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TECHNICAL INEFFICIENCY OF COMMERCIAL MAIZE PRODUCERS IN SOUTH AFRICA : A STOCHASTIC FRONTIER PRODUCTION FUNCTION APPROACH

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A stochastic frontier production function is defined for panel data on maize producing regions of South Africa. Technical inefficiency effects are assumed to be a function of climatic conditions, time and the terms of trade facing maize producers. The model is derived using nine years of data for the six major maize production regions of South Africa. The results demonstrate how maize farmers have increased their efficiency in the face of a cost-squeeze. The increased efficiency seems to be driven by lower levels of intermediate input use when facing higher costs and uncertain weather conditions.

TEGNIESE ONDOELTREFFENDHEID VAN KOMMERSIËLE MIELIEPRODUSENTE IN SUID-AFRIKA : 'N STOGISTIESE GRENS PRODUKSIEFUNKSIE BENADERING

'n Stogistiese grensproduksiefunksie is opgestel uit data uit die mielieproduksiestreke in Suid-Afrika. Die aanname word gemaak dat tegniese ondoeltreffendhede die funksie is van klimaatstoestande, tydstip en ruilvoet van mielieprodusente. Die model is afgelei uit 9 jare se data uit die vernaamste mieliestreke in Suid-Afrika. Die resultate van die model illustreer hoe mielieboere hul doeltreffendheid verhoog het as gevolg van die pryskoste knyptang. Die verhoogde doeltreffendheid blyk 'n resultaat te wees van lae valk interemediêre inset gebruik in die lig van hoër insetpryse en onsekere klimaatsomstandighede.

1. INTRODUCTION

Maize is the most important crop in South Africa, being both the major feed grain and the staple food of the majority of the South African population. Maize accounts for about 40% of the value of crop production and about 15% of total agricultural production. Over the past several decades, South Africa has been predominantly self-sufficient in maize. This was achieved under an extensive regime of farmer support programmes that favoured large-scale maize producers. Higher production levels were encouraged, among other things by policies providing protection from foreign competition, direct and indirect subsidies, and

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other measures of farmer support. The prices paid to farmers were frequently higher than world (parity) prices. These production incentives were accompanied by other measures such as the Agricultural Marketing Act, by drought aid and other disaster payments (Kirsten & Van Zyl, 1996). These policies created distortions, including the planting of maize in high risk areas with marginal land quality, often with low and variable rainfall, which led to environmental degradation and encouraged unsustainable farming practices (Brand *et al.*, 1992). These policies fostered and maintained inefficiency in maize production.

Since the mid-1980's, there has been widespread deregulation of maize marketing and liberalisation of maize price controls. The reforms stemmed partly from the dissatisfaction of farmers with aspects of the controlled marketing system. At a broader level, changes in macro-economic policy and pressure from the GATT negotiations also played a role. The change in price setting in the maize industry to a more market-based system led to a substantial decline in the real price of maize, 50% since 1983. The real price of farm inputs has, however, remained at a fairly constant level, thus imposing a significant cost-squeeze on farmers. Moreover, many of the subsidies and other forms of support available to farmers, for example drought assistance, have been abolished or scaled down (see Kirsten & Van Zyl, 1996).

This paper examines the technical inefficiency of maize farmers in South Africa using panel data from six maize producing areas over nine years. An attempt is also made to explain the changes in the inefficiencies over time. The paper is structured as follows: the next section describes the stochastic production function from which the technical inefficiency effects can be established. Section three presents the estimation and results. This is followed by the conclusion.

2. THE STOCHASTIC FRONTIER PRODUCTION FUNCTION

The stochastic frontier model approach uses parametric estimation to create a frontier from which efficiency levels are computed directly. The stochastic frontier regression model is the classical linear regression model with a non-normal, asymmetric disturbance term. This disturbance term is decomposed into two individual parts, which are assumed to be independent. The first is defined to be normally distributed random errors and represents the usual statistical noise, such as the weather. The second part, the stochastic element, is non-positive and can assume several distributions. This represents aspects of the farmer's behaviour which result in failure to produce maximum output, given the inputs at their disposal, and is under the control of the farmer. Thus, some differences between particular farms may be random, and the errors pick up the individual effects and construct a frontier, with the deterministic part of the regression providing an upper bound on output.

Aigner, Lovell and Schmidt (1977) developed the stochastic frontier model presented here. The general formulation is:

$$Yi = a + bXij + ei, \text{ where } ei = vi - mi \tag{1}$$

where

$$\mu = |U| \text{ and } U \sim N[0,\sigma_\mu^2] \text{ and } \nu \sim N[0,\sigma_v^2].$$

In this production model, the μ_i's are negative, one-sided error terms representing technical inefficiency. The value of μ_i is interpreted as the technical inefficiency of each firm in the sense that they measure the shortfalls in output Y_i from its maximum possible value given by the stochastic frontier. The ν_i's are two-sided error terms representing the usual statistical noise found in any relationship. They are uncorrelated with the regressors.

Assumptions relating to the two elements of the error term are their mutual independence and the requirement that ν_i is normally distributed. The μ_i's are assumed to be uncorrelated with the regressors and are most frequently assumed to be distributed as either half or truncated normal or exponential. Estimating the model in equation (1) results in the usual residuals, the estimated ε_i's. The decomposition of this error term into two components to allow for the actual prediction of the technical efficiencies of individual farms from the stochastic frontier model is from Jondrow, Lovell, Materov & Schmidt (1982). The model used here is a development of equation (1) introduced by Battese & Coelli (1995). The stochastic frontier production function is defined as

$$Y_i = \exp(x_i b + V_i - U_i) \tag{2}$$

where Y_i denotes the production of the ith farm (i=1, 2, ... N) and the x_i's are the inputs. The V_i's are assumed to be iid N $(0,\sigma_V^2)$ random errors, distributed independently of the U_i's. The U_i's are non-negative random variables, associated with technical inefficiency of production, which are assumed to be independently distributed, such that U_i is obtained by truncation (at zero) of the normal distribution with mean $z_i\delta$, and variance σ_2. The z_i's are further explanatory variables concerned with the farm level technical efficiency in production. Finally, β and δ are vectors of unknown coefficients.

Equation (2) specifies the stochastic frontier production function in terms of the original production values. However, the technical inefficiency effects, the U_i's, are assumed to be a function of a set of explanatory variables, the z_i's, and an unknown vector of coefficients, δ. The explanatory variables in this inefficiency model may include some input variables in the stochastic frontier, provided that the inefficiency effects are stochastic. If the first *z*-variable has a value of one and the coefficients of all other *z*-variables are zero, then this case represents the model specified in Stevenson (1980) and Battese & Coelli (1988, 1992). If all elements of the δ-vector are equal to zero, then the technical inefficiency effects are not related to the z-variables and the half-normal distribution, as specified by the results of Aigner, Lovell & Schmidt (1977). If interactions between firm-specific variables and input variables are included as *z*-variables, then the non-neutral stochastic frontier in Huang and Liu (1994) is obtained.

The technical inefficiency effects, U_i in the stochastic frontier model (2), are specified as in equation (3).

$$U_i = z_i d + W_i \tag{3}$$

where the random variable, W_i, is defined by the truncation of the normal distribution with zero mean and variance, σ^2, such that the point of truncation is -$z_i\delta$, i.e. $W_i \geq -z_i\delta$. These assumptions are consistent with U_i being a non-negative truncation of the $N(z_i\delta,\sigma^2)$ distribution. Thus, the technical efficiency of production for the *i*th firm is defined by

$$TE_i = \exp(-U_i) = \exp(-z_i d - W_i) \tag{4}$$

where the prediction of the technical efficiencies is based on its conditional expectation, given the assumptions of the model.

3. ESTIMATION AND RESULTS

Following Batese & Coelli (1988; 1992), the stochastic production function depicted in equation 1 is assumed to be given by:

$$\begin{aligned}\ln(yieldi) = {} & b0 + b1\ln(landi) + b2\ln(otheri) + b3\ln(labour) \\ & + b4\ln(machineryi) + Vi - Ui\end{aligned} \tag{5}$$

The data for the analysis were obtained from regional production statistics provided by the National Maize Producers Organisation (NAMPO) for the six main maize production regions, namely the Western Transvaal, the Central Transvaal, Northern Transvaal, Eastern Transvaal, North Western Free State and Eastern Free State. Nine years of data were used (from 1988 to 1996) to give a total of 54 observations.

In equation 5, *Yield* is the maize yield for each region, *land* is the rental value of land in each region, *labour* is the cost of labour in each region and *machinery* is the cost of machinery use in each region. *Other* includes the cost of intermediate inputs (fertiliser, seed, chemical control and fuel). Ideally, a variable depicting weather or rainfall should also be included in the production function. However, the available rainfall index is highly correlated with machinery and intermediate inputs ($r>0.80$; $p<0.05$). Rainfall (weather) was therefore not included in the final equation for the production function.

As explained above, some input variables in the stochastic frontier may be included in the inefficiency model, provided that the inefficiency effects are stochastic. As this is the case, the rainfall variable was included in the inefficiency model. Following equation (3), the technical inefficiency effects are assumed to be defined by:

$$Ui = d0 + d1(rain) + d2(terms\ of\ tradei) + d3(year) + Wi \tag{6}$$

where *rain* is a region-specific rainfall index for the duration of each growing season in each region. A likely factor that will enhance the effect of rainfall on inefficiency is that drought-aid encouraged farmers to produce maize in marginal areas, thus inducing inefficiency. It is important that, in this respect, the rainfall variable should be viewed as depicting the effects of uncertain climate on production, as well as a proxy for expectations of drought assistance to farmers.

Terms of trade are the ratio of a maize price index to an index of the prices of farming requisites. This is likely to have an impact on the efficiency of maize farms due to the cost-squeeze faced by maize farmers during the period under review. *Year* indicates the year of the observation. The coefficient of this variable will indicate whether maize production efficiency has increased or decreased over time.

Maximum-likelihood estimates of the parameters of the model are obtained using the computer program FRONTIER 41 (Coelli, 1994). These estimates, together with the estimated t-statistics are as follows (t-values in brackets):

Stochastic Frontier:

$$\begin{array}{llllll} \ln(\text{yieldi}) = & 2.02 + & 0.56\ln(\text{land}) + & 0.12\ln(\text{other}) + & 0.24\ln(\text{labour}) + & 0.35\ln(\text{machinery}) \\ & (1.91) & (3.18) & (0.73) & (1.48) & (2.05) \end{array} \qquad (7)$$

Inefficiency model:

$$\begin{array}{lllll} U = & 4.09 - & 0.86\ln(\text{rain}) - & 0.06\ln(\text{time}) + & 10.5\ln(\text{terms of trade}) \\ & (2.66) & (-3.22) & (-1.70) & (9.89) \end{array} \qquad (8)$$

Variance parameters:

$$\begin{array}{ll} \sigma^2 = 0.129 & \gamma = 0.843 \\ \quad (5.27) & \quad (35.62) \end{array}$$

As the logarithms were used to estimate the models, the coefficients of the input variables in the Cobb-Douglas model represent elasticities of frontier output. The estimate of the γ-parameter, associated with the variability of the inefficiency effects, is very close to the maximum value of one. This indicates that the technical inefficiency effects are significant in the production of maize. The variance of the random terms, σ^2, is significant for most models, indicating that the stochastic frontier model is significantly different from the corresponding deterministic frontier model.

The signs of the coefficients of the stochastic frontier are all positive, as expected. The most significant variables are land and machinery with coefficients of 0.56 and 0.35 respectively. The coefficient of the *other* variable, even though positive, was non-significant. This is not what was expected *a priori*. However, this variable measures the effects of intermediate input use. Therefore, it is possible that its effects are to some extent captured by the inefficiency model. On the other hand, there are also indications in the literature that intermediate input use has exceeded optimal levels, particularly for fertiliser (see van Zyl *et al.*, 1993). This can be viewed as a situation where production takes place in the irrational phase of the traditional translog production function where marginal increases in the input do not increase output. Both these explanations seem to have merit.

The estimated coefficients in the inefficiency model are of particular interest to this study. All the variables appear to be significant, with signs also as expected. The *rain* coefficient is negative, which indicates that the less rain farmers have, the more inefficient they are. This relationship is expected, but seems to have been exacerbated by expectations of drought aid that make farmers act in a less risk averse manner. The negative estimates for *year* suggest that the inefficiencies of maize production tended to decline throughout the period under review. This is consistent with the positive coefficient on the *terms of trade* variable. As the price of maize relative to the price of inputs declined, maize farmers have become more efficient.

CONCLUSIONS

The results obtained from this analysis are consistent with the results derived at the aggregate level by Van Zyl *et al.* (1993) and Townsend (1997). The major conclusions arrived at include the following:

- intermediate inputs do not have a significant effect on maize yield, confirming that in many cases intermediate input use has exceeded the optimal application levels;

- the effects of labour on maize are also insignificant, while machinery is significantly positive, illustrating the substitution of labour for machinery;

- the more adverse the climate, *i.e.* the less rain farmers have, the more inefficient they are, again indicating that yield targets are probably too high given risky production conditions. As already discussed above, this is probably related to drought-aid received during the period under review, particularly during the latter part of the 1980s that made farmers behave in a less risk averse manner as they expected support in times of crop failures; and inefficiency of maize production tended to decline throughout the period under review. This seems to coincide with market liberalisation and the expectations of decreasing subsidies and other forms of farmer support that occurred during the period under review, as well as increased productivity being the only way to counter continually worsening terms of trade.

In conclusion, the results demonstrate how maize farmers have increased their efficiency in the face of a cost-squeeze. The increased efficiency seems to be driven by lower levels of intermediate input use, particularly within an environment of increasing costs and higher risks.

REFERENCES

AIGNER, D.J., LOVELL, C.A.K. & SCHMIDT, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics,* 6:21-37.

BATTESE, G.E. & COELLI, T.J. (1988). Prediction of firm-level technical efficiencies : With a generalised production function ad panel data. *Journal of Econometrics,* 38:387-399.

BATTESE, G.E. & COELLI, T.J. (1992). Frontier production functions, technical efficiency and panel data with application to paddy farmers in India. *Journal of Productivity Analysis,* 3:153-169.

BATTESE, G.E. & COELLI, T.J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics,* 20:325-332.

BRAND, S., CHRISTODOULOU, N., VAN ROOYEN, C.J. & VINK, N. (1992). Agriculture and redistribution. In: R. Schrire (Eds.), *Wealth or Poverty ? Critical Choices for South Africa.* Cape Town. Oxford University Press.

COELLI, T. (1994). *A guide to FRONTIER Version 4.1 : A computer program for stochastic frontier production and cost function estimation.* Mimeo, Department of Econometrics, University of New England, Armidale, Australia.

HUANG, C.J. & LIU, J-T. (1994). Estimation of a non-neutral stochastic frontier production function. *Journal of Productivity Analysis*, 5:171-180.

JONDROW, J., LOVELL, C.A.K., MATEROV, I.S., & SCHMIDT, P. (1982). On the Estimation of technical inefficiency in the stochastic frontier production function model, *Journal of Econometrics,* 23(2):269-274.

KIRSTEN, J. & VAN ZYL, J. (1996). The contemporary agricultural policy environment : Undoing the legacy of the past. In: J. van Zyl, J.F. Kirsten and H.P. Binswanger. (Eds.), *Agricultural Land Reform in South Africa*. Oxford University Press. Cape Town.

STEVENSON, R.F. (1980). Likelihood functions for generalised stochastic estimation. *Journal of Econometrics,* 13:57-66.

TOWNSEND, R.F. (1997). Policy distortions and agricultural performance in the South African economy. Unpublished PhD Thesis, University of Pretoria.

VAN ZYL, J. VAN SCHALKWYK, H.D. & THIRTLE, C. (1993). Entrepreneurship and the bottom line: How much of agriculture's profit is due to changes in prices, how much due to productivity? *Agrekon,* 32(4):223-229.