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Technical efficiency and productivity of maize producers in eastern Ethiopia: a study of farmers within and outside the Sasakawa-Global 2000 project

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Abstract

This paper investigates the technical efficiency of two samples of maize producers in eastern Ethiopia, one involving farmers within the Sasakawa-Global 2000 project and the other involving farmers outside this program. The study uses stochastic frontier production functions in which the technical inefficiency effects are assumed to be functions of the age and education of the farmers, together with the time spent by extension advisers in assisting farmers in their agricultural production operations. For the cross-sectional data obtained for the 1995/96 agricultural year, Cobb–Douglas stochastic frontiers are found to be adequate representations of the data, given the specifications of the translog stochastic frontiers for farmers within and outside the project. The empirical results indicate that farmers within the SG 2000 project are more technically efficient than farmers outside the project, relative to their respective technologies. The mean frontier output of maize for farmers within the SG 2000 project is significantly greater than that for the farmers outside the project.

1. Introduction

Ethiopia is a country struggling to recover from almost three decades of civil war and drought. Nearly two decades of harsh authoritarian rule under a military government has added to these problems. Ethiopia had food security until the 1960s, but since the drought of 1975, food production has been very poor and has lagged behind the population growth. As a result, a significant volume of food (mainly as aid) has been received every year. It is expected that these trends will continue. The Food and Agriculture Organization of the United Nations expects the food deficit to reach 2.5 million tons by the year 2010, unless there are sharp increases in agricultural production (Mulugeta, 1995).

The agricultural sector in Ethiopia is almost entirely dominated by small-scale, resource-poor farmers who produce 90 to 95 percent of all cereals, pulses and oilseeds. The problems of small-scale agriculture include the use of traditional technology of low productivity, extension services which are inadequately

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funded, a shortage of oxen for cultivation and shortages and poor distribution of agricultural inputs. The poor performance of the agricultural sector is argued to be due to inadequate attention to agricultural research and education which are considered to be important inputs in agricultural development (Belete et al., 1991). However, unless there is an efficient extension service, even useful research will have limited impact (Pickett, 1991).

Ethiopian farmers produce more maize than any other crop. Maize and other major cereals, such as wheat, barley, sorghum and teff[1], supply about 70 percent of the calories in Ethiopian diets (Ministry of Agriculture, 1995). Traditional cereal farming is not only low-yielding but also results in the mining of plant nutrients from the soil. After harvest, traditional farmers remove the stalks and the leaves, and sometimes even the maize stumps and roots, for feed, fuel and building materials. These practices leave no crop residue to restore soil nutrients and organic matter.

Small-scale food producers in Ethiopia urgently need to improve total factor productivity which can raise output to meet the country's food consumption needs. Existing low levels of productivity in food production, reflecting low levels of technical efficiency and use of primitive technology, hinder efforts to achieve progress in this direction. The rural development policies, which have been adopted in Ethiopia over three decades, are reviewed by Aredo (1990). The current Ethiopian government, in collaboration with international organisations, has taken initiatives to raise productivity by helping farmers reduce technical inefficiency and fostering the adoption of improved production technologies. A prominent example has been the introduction of the Sasakawa-Global 2000 agricultural project, which features a strong extension component directed to the dissemination of improved technology to small farmers and the improvement of farmers' practices.

Sasakawa-Global 2000 (SG 2000) is a non-profit organisation established to develop programs for technology demonstration in various African countries, in cooperation with national extension services. Since 1986, SG 2000 has helped African farmers to improve their lives through better farming practices (SG 2000, 1995a). The SG 2000 project was initiated in Ethiopia during the spring of 1993, in close collaboration with the Ministry of Agriculture of the Transitional Government of Ethiopia and regional bureaus of agriculture. An objective of the project is to upgrade the capacity of the extension services to disseminate proven research technology to small-scale farmers. In each village involved, SG 2000 and local extension workers select full-time farmers as possible participants. The extension workers visit the farmers and explain the program and conditions for inclusion: willingness to devote a half-hectare field as a plot for the program, to follow extension advice on the plot, to allow field days at the site and help other farmers, and to pay half the input costs before planting (SG 2000, 1995b, p. 11). The farmers apply the inputs, tend the land with oxen and have access to advice from agricultural extension personnel. The farmer's labour, oxen labour and amount of extension advice are variable for the different farmers in the project.

It is important to know whether the small-scale producers under this project have a greater overall productivity and technical efficiency of maize production, compared with farmers outside the project. This problem is a critical issue in eastern Ethiopia, where maize is the main staple food, and in the Ethiopian agricultural sector, as a whole. It also has significance for the future directions for the extension department of the Ministry of Agriculture in Ethiopia.

2. Sample data and variables

The data for this study come from samples of small-scale farmers in two districts (Keresa and Kombolcha) of eastern Ethiopia (Oromia). During November and December 1995, the senior author selected a sample of 20 farmers, who were in the SG 2000 project, from each of these two districts, and interviewed them to obtain input and output data for the 1995/96 agricultural year. In order to facilitate a comparison of the technical efficiency and productivity of farmers within and outside the SG 2000 project, samples of 20 farmers were also selected from those who were not in the SG 2000 project in the two districts. The samples of farmers were selected as representative of the respective agricultural technologies in the two districts,

[1]Teff is a cereal grain that is unique to Ethiopia.

according to the advice of the extension workers involved.[2]

As stated in Section 1, farmers are first selected to participate in the SG 2000 project to grow maize on a one-half hectare of land, using seed, fertiliser and insecticides as specified by the project, the values being essentially the same for all farmers. Hence the yield of maize is the dependent variable used in the production function analyses and the explanatory variables include hours of human labour and hours of oxen labour used in the production year, together with the hours of involvement of extension workers to assist the farmers in their agricultural operations. For the farmers outside the project, the areas on which maize were grown were also one-half of a hectare of land, but instead of using bullocks for ploughing of the fields the farmers used tractors.

One may ask why farmers within the SG 2000 project used oxen to plough the land while those outside the project used tractors. It has been observed that, due to a shortage of oxen in eastern Ethiopia, small-scale farmers who used to plough their land with oxen now depend on hired tractors (SG 2000, 1995a). However, the availability of tractors when needed is not guaranteed. If a farmer used a hired tractor for the first ploughing he might not get one for the second. This problem was considered by the SG 2000 project, and farmers were assisted to get long-term credit for oxen and encouraged to borrow oxen from each other. If borrowing oxen was not possible, the farmers used a system of hiring oxen from other farmers within the project.

A summary of the values of the variables which are used in our analyses is presented in Table 1. The mean output of maize for farmers within the SG 2000 project was about five-fold that for farmers outside the project.[3] The labour time used by the farmers within the project was about 80 percent greater than that used by farmers outside the project, mainly because of the longer time taken in using the improved farming practices, such as planting by row and application of fertiliser and pesticides, and in harvesting the more substantial crop. The extension time is also higher for the farmers within the project because of the more intensive supervision by the extension advisers. The ages of the farmers in the two samples are not significantly different. However, the average number of years of education for farmers within the SG 2000 project was slightly greater than for the farmers outside the project.[4]

3. Stochastic frontier model

In our analysis of the data for the two groups of farmers, we use stochastic frontier production functions. Since the basic stochastic frontier model was first proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977), various other models have been suggested and applied in the analysis of cross-sectional and panel data on producers. Reviews of some of these models and their applications are given by Bauer (1990), Battese (1992), Bravo-Ureta and Pinheiro (1993) and Coelli (1995). Some models have been proposed in which the technical inefficiency effects in the stochastic frontier models are also modelled in terms of other observable explanatory variables. Kumbhakar et al. (1991), Huang and Liu (1994) and Battese and Coelli (1995) present different models for the technical inefficiency effects.

We estimate separate stochastic frontier production functions, of the type proposed by Battese and Coelli (1995), for farmers within the SG 2000 project and those outside the project. Since there are only 20 sample farmers in each of the two districts, different stochastic frontier models are not specified for separate districts. The data for the two districts are combined in the analysis, such that the levels of production in the two districts are permitted to be different by the use of a dummy variable for one district.

[2] It was not feasible to construct a sampling frame and select a random sample of these farmers, given the limited time and resources available for the senior author to do the field work and collect data.

[3] The average outputs for farmers within and outside the SG 2000 project in Ethiopia in 1994/95 were 55 and 15 quintals, respectively, (see SG 2000, 1995a, p. 26). The average output obtained for the farmers outside the project in 1994/95 was thus somewhat higher than for the sample farmers in 1995/96, but those for the farmers within the project were almost identical in the two years.

[4] Using a large-sample t-test, the average years of schooling are only significantly different if a 10% level of significance is used with a one-sided alternative hypothesis.

Table 1
Summary statistics of the variables for farmers in eastern Ethiopia producing maize in 1995/96 [a]

Variable	Mean	Standard deviation	Minimum value	Maximum value
Maize output (quintals/ha)				
Within project	54.7	11.4	30	80
Outside project	11.3	3.4	6	17
Human labour (hours/ha)				
Within project	137.3	10.3	114	159
Outside project	75.3	2.7	68	81
Traction [b] (hours/ha)				
Oxen (Within)	50.6	2.4	45	55
Tractor (Outside)	2.59	0.16	2.3	2.9
Extension advice (hours/ha)				
Within project	163.0	9.2	145	181
Outside project	51.5	4.8	32	58
Farmer's age (years)				
Within project	37.8	9.1	20	60
Outside project	37.1	8.7	21	52
Farmer's education (years)				
Within project	3.0	3.9	0	14
Outside project	1.7	2.1	0	9

[a] Although all farmers within and outside the SG 2000 project used 0.5 ha of land, all input and output statistics are expressed relative to 1 ha of land.
[b] The term, Traction, used in this and the next table, refers to Oxen and Tractors for farmers within and outside the SG 2000 project, respectively.

The stochastic frontier model for farmers within the SG 2000 project is defined by[5]

$$\ln Y_i = \beta_0 + \beta_0^* D_i + \beta_1 \ln(\text{Labour}_i) + \beta_2 \ln(\text{Oxen}_i) + V_i - U_i \quad (1)$$

where the subscript, i, indicates the ith farmer in the sample (i=1, 2,$\cdots$, 40); ln represents the natural logarithm (i.e., logarithm to base e); Y represents the output of maize (in quintals[6]/ha); D represents the district dummy variable, which has value 1 for farmers in the district, Keresa, and 0 otherwise; Labour represents human labour spent in the farming operations (hours/ha); Oxen represents oxen labour used in the farming operations (hours/ha); the βs are unknown parameters to be estimated; the V_is are assumed to be independent and identically distributed random errors having $N(0, \sigma_v^2)$-distribution; and the U_is are non-negative random variables, called technical inefficiency effects, which are assumed to be independently distributed such that U_i is defined by the truncation (at zero) of the normal distribution with mean, μ_i, and variance, σ^2, where μ_i is defined by

$$\mu_i = \delta_0 + \delta_1 \,\text{Age}_i + \delta_2 \,\text{Education}_i + \delta_3 \ln(\text{Extension}_i) \quad (2)$$

where Age and Education are the age and the number of years of formal education of the farmer involved.

The stochastic frontier model for farmers outside the SG 2000 project is as defined by Eqs. (1) and (2), except that the explanatory variable, Oxen, is substituted with Tractor in Eq. (1). A common stochastic frontier model for all farmers, irrespective of whether they were within the SG 2000 project or not, was also estimated, but this model was strongly rejected by the data. This is consistent with our expectations that the farmers within the SG 2000 project use a different

[5]In preliminary analyses, the above Cobb-Douglas model was found to be an adequate representation of the data, given the specifications of the translog stochastic frontier production function, involving the three input variables, Labour, Oxen and Extension. More details are given in Seyoum (1996).

[6]A quintal is a common Ethiopian measure which is equivalent to 100 kg.

technology from farmers outside the SG 2000 project who use more traditional farming methods.

The production function, defined by Eq. (1), specifies that the two different districts in eastern Ethiopia may have different mean levels of maize output. As stated in footnote 5 above, in addition to human and oxen labour being explanatory variables for the output of maize, it was initially hypothesised that extension advice may result in different levels of frontier output.[7] However, from preliminary analyses, it was concluded that different amounts of extension advice do not influence the level of frontier maize outputs.

The model for the technical inefficiency effects, defined by Eq. (2), specifies that the technical inefficiency effects in the stochastic frontier (1) are a function of the age and education of the farmers, together with the hours of extension advice they received from the development agents in the district. More years of formal education are expected to result in smaller values of the technical inefficiency effects, whereas the older farmers are expected to have greater inefficiencies because they are less adaptable to new technological developments. More advice from extension workers is expected to result in smaller values of the technical inefficiency effects, especially for farmers within the SG 2000 project.[8]

The maximum-likelihood estimates for all the parameters of the stochastic frontier and inefficiency model, defined by Eqs. (1) and (2), are simultaneously obtained by using the program, FRONTIER Version 4.1 (see Coelli, 1994), which estimates the variance parameters in terms of the parameterisation

$$\sigma_s^2 = \sigma_v^2 + \sigma^2 \quad (3)$$

and

$$\gamma = \sigma^2/\sigma_s^2 \quad (4)$$

where the γ-parameter has a value between 0 and 1.

The technical efficiency of production of the ith farmer in the appropriate data set, given the levels of his inputs, is defined by

$$\mathrm{TE}_i = \exp(-U_i) \quad (5)$$

The technical efficiency of a farmer is between 0 and 1 and is inversely related to the level of the technical inefficiency effect. The technical efficiencies can be predicted using the FRONTIER program which calculates the maximum-likelihood estimator of the predictor for Eq. (5) that is based on its conditional expectation (cf. Battese and Coelli, 1988).

The stochastic frontier outputs, which include the effects of the random errors in production but not the technical inefficiencies of production, are important in comparing the productivity of farmers within the SG 2000 project with those outside the project. Given the specifications of the stochastic frontier model Eqs. (1) and (2), the stochastic frontier output for the ith farmer, $Y_i^* = \exp(X_i\beta + V_i)$, is the observed output divided by the technical efficiency, $\mathrm{TE_i}$, i.e.,

$$\begin{aligned} Y_i^* &= Y_i/TE_i = \exp(X_i\beta + V_i - U_i)/\exp(-U_i) \\ &= \exp(X_i\beta + V_i) \end{aligned} \quad (6)$$

where X_i represents the vector of values of the functions of the input variables in Eq. (1).

The mean of the stochastic frontier output for the given input values for the ith farmer, is estimated by

$$E(Y_i^*|X_i) = \exp(X_i\beta)\exp[1/2(1-\gamma)\sigma_s^2] \quad (7)$$

The above mean frontier outputs are estimated for the average input values for the farmers in the SG 2000 project and for the farmers outside the project in order to compare the overall productivity of the two groups of farmers.

4. Empirical results

The maximum-likelihood estimates for the parameters of the Cobb–Douglas stochastic frontier production functions for the farmers within and outside the SG 2000 project are given in Table 2. The coefficient of the district dummy variable, which estimates the difference between the mean maize yields for

[7]When the stochastic frontier model includes hours of extension advice in both the production function (1) and the inefficiency model (2), the model is a special case of the non-neutral stochastic frontier model, proposed by Huang and Liu (1994). Non-neutral frontier models are estimated by Coelli and Battese (1996), Battese and Broca (1997) and Ngwenya et al. (1997). The estimation of elasticities of mean output with respect to input variables which are in both the production function and the inefficiency model requires special attention, as outlined in Huang and Liu (1994) and Battese and Broca (1997).

[8]It is likely that the inefficiency effects are related to other variables, such as the level of nutrition of the farmers, availability of credit and other inputs. However, data on these variables were not obtained and so any possible effects of these variables could not be accounted for in our analyses.

Table 2
Maximum-likelihood estimates for parameters of the Cobb–Douglas stochastic frontier production functions for maize farmers within and outside the SG 2000 project in eastern Ethiopia [a]

Variable	Parameter	Within project	Outside project
Stochastic frontier			
Constant	β_0	−8.9 (1.0)	−5.5 (1.3)
District	β_0 [a]	−0.041 (0.027)	−0.318 (0.087)
ln(Labour)	β_1	2.47 (0.13)	2.07 (0.32)
ln(Traction)	β_2	0.21 (0.27)	−0.65 (0.41)
Inefficiency model			
Constant	δ_0	1.6 (2.6)	3.0 (1.7)
Age	δ_1	0.0035 (0.0043)	0.0169 (0.0077)
Education	δ_2	−0.060 (0.036)	0.001 (0.020)
ln(Extension)	δ_3	−0.33 (0.51)	0.65 (0.39)
Variance parameters			
	σ_s^2	0.0107 (0.0040)	0.0286 (0.0063)
	γ	0.74 (0.14)	0.88 (0.39)
ln(likelihood)		49.762	20.992

[a] The estimated standard errors of the coefficient estimators are given in parentheses behind the estimates, correct to two significant digits. The coefficient estimates are given to the corresponding numbers of digits behind the decimal points.

farmers in Keresa and Kombolcha, was negative for both groups of farmers. These results indicate that the frontier maize outputs in Keresa tend to be less than those in Kombolcha. However, the difference between yields in the two districts for farmers within the project is not as significant as that for farmers outside the project. Presumably, the use of more modern farming practices, such as new varieties, fertiliser and pesticides, within the SG 2000 project tends to counteract the lower fertility of the soils in Keresa than in Kombolcha.

The elasticities of labour for both groups of farmers are estimated to be greater than one, which indicates that the farmers are operating in an irrational zone of production (increasing returns to labour). This is perhaps not surprising, given that both groups of farmers were growing maize on a one-half hectare plot of land. It would be interesting to investigate the labour elasticity of output for farmers after they graduate from the SG 2000 project (after their second year of involvement), during which time they are able to implement their newly acquired technology in growing maize on larger areas of land, if available.

The elasticity of oxen labour for farmers within the project is estimated to be 0.21, but the elasticity of tractor hours for farmers outside the project is estimated to be negative. The latter negative estimate might be explained by the fact that tractors are often used only for the first ploughing because of problems caused by an unorganised tractor-hiring system which makes it difficult to get tractors for timely land preparation. As a result, most of the farm operations do not correspond to the cropping calendar. This had a negative influence on production, especially for farmers who depended on rain.

The estimated coefficients for age of farmers in the inefficiency models are positive for both groups of farmers, which indicate that the younger farmers are more technically efficient in maize production than the older farmers, irrespective of whether the farmers are within the SG 2000 project or not. The coefficient of education is negative for farmers within the project, which indicates that farmers with greater years of formal schooling tend to be more technically efficient. This indicates that the farmers with more education respond more readily in using the new technology and produce closer to the frontier output. The coefficient of education for farmers outside the project is effectively zero which indicates that greater years of education for farmers involved in the more traditional farming methods outside the SG 2000 project do not result in increases in technical efficiency of maize production.

The coefficient of the extension variable in the inefficiency model is negative for farmers within the SG 2000 project, which indicates that the involvement of extension advisers tends to reduce the technical inefficiency of maize production of the farmers within the project. However, the positive estimate for the coefficient of extension for farmers outside the project indicates that their technical inefficiency effects tend to increase with greater hours of involvement of the extension workers. These results indicate that, for farmers outside the project, the advice of extension workers is not beneficial in reducing technical inefficiency in more traditional farming, but for farmers within the SG 2000 project the advice is beneficial in helping farmers implement the practices associated with the new technology.

The γ-parameter associated with the variance of the technical inefficiency effects in the stochastic frontiers are estimated to be 0.74 and 0.88 for farmers within and outside the project, respectively. These results indicate that the technical inefficiency effects are a significant component of the total variability of maize outputs for both groups of farmers.

From the estimated standard errors of the coefficients of the inefficiency variables, presented in Table 2, it is evident that most of the individual coefficients are not significantly different from zero (using a 5 percent level of significance). However, testing that the coefficients are jointly equal to zero, using the generalised likelihood ratio test, a highly significant test statistic is obtained for farmers within the SG 2000 project. However, for farmers outside the project the test statistic is only significant at the 25 percent level.

The technical efficiencies of the sample maize farmers within and outside the project are less than one. The predicted technical efficiencies for the farmers within the SG 2000 project range from 0.748 to 0.990, with the mean technical efficiency estimated to be 0.937. For the farmers outside the project, the technical efficiencies ranged from 0.557 to 0.965, with the mean estimated to be 0.794. These estimates indicate that, on average, the farmers within the Sasakawa-Global 2000 agricultural project have higher technical efficiency than farmers outside the project, relative to their respective frontiers associated with the different technologies.

A frequency distribution of the predicted technical efficiencies within ranges of 0.05 is given in Fig. 1 for the two groups of farmers. It is clear that the distribution of technical efficiencies for farmers within the SG 2000 project is closely clustered near 1.0, indicating very high technical efficiencies of the farmers in the project. However, for farmers outside the project, the distribution has a much greater spread of values between 0.55 to 1.0.

The mean frontier outputs, defined by Eq. (6), are estimated for maize farmers within and outside the project, using the corresponding stochastic frontier models. The mean frontier output for farmers within the project is estimated to be 58.82 quintals. For farmers outside the project, the mean frontier output is estimated to be 16.30 quintals. These estimates indicate that farmers within the SG 2000 project have higher mean frontier output than farmers outside the project.

Total factor productivities for the sample farmers within and outside the SG 2000 project could not be calculated because the relevant data on costs and prices were not collected in the survey. However, given the information on costs and outputs for 1994/95 in SG 2000 (1995a, p.26), the ratio of total revenues to total variable costs are 4.40 and 2.37 for farmers within and outside the project, respectively. The average production levels in 1994/95 for Ethiopia were 55 and 15 quintals, respectively, which are approximately equal to those for farmers in this survey, as indicated above (see footnote 3 and Table 1). Thus, the total factor productivities for the farmers within and outside the SG 2000 project in our study would be approximately the values stated above. These values clearly indicate that the SG 2000 project results in much higher productivity than is possible under the traditional small-scale peasant farming in Ethiopia.

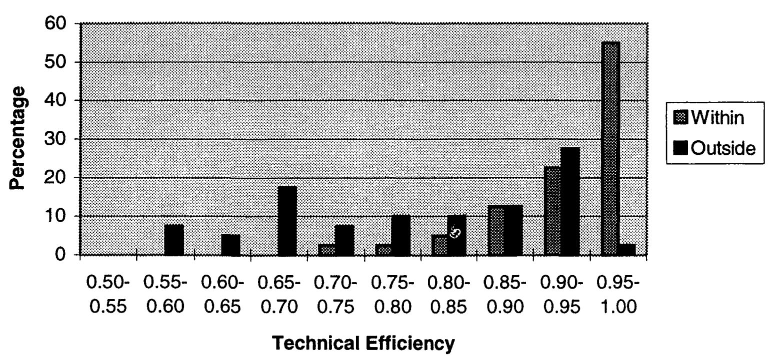

Fig. 1. Distributions of technical efficiencies of maize farmers within and outside the SG 2000 project in eastern Ethiopia.

5. Conclusions

This study estimates stochastic frontier production functions for farmers in two districts in eastern Ethiopia who were either within or outside the Sasakawa-Global 2000 agricultural project. As such, it presents an important contribution to the evaluation of the performance of the SG 2000 project in Ethiopia. Such information indicates that the government should promote the agricultural program introduced by the SG 2000 project to improve the level of efficiency and productivity of maize farmers in Ethiopia. The results that small-scale farmers within the SG 2000 project had significantly higher outputs and productivity, and the technical inefficiency effects in maize production are negatively related to the hours of extension advice, indicate that the program involved should be expanded on a larger scale. With adequately trained extension advisers, who are committed to assisting farmers implement quite simple new technologies of production, there is hope that agricultural productivity may be significantly increased in the future on a national scale. However, it is likely that agricultural production in Ethiopia will need the continuing support of the government and international agencies for some time to come until the level of production and efficiency of farmers is increased to sufficiently high levels.

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