THE RELATIONSHIP BETWEEN FARM SIZE AND THE TECHNICAL INEFFICIENCY OF PRODUCTION OF WHEAT FARMERS IN THE EASTERN FREE STATE, PROVINCE OF SOUTH AFRICA[1]

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Farm-level data for the 1988/89 agricultural year from a sample survey of wheat farmers in Eastern Free State, are analysed in this paper. Stochastic frontier production functions are estimated, in which the technical inefficiency effects are modelled in terms of the size of the farming operation and other explanatory variables. The technical inefficiency effects for the farmers involved are significant and the null hypothesis that the explanatory variables in the model for the inefficiency effects have zero coefficients is rejected. The technical inefficiency effects are negatively and significantly related to the size of the farms.

Elasticities of mean outputs with respect to the different inputs, together with the technical efficiencies of the wheat farmers, are estimated for both the translog and the Cobb-Douglas stochastic frontier production functions. However, the Cobb-Douglas function is not an adequate representation of the data, given the specifications of the translog stochastic frontier production function.

SAMEVATTING : DIE VERHOUDING TUSSEN PLAASGROOTTE EN DIE TEGNIESE DOELTREFFENDHEID VAN KORINGBOERE IN DIE OOS VRYSTAAT

Gegewens wat vir die 1988/89 landboujaar in 'n opname van koringboere in die Oostelike Vrystaat op plaasvlak ingesamel is, is in hierdie artikel ontleed. Stogastiese front produksiefunksies is geskat. Die tegniese ondoeltreffendheidseffekte is hierin gemodelleer in terme van die grootte van die boerderybesigheid en ander verklarende veranderlikes. Die tegniese ondoeltreffendheidseffekte vir die betrokke boere is betekenisvol en die nulhipotese dat die verklarende veranderlikes in die model zero koëffisiënte vir die ondoeltreffendheidseffekte het, word verwerp. Die tegniese ondoeltreffendheidseffekte is negatief en betekenisvol aan plaasgrootte verwant.

Elastisiteite van gemiddelde uitset met betrekking tot die verskillende insette, tesame met die tegniese doeltreffendhede van koringboere is met behulp van beide die translog- en die Cobb-

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Douglas stogastiese front produksiefunksies geskat. Die Cobb-Douglas funksie gee egter nie 'n behoorlike verteenwoordiging van die data as die spesifikasie van die translog stogastiese front produksiefunksie in gedagte gehou word nie.

1. INTRODUCTION

The stochastic frontier production function, first proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), has a random error term added to the technical inefficiency effect in the frontier function to account for measurement errors in production and factors which are not under the control of the firms in the production process. In this paper, we estimate stochastic frontier production functions for wheat farmers in Eastern Free State using cross-sectional data for the agricultural year, 1988/89. Two different functional forms for the stochastic frontier are considered, namely the Cobb-Douglas and the translog production functions.

The farm-level data used in this study were obtained from the general farm management surveys of wheat farmers in Eastern Free State, conducted by the Department of Agriculture's Directorate of Agricultural Economics. The survey data for 1988/89 are considered because these were the last collected prior to the election of the new government in April 1994. Surveys had previously been conducted every three years (on a rotating basis) for the three major wheat-producing areas of Eastern Free State, Swartland and Rûens (Department of Agriculture, 1994). Seventy two farms were visited in Eastern Free State as part of the effort of the Department of Agriculture to provide information to assist farmers to examine their enterprises. The results were made available to farmers for the preparation of future farming plans, such as determining the average production costs of wheat and judging the relative financial position of farmers in the region.

In this study, the analysis of the data on the wheat farmers in Eastern Free State focuses on the estimation of stochastic frontier production functions in which the technical inefficiency of production is assumed to be a function of the size of the land operated and other variables. The remainder of the paper is divided into four sections. Section 2 discusses South African agriculture and the issue of farm size and efficiency. Section 3 defines the translog stochastic frontier production function that is estimated. In Section 4 the empirical results are presented and discussed. Section 5 discusses some conclusions drawn from the study.

2. SOUTH AFRICAN AGRICULTURE AND EFFICIENCY STUDIES

2.1 Introduction

South African agriculture has a long history of governmental intervention through laws which have affected the prices, access and use of natural resources, finance, capital and labour (Groenewald, 1991). Since the early 1970s, South Africa has experienced double-digit inflation, with prices of inputs rising consistently relative to product prices. The agricultural terms of trade declined steadily during this time. These developments led to financial ruination of many commercial farmers, particularly when this process was exacerbated by drought in the early 1980s. The decline was aggravated further by the poor financial returns of many farmers who had over-invested in machinery and used excessive quantities of fertilisers and credit, which were partially in response to various government policies.

The restructuring of South African agriculture, which started in the early 1980s, saw a major change in farm policy as a result of changes in the broader political economy, on the one hand, and of more direct policy reactions to the needs of the farming sector, on the other. It was realised that the perpetuation of a dualistic system of rights, to both occupation and use of farming land, was not reconcilable with the new social and political transformation that was emerging in the country, aimed at equity and uniformity across all people. The main characteristics of this period were the reversal of policies of racial discrimination and the price distortions from the 1980s into the 1990s. The scrapping of the Land Acts was a cornerstone to the process of healing, by entitling those previously excluded from land ownership or possession.

Land distribution in South Africa is among the most skewed in the world, with approximately 86 per cent of agricultural land held by 67,000 white large-scale farmers, with an average size of about 1280 hectares per farm, supporting a rural population of 5.3 million in 1988. In contrast, a rural population of about 13.1 million blacks resided in the homelands, an area of 17.1 million hectares (World Bank, 1994).

The issue of land redistribution is of great significance in the South African agricultural economy. The relationship between the size of the farming operations and the efficiency of production of farmers is an important issue in this context. Various studies have addressed this relationship in both South Africa and other countries. A brief review of some of these studies is given below.

2.2 South African Studies

Hattingh (1986) reported that there was a positive relationship between farm size and efficiency in sheep farming in the Karoo and in cattle ranching in north-western Transvaal. Hattingh (1986) also found the efficiency of irrigated farms at Vaalharts and dryland grain farms in Free State increased from small to medium-sized farms but declined on the larger farms (size categories not reported). Sartorius von Bach, Koch and van Zyl (1992) constructed an index of managerial ability, based on indicators such as budgeting and the keeping of records, and found it to be highly correlated with both farm size and total farm income among farmers in the Vaalharts Irrigation Area. Chavas and Van Zyl (1993) found that managerial ability and size efficiency were positively related, but debt burden and farm-size efficiency were negatively correlated among farmers in the Aberfeldy district of North Eastern Free State.

Van Zyl, Binswanger and Thirtle (1995) discussed the empirical evidence from various researchers which indicate a negative relationship between farm size and efficiency. It was stated (p.11) that: 'The official definition of the viable farm in terms of size has had a profound effect on the relative profitability of farms smaller than the viable size. Given the high levels of official assistance and subsidies to farmers, the viability definition became almost a self-fulfilling prophesy, because under the Agricultural Credit Act all farms below the viable size were excluded from assistance.'

Van Zyl, Binswanger and Thirtle (1995) conducted empirical analyses on farm-level data from official surveys for seven regions in various years. The farm-size efficiency relationship in commercial agriculture was investigated by using three different approaches: total factor productivity, data envelopment analysis (DEA) and regression analysis. Van Zyl, Binswanger and Thirtle (1995) concluded (p.27) that their results established 'the negative relationship between farm size and efficiency in South African commercial farming areas, in spite of a history of distortions and privileges to these farmers which particularly benefited the larger ones.' [5]

2.3 Other Studies

Lau & Yotopoulos (1971) applied the profit function approach in their analysis of relative efficiency in Indian agriculture. Profit functions for small and large farms were compared for a given amount of output and input prices with

[5] *It appears that Van Zyl, Binswanger and Thirtle (1995) frequently use the term 'efficiency' where it would be more appropriate to use the term 'productivity'.*

fixed quantities of land and capital. They found that smaller farms had higher profits per unit of land than large farms and concluded that small farms attained higher levels of technical efficiency.

Berry & Cline (1979) found that the value added per unit of invested capital for the second smallest farm-size group (10 to 50 ha) in the Muda River region of Malaysia exceeded that of the largest farm group (200 to 500 ha) by 65 per cent.

Bagi (1982) estimated stochastic frontier production functions for both small and large farms in West Tennessee. He found that both small and large crop farms had almost equal technical efficiency, but large mixed farms were technically more efficient than small mixed farms.

A World Bank (1983) study of the efficiency of small versus large farms in Kenya, using 1973/74 data, found that output per hectare was 19 times higher and employment per hectare was 30 times higher on holdings under 0.5 hectares than on holdings over 8 hectares.

Coelli & Battese (1996) estimated stochastic frontier production functions using panel data from three villages with diverse agro-climatic characteristics in the semi-arid tropics of India. The technical inefficiency effects in the stochastic frontiers were modelled in terms of farm size, age and education of the farmers and the year of observation. The results indicated a significant inverse relationship between farm size and the level of the technical inefficiency effects in two of the three villages.

2.4 Concluding Comments

Van Zyl, Binswanger & Thirtle (1995) concluded their literature review by stating (p.15): 'The evidence on the farm-size efficiency relationship is mixed. However … in some cases inappropriate analytical methods and measurement variables were used'. We believe that it is important to clearly define the terms and methodologies adopted in investigating the relationship between farm size and the efficiency of farms in any particular region. In the next section, we define the stochastic frontier production function model which is the basis of our analyses on this issue.

3. STOCHASTIC FRONTIER MODEL

In this study, a translog stochastic frontier production function is assumed to be the appropriate model for the analysis of the data on wheat farmers in Eastern Free State. The model to be estimated is defined by

$$\ell n\, Y_i = \beta_0 + \sum_{j=1}^{4} \beta_j x_{ji} + \sum_{j\leq}^{4} \sum_{k=1}^{4} \beta_{jk} x_{ji} x_{ki} + V_i - U_i \ , \tag{1}$$

where the subscript, i, indicates the observation is for the i-th farmer in the survey, i=1, 2,…,71[6];

ℓn represents the natural logarithm (i.e., to the base, e);

Y represents the total value of all agricultural output (expressed in Rands) on the given farm;

x_1 represents the logarithm of the total amount of land (in hectares) operated by the wheat farmer, excluding farmyard and waste land;

x_2 is the logarithm of the total of machinery costs (expressed in Rands);

x_3 is the logarithm of the total of the remuneration for the labour of black and white workers (expressed in Rands);

x_4 is the logarithm of the cost of other inputs for the directly allocatable expenditures in the production of wheat (expressed in Rands);

the V_is are assumed to be independent and identically distributed as normal random variables with mean zero and variance, σ_V^2, independent of the U_is;

the U_is are non-negative random variables, associated with technical inefficiency of production[7], which are assumed to be independently distributed, such that U_i is obtained by truncation (at zero) of the normal distribution with variance, σ^2, and mean, μ_i, where the mean is defined by

6 *Data from one of the 72 sample farms were excluded from the analysis because it was recorded that there was zero remuneration for labour on that farm.*

7 *Given that the value of output is the dependent variable in the frontier function, rather than physical output, the inefficiency effects in the model may be influenced by allocative inefficiencies, in addition to technical inefficiencies of production.*

$$\mu_i = \delta_0 + \delta_1 \, \ell n(\text{Land}_i) + \delta_2 (\text{Pasture}_i / \text{Land}_i) + \delta_3 (\text{Variable}_i / \text{Fixed Costs}_i) \quad (2)$$

where

$\text{Pasture}_i/\text{Land}_i$ is the ratio of the area of pasture land to the total area of land operated; and $\text{Variable}_i/\text{Fixed Costs}_i$ is the ratio of the cost of other inputs to the fixed costs of the farming operation.

The technical inefficiency effects in equation (2) are modelled in terms of the logarithm of area of land operated, whereas Coelli and Battese (1996) and Ngwenya (1996) used land directly[8]. The Pasture/Land ratio is expected to have a positive effect on the size of the technical inefficiency effects, i.e., as the relative area of pasture land increases, and so the time the farmer allocates towards pasture improvement or livestock enterprises increases, the technical inefficiency of the overall farming operation of the wheat farmers is expected to increase. The ratio of the variable to fixed costs is used to estimate how the inefficiency effects change with increasing the costs of other inputs (associated with x_4 in the production frontier) relative to the fixed costs of the farming operation.

The stochastic frontier model, defined by equations (1) and (2), is a special case of that proposed by Battese & Coelli (1995), in which the inefficiency effects in the stochastic frontier are modelled in terms of other explanatory variables and all the parameters of the model are simultaneously estimated using the method of maximum likelihood. The model is also a special case of the non-neutral stochastic frontier model, proposed by Huang and Lui (1994), because the input variables, land and cost of other inputs, are included in both the frontier function and as explanatory variables for the model for the inefficiency effects.

The technical efficiency of the i-th farmer, given the specifications of the model (1)-(2), is defined by

$$TE_i = \exp(-U_i) \quad (3)$$

[8] *In the specification of the model in Ngwenya (1996), the logarithm of land is used, but the empirical results which are reported were actually for land, not the logarithm of land. Our analyses, presented in this paper, indicate that a better fit is obtained by use of the logarithm of land.*

Various tests of hypotheses for the parameters of the frontier model are conducted using the generalised likelihood-ratio statistic, l, defined by

$$l = -2\,\ell n\ [L(H_0)/L(H_1)] \qquad (4)$$

where

L(H_0) is the value of the likelihood function for the frontier model, in which the parameter restrictions specified by the null hypothesis, H_0, are imposed; and L(H_1) is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then l has approximately a chi-square (or mixed chi-square) distribution with degrees of freedom equal to the difference between the number of parameters estimated under H_1 and H_0, respectively.

The parameters of the stochastic frontier model (1)-(2) and the technical efficiencies of the farmers are estimated using the computer program, FRONTIER Version 4.1, written by Coelli (1994). This program estimates the parameters of the model, such that the variance parameters are expressed in terms of γ and σ_s^2, which are defined by $\gamma \equiv \sigma^2 / \sigma_s^2$ and $\sigma_s^2 \equiv \sigma_v^2 + \sigma^2$.

A summary of the values of the variables in the stochastic frontier model is presented in Table 1. The area of land operated by the wheat farmers averaged slightly less than 1,100 hectares. The cost of machinery averaged about R250 000, which was more than double the expenditure on labour. The average cost of other inputs was slightly less than R100 000. Only a relatively small area of the land operated by wheat farmers was under pasture, associated with livestock enterprises.

Table 1: Summary Statistics for Variables in the Stochastic Frontier Production Function for Wheat Farmers in Eastern Free State in 1988/89

Variable*	Sample Mean	Sample St Dev	Minimum	Maximum
Output (R)	477 448	346 304	66 690	2 050 221
Land (ha)	1 074	621	210	2 657
Machinery (R)	254 464	278 271	21 670	1 448 532
Labour (R)	112 362	266 903	5 802	1 378 608
Other Inputs (R)	97 766	91 346	12 810	428 223
Fixed Costs (R)	212 090	287 778	34 101	1 522 000
Pasture Land (ha)	56	108	0	770

* Land is measured in hectares. All other variables are measured in Rands.

4. EMPIRICAL RESULTS

4.1 Estimates and Tests

The maximum-likelihood estimates for the parameters in the translog and the Cobb-Douglas stochastic frontier production functions for the wheat farmers in Eastern FreeState are presented in Table 2. The coefficients of the input variables in the Cobb-Douglas model are elasticities of *frontier output*, but those for the translog model are not. For the translog production function, the output elasticities with respect to the inputs are functions of the first-order coefficients and the second-order coefficients, together with the levels of the inputs. Hence, we do not discuss the individual coefficient estimates in the translog model, but present estimates of the elasticities in a subsequent section.

Table 2: Maximum-Likelihood Estimates for Parameters of the Translog and Cobb-Douglas Stochastic Frontier Models for the Wheat Farmers in Eastern Free State in 1988/89*

Variable	Parameter	Translog	Cobb-Douglas
Stochastic Frontier			
Constant	β_0	-11.8 (1.9)	3.61 (0.98)
ℓn (Land)	β_1	-4.50 (0.33)	-0.11 (0.14)
ℓn (Machinery)	β_2	1.65 (0.18)	0.286 (0.061)
ℓn (Labour)	β_3	1.313 (0.093)	0.067 (0.041)
ℓn (Other Inputs)	β_4	3.59 (0.20)	0.55 (0.13)
$[\ell n$ (Land)$]^2$	β_{11}	-0.714 (0.029)	
$[\ell n$ (Machinery)$]^2$	β_{22}	0.0007 (0.0027)	
$[\ell n$ (Labour)$]^2$	β_{33}	-0.056 (0.013)	
$[\ell n$ (Other Inputs)$]^2$	β_{44}	-0.095 (0.013)	

Variable	**Parameter**	**Translog**	**Cobb-Douglas**
ℓn (Land)× ℓn (Machinery)	β_{12}	0.154 (0.021)	
ℓn (Land)× ℓn (Labour)	β_{13}	0.493 (0.014)	
ℓn (Land)× ℓn (Other Inputs)	β_{14}	0.637 (0.023)	
ℓn (Machinery)× ℓn (Labour)	β_{23}	-0.012 (0.013)	
ℓn (Machinery)× ℓn (Other Inputs)	β_{24}	-0.196 (0.020)	
ℓn (Labour)× ℓn (Other Inputs)	β_{34}	-0.299 (0.023)	
Inefficiency Model			
Constant	δ_0	0.7 (8.6)	-4.9 (20.7)
ℓn (Land)	δ_1	-0.3 (1.4)	0.3 (1.4)
Pasture/Land	δ_2	3.1 (8.8)	2.5 (11.9)
Variable/Fixed Costs	δ_3	-0.9 (1.4)	0.8 (2.3)
Variance Parameters			
	σ_S^2	1.35 (0.30)	0.7 (2.5)
	γ	0.999999 (0.000035)	0.88 (0.42)
ℓn **(Likelihood)**		**-17.999**	**-30.388**

* The estimated standard errors for the maximum-likelihood estimators are given in parentheses under the coefficient estimates, correct to at least two significant digits. The maximum-likelihood estimates of the parameters of the model are given correct to the same number of digits behind the decimal places as their corresponding standard errors.

The estimates of the coefficients for the inefficiency variables are of particular interest in this study. In the translog model, the coefficient of the logarithm of land is negative, which implies that wheat farmers who operate larger farms are *less inefficient* than those with smaller farms in Eastern Free State. However, for the Cobb-Douglas model, the opposite is observed. The estimated coefficients of the ratio of pasture land to the total land operated are positive for both models, which indicates that technical inefficiency of the wheat farmers increases as the proportion of pasture land increases. Further, the estimated coefficient of the ratio of variable to fixed costs is negative for the translog model, which indicates that the effect of increasing the relative level of variable costs to fixed costs reduces the inefficiency of production of wheat farmers in the region. The coefficient of the ratio of variable costs to fixed costs is estimated to be positive for the Cobb-Douglas model. The estimated standard errors of the estimators of the individual coefficients of the explanatory variables are large relative to their estimates. This indicates that the individual coefficients may not be statistically significant, but generalised likelihood-ratio tests of some composit hypotheses are presented and discussed below.

The estimate of the γ-parameter, associated with the variability of the technical inefficiency effects, is very close to the maximum value of one for the translog model, whereas the estimate is considerably less than one for the Cobb-Douglas model. These results indicate that the technical inefficiency effects are significant in the production of wheat in Eastern Free State. However, the variance of the random error term does not appear to be significant for the translog model, and so the stochastic frontier model may not be significantly different from the corresponding deterministic translog frontier model. This is a surprising result for a production frontier model for farm-level data, in which random errors associated with measurement errors in the output and the effects of excluded variables are expected to be significant.

Three tests of hypotheses for the parameters of the translog stochastic frontier production function are considered. The null hypotheses and the test results are presented in Table 3. The first null hypothesis, H_0: $\gamma=\delta_0=\delta_1=\delta_2=\delta_3=0$, which implies that the technical inefficiency effects are absent from the model, is rejected. Hence the traditional average response function is not an adequate representation for the data, given the specifications of the translog stochastic frontier production function.

The second null hypothesis, H_0: $\delta_1=0$, that the coefficient of the logarithm of land is zero for farmers in Eastern Free State, is rejected. This result may seem to be surprising, given the relatively large standard error for the estimator for the coefficient of the logarithm of land in the inefficiency model, reported in Table 2. However, we prefer the generalised likelihood-ratio test of the hypothesis that δ_1 is zero, rather than the asymptotic t-test on the estimated coefficient.

The last null hypothesis considered in Table 3, $H_0 = \beta_{ij} = 0$, states that the coefficients of the second-order variables in the translog model are zero. This null hypothesis is rejected and so the Cobb-Douglas function is not an adequate representation for the data from the wheat farmers of Eastern Free State in the agricultural year, 1988/89, given the assumptions of the translog stochastic frontier model (1)-(2). This implies that the Cobb-Douglas estimates should not be given much consideration. However, estimates for the coefficients of the Cobb-Douglas function are presented to indicate how different results can be obtained when it is specified rather than the translog model.

Table 3: Generalised Likelihood-Ratio Tests of Hypotheses Involving Parameters of the Translog Stochastic Frontier Production Function for Wheat Farmers of Eastern Free State in 1988/89

Null Hypothesis	ℓn L(H_0)	λ	Critical Value	Decision
H_0: $\gamma=\delta_0=\delta_1=\delta_2=\delta_3=0$	-28.889	21.78	10.37*	Reject H_0
H_0: $\delta_1 = 0$	-23.148	10.30	2.71	Reject H_0
H_0: $\beta_{ij} = 0$	-30.388	24.78	18.31	Reject H_0

* The critical value for the generalised likelihood-ratio test of the first null hypothesis, with $\gamma = 0$, is obtained from Table 1 of Kodde and Palm (1986). The degrees of freedom for this test are calculated as q+1, where q is the number of parameters, other than γ, specified to be zero in H_0. Thus, in this case, q = 4.

4.2 Technical Efficiencies

The predicted technical efficiencies of the wheat farmers for 1988/89 are presented in Table 4. The predicted technical efficiencies for farmers, obtained from the translog model, range from 0.166 to 0.998, with mean technical efficiency estimated to be 0.671. The predictions obtained from the Cobb-Douglas model range from 0.355 to 0.924 and the mean technical efficiency was 0.787. The technical efficiencies obtained from the Cobb-Douglas model appear to be significantly different from those obtained from the translog model. This indicates the extent to which incorrect inference about technical efficiency can be made when the Cobb-Douglas function is not an adequate representation for these data, given the assumptions of the translog stochastic frontier model.

A graph of the frequency distributions of the predicted technical efficiencies is given in Figure 1. The graph gives the frequencies of occurrence of technical efficiencies within intervals of width 0.05 for the two different

Table 4: Estimated Technical Efficiencies for Farmers in Eastern Free State for 1988, Given the Specifications of the Translog and Cobb-Douglas Stochastic Frontier Production Functions

Farmer	Translog	Cobb-Douglas	Farmer	Translog	Cobb-Douglas
1	0.297	0.845	37	0.550	0.829
2	0.804	0.860	38	0.998	0.924
3	0.562	0.763	39	0.487	0.826
4	0.872	0.755	40	0.949	0.842
5	0.908	0.776	41	0.987	0.903
6	0.349	0.794	42	0.996	0.901
7	0.363	0.794	43	0.573	0.844
8	0.901	0.909	44	0.987	0.892
9	0.996	0.777	45	0.367	0.474
10	0.493	0.785	46	0.237	0.389
11	0.605	0.857	47	0.429	0.693
12	0.646	0.830	48	0.377	0.773
13	0.998	0.794	49	0.457	0.753
14	0.412	0.758	50	0.665	0.597
15	0.753	0.842	51	0.513	0.846
16	0.381	0.693	52	0.505	0.827
17	0.983	0.865	53	0.652	0.786
18	0.996	0.791	54	0.991	0.859
19	0.998	0.811	55	0.776	0.760
20	0.901	0.832	56	0.693	0.846
21	0.549	0.797	57	0.684	0.744
22	0.998	0.902	58	0.957	0.893
23	0.997	0.854	59	0.166	0.355
24	0.484	0.827	60	0.212	0.445
25	0.468	0.863	61	0.772	0.813
26	0.416	0.685	62	0.675	0.759
27	0.970	0.883	63	0.280	0.593
28	0.555	0.832	64	0.995	0.850
29	0.701	0.891	65	0.994	0.840
30	0.635	0.724	66	0.382	0.631
31	0.357	0.746	67	0.461	0.773
32	0.737	0.891	68	0.577	0.836
33	0.664	0.881	69	0.482	0.744
34	0.906	0.908	70	0.441	0.600

Farmer	**Translog**	**Cobb-Douglas**	**Farmer**	**Translog**	**Cobb-Douglas**
35	0.866	0.921	71	0.862	0.865
36	0.980	0.906	**Mean**	**0.671**	**0.787**

frontier functions. The distribution of technical efficiencies from the translog model is somewhat bi-modal in shape, with a relatively large number of farms with technical efficiencies greater than 0.95. This figure and the discussion above indicate that the form of the stochastic frontier function has a significant bearing on the technical efficiencies obtained for the sample farmers.

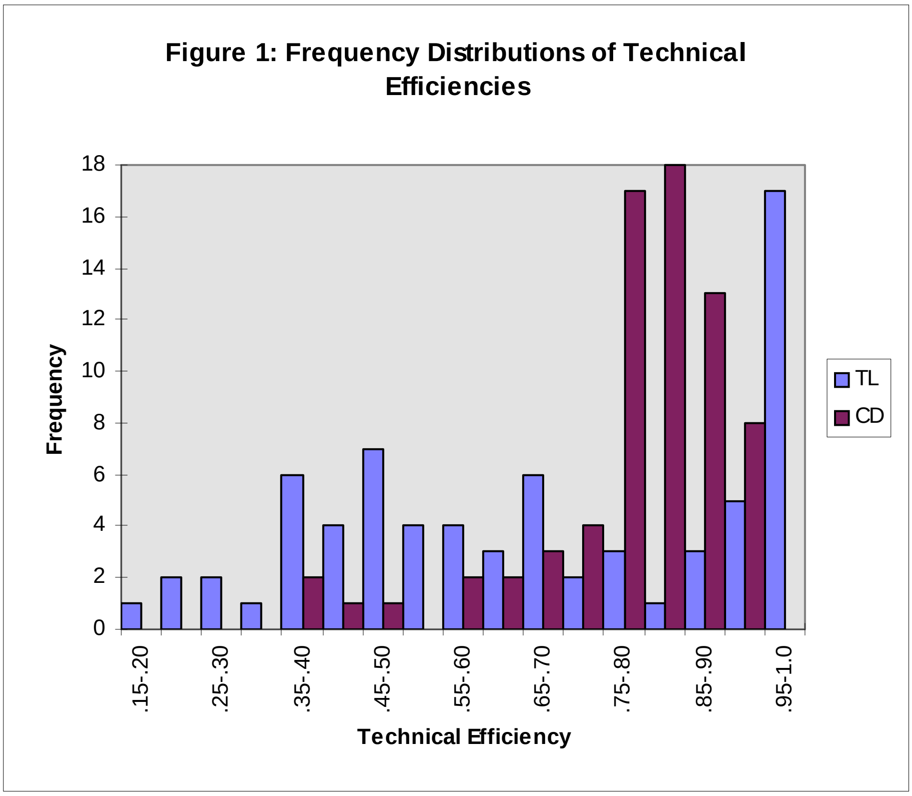

Figure 1: Frequency distirbutions of technical efficiencies
Note: TL = Translog model
CD = Cobb-Douglas function

4.3 Elasticities

In the translog stochastic frontier production function, the elasticities of output with respect to the different inputs are functions of the levels of the inputs involved. Further, the elasticity of the *mean output* with respect to land is also a function of the technical inefficiency effects because the model for the technical inefficiency effects is a function of land, as specified in equation (2). In general, the elasticities of mean output with respect to the four input variables are defined by

$$\partial \ln E(Y_i) / \partial x_{ji} = b_j + 2b_{jj}x_{ji} + \sum_{k \neq j} b_{jk} x_{ki} - C_i \left(\frac{\partial m_i}{\partial x_{ji}} \right) \quad j = 1,2,3,4 \qquad (5)$$

where μ_i is defined by equation (2) and C_i is defined by

$$C_i = 1 - \frac{1}{\sigma} \left\{ \frac{\phi\left(\frac{\mu_i}{\sigma} - \sigma \right)}{\Phi\left(\frac{\mu_i}{\sigma} - \sigma \right)} - \frac{\phi\left(\frac{\mu_i}{\sigma} \right)}{\Phi\left(\frac{\mu_i}{\sigma} \right)} \right\} \qquad (6)$$

and ϕ and Φ represent the density and distribution functions of the standard normal random variable, respectively (see equation (9) in Battese and Broca, 1997). The first term in the elasticity of mean output in equation (5) is called the *elasticity of frontier output* by Battese and Broca (1997). This elasticity indicates the responsiveness of frontier output (for best-practice production) to increases in the inputs. The second term is called the *elasticity of the technical efficiency.*

For the inefficiency model, specified by equation (2), the partial derivatives of the mean, μ_i, with respect to the logarithms of the costs of machinery, labour, and other inputs are zero. However, for land, the component of the elasticity of mean output, which is associated with the inefficiency effects, is given by

$$\left(\frac{\partial \mu}{\partial \ln(Land)} \right) = \delta_1 - \delta_2 \, (\text{Pasture} / \text{Land}) \qquad (7)$$

The elasticities of mean output are estimated at the means of the input variables and the explanatory variables for the inefficiency effects in equation (2). The estimates are presented in Table 5, together with those obtained from the Cobb-Douglas model. For the translog model, the elasticities of *mean output* with respect to land and machinery are estimated to be positive at the mean input values, but those for labour and other inputs are estimated to be negative. The latter results indicate that the use of labour and other inputs (included in cost of other inputs) appear not to be economically optimal. The elasticities of land and machinery are quite large, being estimated to be 0.54 and 0.35, respectively, at the mean values. The estimated standard errors of the elasticity estimators are relatively large. The elasticity of *frontier output* with respect to land is estimated to be 0.49 at the mean, which is less than that for the mean output because the coefficient of the logarithm of land in the inefficiency model is negative and so there is a positive contribution of the elasticity of technical efficiency in obtaining the elasticity of mean output for land.

Table 5: Elasticities of Mean Output Under Different Model Specifications for the Eastern Free State Farmers in 1988/89*

Model	Elasticity with respect to			
	Land	Machinery	Labour	Other Inputs
Translog	0.54	0.35	-0.15	-0.06
Cobb-Douglas	-0.13	0.286	0.067	0.55

For the Cobb-Douglas model, the elasticity of mean output with respect to land is estimated to be -0.13, whereas the elasticity of the frontier output is estimated to be -0.11, as reported in Table 2. The elasticities for machinery and labour are similar to those obtained from the translog model at the mean values, but those for land and other inputs are quite different for the two models. However, the results obtained from the Cobb-Douglas model should not be given much consideration, because the Cobb-Douglas model is not an adequate representation of the data, given the specifications of the translog stochastic frontier production model.

5. CONCLUSION

The empirical analyses indicate that the technical inefficiency effects for wheat farmers in Eastern Free State are highly significant, given the specifications of the translog stochastic frontier production function. Further, the technical inefficiency effects were found to have a significant inverse relationship with farm size. Also, the Cobb-Douglas frontier model was not an adequate representation of the data for wheat farmers in Eastern Free State in 1988/89.

The finding that there exists a negative relationship between farm size and the technical inefficiency effects for wheat producers implies that increases in farm size are associated with decreases in the technical inefficiency of production of wheat farmers. This conflicts with the results obtained by van Zyl, Binswanger and Thirtle (1995) for Eastern Free State and the other regions investigated in their work. However, these researchers did not estimate a stochastic frontier production function. As stated above, their analyses involving total factor productivity calculations did not specifically estimate technical (in)efficiency of production but overall productivity, of which technical efficiency is a component. In addition, Van Zyl, Binswanger and Thirtle (1995) used value of land (to adjust for quality differences) in their analyses, whereas, in this paper, the logarithm of the land area operated by the farmers is used as an explanatory variable for the technical inefficiency effects in a stochastic frontier model. The empirical results in this paper indicate that a positive relationship between technical inefficiency of production and land area operated would be estimated if the Cobb-Douglas function was assumed to specify the technology of the wheat farmers. It appears that when the technology is inappropriately represented by the Cobb-Douglas model, the technical inefficiency effects in the stochastic frontier are estimated to be positively related to land because the second-order effects of the input variables are not accounted for.

Although this study does not include a discussion of variables such as management, rainfall data and extension services, a more refined analysis would be possible, if such data were readily available. The findings obtained in this paper are obviously relative to the data set involved and the technology of the commercial wheat farmers in Eastern FreeState in 1988/89. However, they suggest that the efficiency argument *does not* 'provide a powerful argument for land reform … in South African commercial agriculture' as stated by Van Zyl, Binswanger and Thirtle (1995, p.41). However, conclusions of significance for policy purposes may need more detailed analyses, possibly requiring a more extensive set of panel data.

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