig. 3 below in the case of two inputs x_1 and x_2.

Consider $X_k = (X_{k1}, Xk_2)$, $K \in [1, 2, ------, N]$ and $X_k \in L(Y)$. X_k is an actual observation of inputs used by farm *K* to produce a given output of *Y*.

If in Fig. 3 input vectors *A*, *B* and *C* have been observed, we then ask the question: Is X_k an efficient input vector? This question can be answered in the following ways. If X_k can be reduced proportionally and still be part of *L (Y)*, then X_k is not efficient. If on the contrary no reduction is possible without bringing X_k outside *LY*, then X_k is efficient. We can illustrate the magnitude of inefficiency for X_k on Fig. 3 by drawing a straight line from X_k to the origin *O*. The line crosses the line *Q-Q* which is the lower boundary of *L (Y).* Input observations on the lower boundary are efficient, and *Q-Q* is therefore the subset of *L (Y)* consisting of either efficient observations or linear (convex) combination of such. The line *0Xk* interacts with *Q-Q* at the point given the mark *'a'* which is a linear combination of the actual input observations A and B. Both *A* and *B* are efficient input combinations. The definition of technical efficiency for X_k can then be given as:

$$TEx_k = 0a/0X_k \qquad (10)$$

The Model. In calculating technical efficiency, it is better to introduce DEA via ratio form. For each DMU, we would like to obtain a measure of the ratio of all outputs over all inputs, such as $u'y/v'x_i$, where u is an $M X 1$ vector of output weights and v is a $KX1$ vector of input weights. To select optimal weights, we specify the mathematical programming problem:

$$\begin{aligned} &Max_{u,v} (u'y_i/v'x_i), \\ &St \quad u'y_j/v'x_j \leq 1, j = 1,2....,N, \\ &u,v \geq 0. \end{aligned} \qquad (11)$$

This model involves finding values for u and v, such that the efficiency measure of the i-th DMU is maximized, subject to the constraint that all efficiency measures must be less than one. However, one problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this, one can impose the constraint:

$v'x_i = 1$, which provides,

$$\begin{aligned} &Max_{u,v}.(\Box'y_i) \\ &St \quad \nu'x_i = 1, \\ &\mu'y_j-\nu'x_j \leq 0, \ j = 1,2,\dots,N, \\ &\mu,\nu \geq 0, \end{aligned} \qquad (12)$$

Where the notation change from μ and v reflects the transformation. This model has been automated in the computer programme*, 'Data Envelopment Analysis.* The DEA model in this study was estimated with the *'Data Envelopment Analysis, Version 2* (Coelli & Perelman, 1996).

Determinants of efficiency. In order to know the influence of some variables on the level of technical efficiency, the predicted technical efficiency score were then regressed against the identified variables. The model is presented as:

$$TE = f(Z), \qquad (13)$$

Where TE is the predicted technical efficiency and Z is a vector of determinants of efficiency.

MATERIALS AND METHODS

This section discusses the materials and techniques of data collection and data analysis. The analysis in this study is based on data collected on 200 small scale food crop farmers in Ondo state, Nigeria. Ondo state is one of the 36 states in Nigeria and is located in the Southwestern part of the country. Within the state, there are three distinct ecological zones: the mangrove forest to the south, the rain forest in the middle belt and the derived savanna to the North. The state is well suited for production of crops such as maize, cassava, yam, rice, beans and cocoyam. The bulk of agricultural products come from small scale farmers who manually cultivate rain-fed crops. Mixed cropping system of farming is common among the farmers.

For this study, the data covered two of the three zones in the state, based on ecological consideration (i.e., the North & the middle belt zones of the state, where agricultural production is common). Selection of respondent farmers was multi-stage and involved random and purposive sampling method. In the first stage, the villages in each zone were divided into two strata (urban & rural). The rural stratum was purposively selected as agricultural production is more common in the rural settings than in the urban areas. Within the rural stratum, two villages were randomly selected from each zone. The second stage of selection involved selecting 50 farmers from each selected village, making a total of 200 small scale farmers.

Structured questionnaire was designed to collect data used in the study. Information was collected on different output of the farmers, which were then converted to the value of output, based on the prevailing market prices. Data collected on inputs were categorized into five groups: land, labour, implements, fertilizer and seed. Data were also collected on socio-economic variables of decision-makers of each of the farm households. Such variables include farmer's age, level of education, household size and farm size, as well as other relevant variables. Land was measured in hectares, labour in man days. Implements, seeds and fertilizer were measured in both physical quantity as well as the values of those inputs. Depreciation on implements was also measured. Level of education was measured in number of years of schooling.

RESULTS AND DISCUSSION

Estimated parameters of the stochastic frontier production function. Inference about the stochastic frontier production model is based on the maximum likelihood estimates. The maximum likelihood estimates of the parameters of the models are obtained using the frontier computer programme, Frontier 4.1 (Coelli & Perelman, 1996). For the estimated model, the variance parameter γ is 0.82, which is quite high. This value confirms significant presence of technical inefficiency in the production of the farmers represented by the data.

The production elasticity measures the proportional change in the level of value of farm output as a result of a percentage change in i-th input levels, with all other inputs held constant. For this model, the estimated elasticity have the expected signs. The t-ratios of the estimated coefficients indicate that all the variables in the models are significant at 5% level of significance. The elasticity of mean value of output is estimated to be an increasing function of land, an increasing function of implements, an increasing function of fertilizer, an increasing function of seed as well as an increasing function of labour. Returns-to-scale parameter of 1.01 indicates an increasing returns-to-scale, although the parameter is not significantly different from 1. This result is similar to the result obtained by Ajibefun *et al*. (2002).

Technical efficiency predictions. The results of technical efficiency prediction for the sample farmers are presented in Table I. For both the stochastic frontier production function and the data envelopment analysis, we do not observe large

Table I. Frequency Distribution of Technical Efficiencies

Efficiency Level	SFPF	DEA
< 0.3	8	8
0.30-0.40	16	12
0.41-0.50	20	28
0.51-0.60	24	36
0.61-0.70	60	56
0.71-0.80	44	40
0.81-0.90	24	20
0.91-1.00	4	0

Fig. 1. Farrell's Measure of Technical and Allocative Efficiency

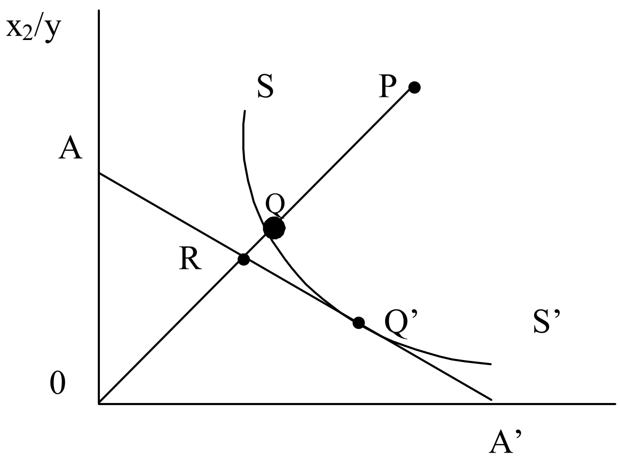
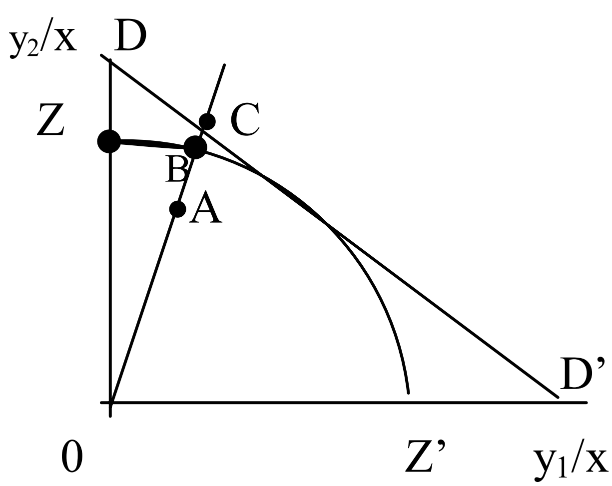


Fig. 2. Technical and allocative efficiency from an output orientation



differences in the technical efficiencies. While the predicted technical efficiencies vary widely across farms for both estimation methods, there are only slight variations across the two different estimation techniques. The mean technical efficiency (0.68) for the stochastic frontier production function is higher than the mean technical efficiency (0.65) for the data envelopment analysis. The differences in the predicted efficiencies are attributable to the fact that the two

Fig. 3. DEA input production possibility set in X_1 –X_2 space

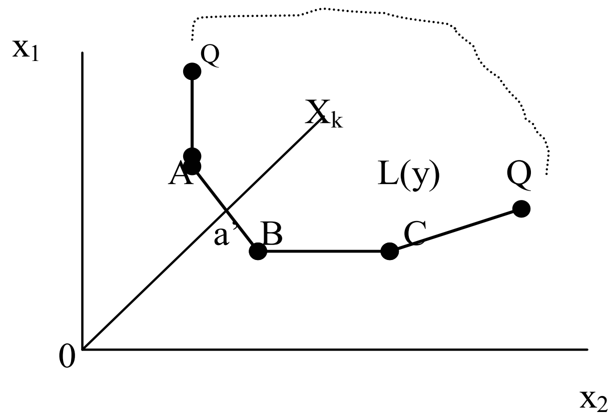
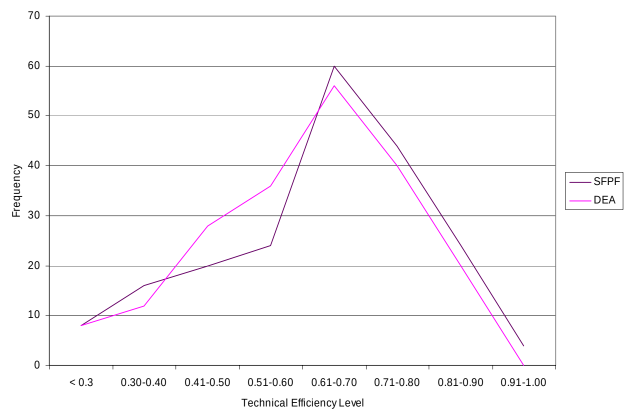


Fig. 4. Comparative Distribution of Technical Efficiency Estimates



approaches measure technical efficiency relative to different frontiers (Battese & Coelli, 1995). Since the DEA model is non-stochastic, noise is reported as inefficiency, hence a lower mean technical efficiency.

To give a better indication and comparison of the distribution of the predicted technical efficiencies, frequency distribution for the two models are presented below.

For a better comparison of the distribution for both SFPF and the DEA, the frequency distribution is plotted in Fig. 4. The distribution shows an interesting pattern. There are clearly two distribution regions. The first region exists at efficiency range between 0.0 and 0.60, while the second region exists between efficiency range of 0.61 and 1.0. In the first region, the distribution of efficiency estimates from both estimation techniques is dissimilar, indicating somewhat wide difference in efficiency prediction from both techniques. While there appears to be wide differences in efficiency estimates between 0.0 and 0.6 efficiency range the distribution tends to be very similar between 0.61 and 1.0 efficiency range. The distribution moves in the same pattern in this region. The distribution shows that there are more farmers in the lower efficiency range for the DEA than for the SFPF. In addition, the distribution in the lower efficiency region shows varying patterns for the SFPF and the DEA. The figure shows a close relationship in the efficiency distribution.

Determinants of technical efficiency. The results of the determinants of technical efficiency for both estimation methods are similar. For both methods, age of farmers as well as education level have significant influences on the level of technical efficiency. This result is similar to that obtained by Seyoum *et al.* (1998). While age has inverse effect on the level of technical efficiency for both methods, educational level of respondents positively influences technical efficiency of the respondents for both techniques. The results obtained here are in line with the *a priori* expectation. Education is expected to make farmers less conservative and more receptive to new technology and innovation, which will consequently lead to higher technical efficiency. Age on the other hand is expected to lead to reduction in the level of technical efficiency. Older farmers will have less physical efforts to put in to their farming operation.

CONCLUSION

This study compares the prediction ability of two different techniques, the parametric stochastic frontier production function and the non-parametric data envelopment analysis in technical efficiency prediction, using data on small scale food crop production in Nigeria. The results of analysis indicate variation in the distribution patterns of technical efficiency estimates from the two methods. From a policy standpoint, it is concluded here that a combination of the technical efficiency scores obtained from the two techniques are proposed as the preferred set of technical efficiency scores, given the importance of accurate technical efficiency estimates in policy decision making.

REFERENCES

Aigner, D.J. and S.F. Chu, 1968. "On Es. timating the Industry Production Function". *American Econ. Rev.,* 58: 826–39

Ajibefun, I.A., G.E. Battese and A.G. Daramola, 2002. "Determinants of Technical Efficiency in Smallholder food crop farming: Application of Stochastic Frontier production Function". *Quarterly J. Int. Agric.,* 41: 225–40

Bardason, H. and T. Vassdal, 1998. "Efficiency in Norwegian Trawl Fisheries: A Non-Parametric Frontier Production Analysis". *Proceedings of the Ninth Conference of the International Institute of Fisheries Economics and Trade*, pp: 322–33. Tromso, Norway

Battese, G.E. and T.J. Coelli, 1998. Prediction of Firm-level Technical Efficiencies with A Generalized Frontier Production Function and Panel Data. *J. Econometrics*, 38: 387–99

Battese, G.E. and T.J. Coelli, 1995. "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data". *Empirical Economics*, 20: 325–32

Coelli, T. and S. Perelman, 1996. "*A Comparison of Parametric and Non-Parametric Distance Functions: with Application to European Railways*", pp: 1–16. CREPP, Universite de Liege, Working Papers, No. 3/96

Fare, R., S. Grosskopf, C.A.K. Lovell and C. Pasurka, 1989. "Multilateral Productivity Comparisons When some Outputs are Undesirable: A Non-Parametric Approach". *Rev. Econo. Stat.,* 71: 90–8

Fare, R., S. Grosskopf, C.A.K. Lovell and S. Yaisawarng, 1993. "Derivation of Shadow Prices for Undesirable Outputs: A Distance Function Approach". *Rev. Econ. Stat.,* 75: 374–80

Farrell, M.J., 1957. "The Measurement of Productive Efficiency. *J. Royal Statistical Sci. Series A*., 120: 253–90

Ferrier, G.D. and C.A.K. Lovell, 1990. Measuring Cost Efficiency in Banking: Econometric and Linear Programming Evidence. *J. Econometrics,* 46: 229–45

Forsund, F.R. and L. Hjalmarsson, 1997. "Generalised Farrell Measures of Efficiency: An Application to Milk Processing in Swedish Dairy Plants". *Econ. J.,* 89: 294–315

Grosskpof, S., Hayes L. Taylor and W. Weber, 1996. "Budget Constrained Frontier Measures of Fiscal Equality and Efficiency in Schooling. *Rev. Econ. Stat.,* 93: 65–84

Kopp, R.J. and U.K. Smith, 1980. "Frontier Production Function Estimation for Steam Electric Generation: A Comparative Analysis". *Southern Econ. J.,* 47: 163–73

Lovell, C.A.K., S. Richardson, P. Travers and L.L. Wood, 1994. "Resources and Functioning". *In*: Eichhorn, W. (ed.), *A New View of Inequality in Australia*". Models and Measurement of Welfare and Inequality, Springer,-Verlag, Berlin.

Seyoum, E.T., G.E. Battese and E.M. Fleming, 1998. "Technical Efficiency and Productivity of Maize Producers in Eastern Ethiopia: A Study of Farmers Within and Outside the Sasakawa-Global 2000 Project". *Agric. Econ.,* 19: 341–8

Thiam, A. and B. Bravo-Ureta, 2000. "*Technical Efficiency in Developing Country Agriculture: A Meta-Analysis*". Paper Presented at the XXIV Conference of International Association of Agricultural Economists, 12-19, August, 2000, Berlin.

(Received 09 September 2006; Accepted 15 March 2007)