THE TECHNICAL EFFICIENCY OF SMALL AGRICULTURAL PRODUCERS IN CENTRAL ETHIOPIA

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1. INTRODUCTION

1.1 Background

Ethiopia is a developing country which depends heavily on agriculture for economic development. The agricultural sector is characterised by four agro-climatic zones: mountain areas, cool highlands, temperate highlands and semi-arid lowlands. The majority of farmers are small-scale peasants and 50 per cent of agricultural production is for subsistence.

Agricultural performance has been disappointing over the past three decades: agricultural output is estimated to have grown at a decreasing rate, and has even declined in recent times. Robinson and Yamazaki (1986) noted that the rate of growth in the agricultural output was 3.3 per cent in the first five-year development plan (1957-61), 2.9 per cent in the second-plan period (1962-67) and only about 1.2 per cent in the third plan (1968-73). They observed that the revolution brought about through the ascension to power of the Mengistu regime in 1974 did nothing to change this deteriorating trend, with a negative rate of agricultural growth of -0.4 per cent for the 1980s (World Bank 1991), reflecting a continuity between the pre- and post-1974 periods (before and after the revolution). Food production has lagged behind population growth, and the average food output per head for the three-year period, 1987-89, was 11 per cent below the comparable figure for 1979-81 (World Bank 1991).

Many analysts have tried to identify the causes of poor performance in the agricultural sector of Ethiopia. Factors isolated include inadequate attention to agricultural research and education, unavailability of sufficient agricultural inputs, a lack of human resource development in rural areas, and seriously deficient investment in capital equipment. In addition to problems specific to the agricultural sector, Robinson and Yamazaki (1989) noted that the causes of famine in Ethiopia in recent times included drought, civil war and misguided macroeconomic policies

1.2 Research Objectives

Policy makers have a number of avenues they can follow in attempting to remedy the current lack of progress in agriculture. For the purposes of this study, two avenues related to the technical aspects of agricultural production by peasants are considered. Policy makers can either attempt to improve the uptake of improved technologies relevant to small-scale agricultural production by improving research and development processes, or they can take steps which enable peasants to improve technical efficiency in production. While the former is likely to yield most long-term benefits, it will also probably take a long time and considerable funds and effort in yielding significant results. Raising technical efficiency offers more immediate gains at modest costs if it can be shown that substantial technical inefficiencies are present in peasant agriculture.

This research is therefore based on an analysis of the technical inefficiency of production by peasant farmers in the agricultural sector. Central Ethiopia is chosen as the region for undertaking this research work, and particular attention is given the critical issue of fertiliser use in improving production methods. The aims of the study are:

- to estimate the technical efficiencies of individual peasant farmers in the agricultural sector in Central Ethiopia
- to investigate whether the mean technical efficiency differs between farmers who use fertiliser and those who do not.

Wolde-Mariam (1991) reported that only 24 per cent of peasants in Ethiopia use fertiliser on their farms, with the proportion who have ever used fertilisers less than 20 per cent and declining (from 14 per cent in 1982-83 to 10 per cent in 1984-85). Ethiopian peasants still have limited access to extension services. These two factors are believed to reflect widespread technical inefficiency in agricultural production. Accordingly, peasant farmers are classified according to whether they use fertiliser in the belief that use of fertiliser indicates access to extension advice about technically efficient production and the use of modern farming methods.

In the following section, a description is given of the structure, contributions and prospects of agriculture in Ethiopia and an assessment of agricultural performance during the period, 1975-76 to 1985-86.[1] Section 3 comprises an overview of methods for investigating the technical inefficiency of production. The concept of a stochastic frontier production function is discussed, and models and their estimation procedure are outlined. Section 4 focuses on data, variables used and model formulation for the empirical analyses which are presented in section 5. Policy and research implications are presented in the final section

2. ETHIOPIAN AGRICULTURE

2.1 Structure

The peasant sector in the Ethiopian agricultural sector cultivates about 96 per cent of the total cultivated area, and contributes 96 per cent of the nation's agricultural output and 90 per cent of foreign exchange earnings Farmers in this sector use simple production technologies involving rudimentary implements Power is limited to that provided by draft animals

Peasants are organised by peasant associations which until recently played a key role in promoting economic and social development, and establishing collective institutions to form service cooperatives These service cooperatives were responsible for processing and marketing the output of the peasant associations, supplying production inputs and ensuring the availability of essential goods demanded by the rural population.

Peasants cultivated on average about 5.5 million hectares of land in the period 1975/76 to 1985/86 of which 83, 13 and 4 per cent were planted to cereals, pulses and oilseeds, respectively. Corresponding output shares were 87, 12 and 1 per cent (Belete 1989). There is no evidence of a significant upward trend in either area or output during this period; both remained fairly constant.

Livestock are very important to peasant farming in Ethiopia, providing power for ploughing, planting and threshing, and transport of crops from farms to homes and to the marketing centres They provide essential service in transport because some rural roads are impassable at times during the year and some are not accessible to vehicles at all. Livestock are also needed as a means of supplementing crop production and as a source of income to purchase grains over the dry season. Livestock production is concentrated in the highlands where livestock diseases are minimal. Despite the importance and size of the livestock population for peasant agriculture, productivity is very low (Belete 1989). The number of livestock in Ethiopia is not in balance with the available feed resources, leading to unsustainable stocking levels; there is a high prevalence of contagious livestock diseases; the livestock marketing system is underdeveloped; methods of animal husbandry are rudimentary; and improved breeding practices are seldom practised.

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[1] The choice of this period for describing the agricultural sector is made because the past decade has been marked by circumstances considered to be most abnormal. The major change in recent years has been institutional as socialist principles in agricultural production and marketing have been largely abandoned.

The second important sector in Ethiopian agriculture comprises the producer cooperatives. These cooperatives were established after the land reform of 1975 with the intention to solve the problem of land fragmentation and raise the technical capacity of farmers to use modern technology and exploit economies of scale. Producer cooperatives cultivated between 43 000 and 205 000 hectares of the major crops over the period, 1978-79 to 1985-86. Cereals, oilseeds and pulses occupied on average 79, 13 and 8 per cent of the total land in cultivation (Belete 1989) although the area under production fluctuated substantially. The percentage of total output from the producer cooperatives showed a steady increase over this period.

Third, state farms were introduced to alleviate the country's food problems, produce an adequate amount of raw materials for domestic industries, expand output for foreign exchange earnings, encourage the establishment of agro-industries and create employment opportunities. This sector owned highly mechanised large farms during the revolutionary period and employed few people. Its importance is in decline with changing development strategy. Following their establishment after the revolution, state farms expanded in terms of number, area and type of operation. Belete (1989) recorded growth in cultivated area from 31 000 ha in 1975-76 to 191 000 ha in 1985-86, while the total output of crops increased from 67 000 t to 228 000 t over the same period. As in the other two sectors, cereals occupy the largest area of cultivated land, followed by oilseeds and pulses. Belete (1989) noted a decline in yields for all crops on state farms over this decade.

State farms, according to Griffin (1992), were organised hurriedly and expand rapidly, giving rise to managerial problems. Few farm managers had experience in running large agricultural enterprises and many were not properly trained. Although farms possessed a great deal of capital equipment, much of the machinery was out of operation at any time and productivity of capital was very low. The control structure was excessively centralised, with management decisions essentially based on agronomic notions about what constitutes good 'scientific' farming. The farms were not helped when the government imposed low output prices on them and kept these prices fixed to maintain 'reasonable' prices for essential food items. Griffin (1992) noted that the total weighted average number of hectares per worker was very high in this sector and it was inefficient compared with the peasant and producer cooperatives, regularly operating at a loss.

2.2 Contributions

Ethiopia's economy is predominantly dependent on agriculture as a source of employment, foreign exchange earner, supplier of food, supplier of raw materials and source of surplus labour for the industrial sector. Agriculture is a source of livelihood for over 52 million people; in the mid-1980s, about 85 per cent of the population lived in rural areas and 87 per cent of the labour force was engaged in agricultural production. The agricultural share of GDP averaged 48 per cent over the period, 1970-71 to 1985-86, but was declining (Belete 1989). Its share of GDP declined from 58 per cent in 1965 to 42 per cent in 1989 (World Bank 1991).

As reported above, agricultural growth in Ethiopia was sluggish before and after the revolution in 1975. Relatively insignificant growth took place in cereal and pulse production during the post-revolutionary decade, with an absence of expansion of the cultivated area and declines in yields, particularly on state farms (Belete, Dillon and Anderson 1991). Griffin (1992) also reported that land productivity declined and Belete (1989) revealed that most crops had negative growth rates in yield over the period 1975-76 to 1985-86 After the 1975 revolution, the military government emphasised agricultural production and gave priority to the agricultural sector in their development plans Government expenditure in agriculture rose, and in 1977 was almost four times the amount in 1974 (Griffin 1992) Other sectors thought to be of importance to agriculture, such as education and health, also benefited from sharp increases in government expenditure However, these good intentions and initial increases in outlays evaporated as the government encountered serious economic problems Robinson and Yamazaki (1989) observed that Ethiopian agricultural planning during the revolutionary period was not notably successful, exacerbating inappropriate polices, the turmoil and disruption which accompanied the revolution and drought in various parts of the country

Over the decade, 1975-76 to 1984-85, agriculture contributed about 88 per cent of total exports (Belete, Dillon and Anderson 1991) Coffee was the major contributor followed by livestock, pulses and oilseeds Agricultural exports also provide an important source of government revenue through export taxes

Griffin (1992) reported a disappointing growth rate in food crop output of 1 26 per cent per annum, most of which came from an expansion in state farms and producer cooperatives This modest gain was achieved by area expansion rather than increases in crop yields The country is quite well endowed with agricultural resources with some of the most fertile land in Africa Yet Kidane and Abler (1994) pointed out that, over the past two decades, no other country has experienced food problems as severe as in Ethiopia Drought and famine resulted in the migration of millions of people in search of food, with many people settling in refugee camps set up by the government or foreign agencies As a result, much of the land normally cultivated went out of production Massive food aid and relief efforts had a paradoxical effect of further reducing domestic agricultural output, thus making the long-run situation even more uncertain (Robinson and Yamazaki 1989) In addition to food aid, food imports increased as a proportion of total merchandise imports, from 7 per cent in 1965 to 17 per cent by 1989 (World Bank 1991).

The agricultural sector is also a source of surplus labour given that around 85 per cent of the population live in rural areas As Griffin (1992) noted, rural workers have a much lower productivity than their urban counterparts. There is very little economic surplus in agriculture because of low labour and land productivity in agriculture which, in turn, is due to poor technical performance in agricultural production. Rural underemployment and seasonality of labour requirements also contribute to low labour productivity.

2.3 Problems and Solutions

Agricultural problems in Ethiopia can be classified into four categories. The first relates to the modes of production which have existed in Ethiopian farming systems. Of the three modes of production outlined above, peasant farming offers most potential for accelerated agricultural development as the current political climate is not conducive to an expansion of state farms or producer cooperatives. Yet Belete, Dillon and Anderson (1991) reported that 85 per cent, 50 per cent and 76 per cent of total agricultural credit, fertiliser and improved seeds, respectively, and some 60 per cent of public investment had been directed to the socialist enterprises which accounted for only 5 per cent of the total cultivated land and 4 per cent of the national crop output in 1985. Small-scale farmers have not been given the incentives necessary to expand agricultural production.

The second problem area is the low level of technology in Ethiopian agriculture, especially in the peasant sector. Agricultural policy makers need to address how best to introduce technological change to improve agricultural performance. However, it is difficult to introduce improved technologies because of low education, awareness and motivation. Kidane and Abler (1994) observed that new technology has not been permitted to make any significant inroads. Belete, Dillon and Anderson (1991) highlighted a lack of application of modern technologies, reflected in the large gap between crop yields on farmers' fields and research plots where new techniques are developed. Aklilu (1980) observed that Ethiopia, along with most African countries, had not participated in applying the results of new technologies to any significant extent. These countries lay undue stress on their relatively favourable land-to-labour ratio and continue to look to their seemingly abundant land, rather than improved technologies, to increase food and agricultural output.

The third problem area is chronic inefficiencies in agricultural production. Allocative inefficiencies have been massive, arising from imperfections in agricultural markets and government policies that distort incentives to producers. Griffin (1992) stipulated that, given its acute scarcity in Ethiopia, all forms of capital should be used in the most efficient way possible. Yet state farms have not used resources efficiently as their methods of production are capital-intensive and reliant on imported inputs, and returns to capital are negative. They have made no contribution to capital accumulation and growth in the past, their large deficits represented negative savings, and they have absorbed surpluses generated by other sectors. Griffin (1992) also stated that producer cooperatives generate only small financial surpluses. On the other hand, peasants have little capital, which is expensive, and they face formidable obstacles to invest in farming operations, yet their output per unit of capital is very high.

Technical inefficiencies in production are also considered substantial in agricultural production. Lack of appropriate incentives to produce, absence of suitable extension advice, an inability to acquire farm inputs and land fragmentation have all contributed to technical inefficiencies in peasant production. Fragmentation used to be the result of inheritance whereas, following the revolution, it became the result of concerns for equity and its maladministration. It has added greater distance for farmers to travel to their fields, making it very difficult for peasants to be technically efficient (Wolde-Mariam 1991).

Fourth, rural areas in Ethiopia have long experienced gross inequities. Before 1975, the agrarian economy in Ethiopia was characterised by a feudal system in which an agricultural surplus was extracted by a relatively small group of landlords. This surplus was collected in the form of commodity rents or the landowner's portion of output designated in a share-cropping arrangement. The feudal system kept the peasantry impoverished and preserved primitive cultivation practices. Wolde-Mariam (1991) described the land tenure system during this period as one where many people were not allowed to own land Apart from landless labourers, many landless peasants operated as tenants A number of peasant households owned and cultivated their own small plots of land, but landlords controlled most land A few commercial farmers operated modern large-scale farms, often leasing the land from the government. At the time of the land reform in 1975, the proportion of peasants who owned land was slightly less than 50 per cent, while nearly 39 per cent were landless peasants More than 61 per cent of the peasant households cultivated only 26 per cent of the land, while 18 per cent of farmers had 53 per cent of the land (Wolde-Mariam 1991).

The situation facing peasants did not change much after 1975, when land reform was proclaimed, because peasants now hold land ranging from only 0 1 ha to 4 0 ha.[2] These disparities among peasants, as Wolde-Mariam (1991) outlined, are due primarily to the fact that peasant associations had a mandate to redistribute the land based on the size of peasant households, so that those with large families got larger shares of land and smaller families got less land, resulting in inequalities in land ownership. While the land reform gave rights to former landless peasants and tenants, it did not adequately provide the security of tenure essential for the adoption of improved farming practices. There have been no significant changes in small farm units or their production practices, a situation exacerbated by corruption and incompetence (Kidane and Abler 1994) and the persistence of inadequate support services

While problems impeding agricultural development need to be tackled on a number of fronts, only technical inefficiency in production is considered here, and then only in relation to peasant production as the predominant mode of production likely to be supported in the future The Ethiopian government is now cognisant of past failure to support peasant production, and has taken steps to improve the pricing structure for agricultural products with clearer incentives to producers, thereby providing the framework for improving allocative efficiency Given the significant structural problems in Ethiopian agriculture and the existing level of technology, the easiest and quickest way of improving agricultural performance may be devising means of improving technical efficiencies where substantial technical inefficiencies of production are identified. Such identification is the topic of this study

3. STOCHASTIC FRONTIER PRODUCTION FUNCTIONS AND ESTIMATION OF THE TECHNICAL INEFFICIENCY OF PRODUCTION

Following well-established conventions, the stochastic frontier production function is applied in this study to assess technical inefficiency of production by peasant producers in Central Ethiopia The stochastic frontier production function can be defined by:

[2] This is particularly so in Central and North Ethiopia 'where land has always been distributed under a kinship system' (Kidane and Abler 1994, p. 180).

$$Y_i = f(x_i;\beta) + (V_i - U_i),\ i = 1, 2, \ldots, N,$$

where

Y_i is the observed level of production of the i-th firm,

$f(x_i;\beta)$ is a suitable function of a vector, x_i, of inputs for the i-th firm,

β is a vector unknown parameters,

V_i is a random error having mean zero, and

U_i is a non-negative random variable associated with technical inefficiency of production of the i-th firm

Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) assumed that the random error, V_i, was independently and identically distributed as a normal random variable with mean, zero, and variance, σ_v^2. The random variable, U_i, was assumed to have half-normal distribution or exponential distribution

In this model, the observed output, Y_i, is bounded above by the stochastic quantity, $f(x_i;\beta) + V_i$, where V_i accounts for random variation of production outside the control of the individual firms

Consider two firms represented by i and j Firm i uses inputs, x_i, and produces output, Y_i The corresponding frontier output, Y_i^*, exceeds the value on the deterministic production, $f(x_i;\beta)$ Battese (1992) referred to this situation as 'favourable' conditions for which the random error, V_i, is positive On the other hand, firm j uses inputs with values, x_j, and produces output, Y_j The corresponding frontier output is Y_j^*, which is less than the value on the deterministic production, $f(x_j;\beta)$ In this case, the productive activity of firm j is associated with 'unfavourable' conditions for which the random error, V_j, is negative

Given that the above stochastic model is in original units of production, then the technical efficiency of the i-th firm is defined by the following ratio:

$$TE_i = Y_i/[f(x_i;\beta) + V_i]$$

This measure of technical efficiency for the i-th firm is defined for the given levels of the inputs, specified by the vector, x_i. However, if the model is defined in terms of the logarithm of output, then the technical efficiency of the i-th firm is defined by:

$$TE_i = \exp(Y_i)/\{\exp[f(x_i;\beta) + V_i]\} \equiv \exp(-U_i).$$

Jondrow, Lovell, Materov and Schmidt (1982) considered the stochastic frontier and proposed that the technical inefficiency effect, U_i, be predicted by the conditional expectation of U_i, given the composed error, $E_i \equiv V_i - U_i$.

Estimation of frontier production functions, and the associated prediction of the technical efficiency of firms, has been applied in various disciplines, ranging from service sectors to production sectors Both panel and cross-sectional data have been used in these studies. Extensive bibliographies on empirical studies of frontier production functions and efficiency analyses are given by Ley (1990) and Beck (1991) while Battese (1992) surveyed empirical applications in agricultural economics. The number of applied studies in this research area has increased rapidly in recent years.

4. DATA, VARIABLES AND MODEL FORMULATION

4.1 Data Source

The data used in this study are from a survey of Ethiopian farmers conducted in March 1990 and used by Kidane and Abler (1994) to examine the characteristics of production technologies in Ethiopian agriculture The survey covered the whole country and involved 14 administrative regions two each from North-West, North-East and Central Ethiopia, and eight from South Ethiopia. Within each region, there are several districts and within each district several villages A village was chosen within each district on the basis of stratified random sampling with probability proportional to size. All households willing to respond were interviewed within each village. Data from the Central region used in this study initially comprised a sample of 1012 farmers.[3] When observations with missing values and zero revenue, equipment and land were removed, the sample size was reduced to 843

Technical efficiencies are estimated for peasant farmers who apply fertiliser and those who do not apply fertiliser For the Central region, 447 farmers applied no fertiliser, whereas 396 farmers applied at least some fertiliser in their farming operations in 1990.

4.2 Variables Used

The dependent variable used in the production function analyses is the gross value of crop and livestock output (in birr)[4] during the 1990 agricultural season. Non-marketed output was valued at market prices.[5]

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[3] The Central region was selected for analysis because of its superior data quality. In general, this region comprises cool highlands, and has less severe population pressures and better soils than other regions (Kidane and Abler 1994).

[4] Kidane and Abler (1994, p. 184) reported an official exchange rate of 2.07 birr to the US dollar at the time of data collection.

[5] Use of value of output as the dependent variable in the frontier production function, rather than output in physical units, introduces possible interpretive difficulties in the frontier production function analysis. Unless all farmers face the same product price structure, the random variable, U_i, in the stochastic frontier model accounts for overall economic inefficiency rather than only technical inefficiency of production. However, strict government control over price-setting in agriculture at the time of the survey suggests it is a reasonable assumption that all farmers do face the same output prices.

Four main explanatory variables are used in the production frontiers in this study. They are land, fertiliser, the number of items of equipment used by the farmers in their farming operations and the number of cattle owned.[6] Equipment is measured by number of implements owned by a farmer, which ranges from hand hoe to ploughs. Land is the area cultivated by the farmer (in hectares). Fertiliser (if used) is measured in kilograms.

Despite being an important input in agricultural activity in developing countries, labour is not included in the empirical analysis. While noting the importance of labour, Kidane and Abler (1994) did not obtain data on the amount of time which the sample farmers devoted to agricultural production.[7]

Four dummy variables, categorised into two groups, are considered in this study. The first involves rainfall dummies, which indicate the incidence of rains heavier or lighter than normal. The second group involves soil dummies, which indicate 'soil is fair' or 'soil is poor' relative to the base which is 'soil is good'. All dummy variables have a value of one for 'yes' and zero otherwise. Dummy variable values are derived from the opinion of the head of the household. Table 1 contains summary statistics of these variables, classified according to whether farmers use fertiliser or not. It shows that the sizes of the output, equipment, cattle and land variables are somewhat larger for farmers who use fertiliser. It is evident from Table 1 that only about 10 per cent of farmers thought that the rains in 1990 were heavier than normal whereas about 4 per cent reported rains lighter than normal. This means that 1990, when the survey was carried out, was a year in which severely adverse weather conditions were generally absent.

Almost all sample farmers had a value of one for one of the soil dummy variables because the sample means of the soil dummy variables in Table 1 add to over 0.90. Thus, more than 90 per cent of the sample farmers regarded their soil as either fair or poor rather than good. This suggests that the inclusion of the second soil dummy variable in the frontier model may not result in any significant improvement in the explanation of value of output over that obtained by using only one soil dummy variable.

4.3 Model Formulation

Two functional forms were considered for the stochastic production frontier, namely, the Cobb-Douglas and translog functions

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[6] Draft animals are not measured separately in the data but are included in the overall number of cattle owned by the farmer.

[7] This setback is not considered an insurmountable disadvantage of this study relative to most other studies of technical efficiency of smallholder agriculture, even though it introduces the possibility of model mis-specification. Collection of accurate data on labour inputs in smallholder agriculture is notoriously difficult. Even where they are included in studies similar to this one, the validity of labour input data collected is usually highly dubious unless considerable resources, including experienced and skilled human resources, are committed to their collection, which is rare.

Table 1

Summary Statistics for Variables for Sample Farmers in Central Ethiopia

Variable	Sample mean		Sample standard deviation		Minimum value		Maximum value	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Output	705	689	466	495	46	46	3250	3939
Equipment (no.)	11.2	1[illegible].0	4.1	3.8	2.0	2.0	42.0	32.0
Cattle (no.)	4.7	3.4	2.2	1.9	1.0	1.0	15.0	15.0
Land (ha)	2.3	1.80	1.0	0.9	0.25	0.13	6.5	8.0
Fertiliser (kg)	101.3	-	90.5	-	1.0	-	700.0	-
Heavy rain	0.10	0.05	0.30	0.25	0	0	1.00	1.00
Light rain	0.04	0.04	0.20	0.20	0	0	1.00	1.00
Soil fair	0.40	0.77	0.49	0.42	0	0	1.00	1.00
Soil bad	0.48	0.18	0.47	0.38	0	0	1.00	1.00

Note: The columns indicated by (1) represent data for farmers who use fertiliser, whereas the columns indicated by (2) represent data for farmers who do not use fertiliser.

4.3.1 Cobb-Douglas production frontier

The stochastic frontier production function of Cobb-Douglas type is defined in logarithmic form as:

$$\ln Y_i = \beta_0 + \beta_1 \ln E_i + \beta_2 \ln C_i + \beta_3 \ln L_i + \beta_4 \ln F_i + V_i - U_i, \quad i = 1, 2, ..., N, \qquad (1)$$

where:

ln represents the natural logarithm;

Y_i represents the total value of output of the i-th farmer;

E_i is the number of implements used by the i-th farmer;

C_i is the number cattle owned by the i-th farmer;

L_i is the area of land operated by the i-th farmer;

F_i is the quantity of fertiliser used by the i-th farmer (given that $F_i > 0$);

β_0, β_1, β_2, β_3 and β_4 are unknown parameters to be estimated;

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

the U_is are non-negative random variables which are assumed to be independent and identically distributed, obtained by the truncation at zero of the $N(\mu, \sigma^2)$ distribution, and

N represents the number of sample farmers in the data set involved, where N = 447 for farmers who apply no fertiliser and N = 396 for farmers who apply some fertiliser

Maximum-likelihood estimates of the parameters of the stochastic frontier model are obtained using the computer program, FRONTIER, Version 2.0 (Coelli 1991). The variance parameters are estimated in terms of the parameters, $\sigma_s^2 \equiv \sigma_v^2 + \sigma^2$ and $\gamma = \sigma^2 / \sigma_s^2$. If $\gamma = 0$, then the model is equivalent to the traditional average response function which is efficiently estimated using ordinary least-squares regression. Modifications of the Cobb-Douglas model are made to permit the intercept parameter to be different for farmers who have different rainfall and soil conditions. This model is expressed in logarithmic form as

$$\ln Y_i = \beta_0 + \delta_1 D_{1i} + \delta_2 D_{2i} + \delta_3 D_{3i} + \delta_4 D_{4i} + \beta_1 \ln E_i + \beta_2 \ln C_i + \beta_3 \ln L_i + \beta_4 \ln F_i + V_i - U_i \qquad (2)$$

where:

D_{1i} has value 1 if the i-th farmer felt that the rains were heavier than normal (0, otherwise),

D_{2i} has value 1 if the i-th farmer felt that the rains were lighter than normal (0, otherwise),

D_{3i} has value 1 if the i-th farmer said his soil was fair (0, otherwise);

D_{4i} has value 1 if the i-th farmer said his soil was poor (0, otherwise); and

δ_1, δ_2 δ_3 and δ_4 are unknown intercept parameters to be estimated.

The frontier production function defined by equation (2) specifies that the incidence of heavier or lighter rains and the different classes of soil only affect the level of output of the farmers, not the elasticities of production of the different inputs. The model can be extended to permit the elasticities of production to be different for the different values of the dummy variables by introducing interactions between the input variables and the dummy variables. This model is defined by:

$$
\begin{aligned}
\ln Y_i = \beta_0 &+ \delta_1 D_{1i} + \delta_2 D_{2i} + \delta_3 D_{3i} + \delta_4 D_{4i} \\
&+ \beta_1 \ln E_i + \beta_2 \ln C_i + \beta_3 \ln L_i + \beta_4 \ln F_i \\
&+ \delta_{11} D_{1i} \ln E_i + \delta_{12} D_{2i} \ln E_i + \delta_{13} D_{3i} \ln E_i + \delta_{14} D_{4i} \ln E_i \\
&+ \delta_{21} D_{1i} \ln C_i + \delta_{22} D_{2i} \ln C_i + \delta_{23} D_{3i} \ln C_i + \delta_{14} D_{4i} \ln C_i \\
&+ \delta_{31} D_{1i} \ln L_i + \delta_{32} D_{2i} \ln L_i + \delta_{33} D_{3i} \ln L_i + \delta_{34} D_{4i} \ln L_i \\
&+ \delta_{41} D_{1i} \ln F_i + \delta_{42} D_{2i} \ln F_i + \delta_{43} D_{3i} \ln F_i + \delta_{44} D_{4i} \ln F_i + V_i - U_i. \qquad (3)
\end{aligned}
$$

It is of particular interest to test the hypothesis that the elasticities of production for the different inputs are the same irrespective of the values of the different dummy variables.

4.3.2 Translog production frontier

The translog frontier production function is defined by the following equation.

$$
\begin{aligned}
\ln Y_i = \beta_0 &+ \beta_1 \ln E_i + \beta_2 \ln C_i + \beta_3 \ln L_i + \beta_4 \ln F_i + \beta_{11}(\ln E_i)^2 + \beta_{12}(\ln E_i)(\ln C_i) \\
&+ \beta_{13}(\ln E_i)(\ln L_i) + \beta_{14}(\ln E_i)(\ln F_i) + \beta_{22}(\ln C_i)^2 + \beta_{23}(\ln C_i)(\ln L_i) \\
&+ \beta_{24}(\ln C_i)(\ln F_i) + \beta_{33}(\ln L_i)^2 + \beta_{34}(\ln L_i)(\ln F_i) + \beta_{44}(\ln F_i)^2 + V_i - U_i \qquad (4)
\end{aligned}
$$

The elasticities are functions of the levels of the inputs involved. If the coefficients of the second order terms are zero, then the model reduces to the basic Cobb-Douglas frontier, defined by equation (1). Hence, testing whether these coefficients are zero is of interest in model specification.

Dummy variables could be included in the translog model to permit different levels of output for farmers with different rains and soil types. Permitting the elasticity parameters to vary for the different values of the dummy variables would result in a very large number of variables and parameters, however, and was not attempted in this study.

4.4 Common Cobb-Douglas Frontier

The various models specified above are based on two separate groups of farmers, namely those who use fertiliser and those who do not. If it is concluded that, given the specifications of the translog stochastic frontier, the Cobb-Douglas model is an adequate representation of the data, a common Cobb-Douglas frontier model is to be specified to test whether it is preferred on statistical grounds to two separate models. Tests would also be carried out for differences in the intercepts for rainfall and soil characteristics, and for differences in elasticities and variance parameters. The common Cobb-Douglas stochastic frontier model (excluding elasticity dummies) is defined by:

$$
\begin{aligned}
\ln Y_i = \beta_0 &+ \delta_0 D_{0i} + \delta_1 D_{1i} + \delta_2 D_{2i} + \delta_3 D_{3i} \\
&+ \beta_1 \ln E_i + \beta_2 \ln C_i + \beta_3 \ln L_i + \beta_4 \ln\{\mathrm{Max}\,[F_i, D_{0i}]\} + V_i - U_i \qquad (5)
\end{aligned}
$$

where D_{0i} = 1 if the i-th farmer applies no fertiliser (= 0, otherwise) and other variables are as previously defined.

5. EMPIRICAL RESULTS

5.1 Model Selection

Various models, outlined above, were subjected to statistical tests in explaining peasant agricultural output in Central Ethiopia. Test results confirmed the null hypothesis that the Cobb-Douglas and translog functional forms were equivalent, indicating that the Cobb-Douglas function is an adequate representation of the data. Discussion below is therefore restricted to results obtained using a Cobb-Douglas functional form

Having settled on the use of the Cobb-Douglas, the next step was to compare the common Cobb-Douglas model with separate models for farmers who do and do not use fertiliser. Tests of hypotheses associated with the common Cobb-Douglas model are presented in Table 2. The first null hypothesis considered is that the common Cobb-Douglas model is an adequate representation of the data, given specification of the two Cobb-Douglas frontiers with possibly different intercepts associated with the different rainfall and soil characteristics. Since the generalised likelihood-ratio statistic, λ, is less than the 95 per cent point for the χ^2 distribution, this null hypothesis is not rejected. Hence the common Cobb-Douglas frontier model is accepted as an adequate representation of the data.

Table 2 Tests of Hypotheses of the Parameters of the Common Cobb-Douglas Model for Farmers in Central Ethiopia

Null hypothesis	$\chi^2_{0.95}$	LLF	λ
H_0: common CD model	16.92	-705.313	11.86
H_0: $\delta_1=\delta_2=\delta_3=0$	7.81	-712.409	14.19

The generalised likelihood ratio statistic is also presented in Table 2 to test whether the intercept parameters are the same for different rainfall and soil characteristics for the common Cobb-Douglas frontier. This hypothesis is rejected because the value of the generalised likelihood-ratio statistic, 14.19, exceeds the 95 per cent point for the χ^2 distribution.

Table 3

Maximum-Likelihood Estimates for Parameters of the Common Cobb-Douglas Model

Variable	Parameter	With dummy variables	Without dummy variables
Constant	β_0	5.29	5.37
		(0 13)	(0.13)
D_0 (zero fertiliser)	δ_0	-0.49	-0.39
		(0.15)	(0.14)
Equipment	β_1	0.453	0.464
		(0 058)	(0.058)
Cattle	β_2	-0 018	-0.019
		(0 037)	(0.038)
Land	β_3	0.716	0.720
		(0 040)	(0.038)
Fertiliser	β_4	0 083	0.046
		(0 035)	(0.032)
D_1(Heavier rains)	δ_1	-0 066	-
		(0 073)	
D_2 (Lighter rains)	δ_2	-0.203	-
		(0 093)	
D_3 (soil fair)	δ_3	0 128	-
		(0.045)	
	σ_s^2	5.9	5.0
		(3 5)	(2.9)
	γ	0.973	0.969
		(0.018)	(0.020)
	μ	-12.6	-10.2
		(8.8)	(7.0)
Log-likelihood function ≡ LLF		-705.313	-712.409

Estimates for the common Cobb-Douglas frontier model are presented in Table 3. The estimated coefficient for the dummy variable for no fertiliser use is significantly negative, as expected, implying that the intercept of the production frontier is lower for farmers who do not use fertiliser. The dummy variable for heavier than normal rains is also negative but insignificantly different from zero while that for lighter than normal rains is, as expected, negative and significantly different from zero at the 5 per cent level. Kidane and Abler (1994) obtained marginally insignificant results for both variables applying the average production function, although the coefficient obtained for heavy rains dummy without fertiliser use was positive. Rather surprisingly, the coefficient of the fair soils dummy variable is significantly positive, indicating that the intercept of the production frontier is higher for farmers on fair soils than for those on good soils. The likely explanation is that farm size is, on average, substantially larger for farmers who have only fair soils than for those on good soils. This result differs from the results obtained for average production functions by Kidane and Abler (1994); they found the coefficient on the 'soils are fair' dummy variable negative but insignificantly different from zero both for farmers who do and do not use fertiliser.

The partial elasticities of output for land, machinery and fertiliser have expected signs and are significantly greater than zero at least at the 5 per cent significance level. Land has the major influence on output, with an elasticity of 0.72. This compares with elasticity estimates of 0.67 and 0.55 for the average production functions of farmers with and without fertiliser, respectively, obtained by Kidane and Abler (1994). Next in importance is machinery, with an elasticity of 0.45. Kidane and Abler (1994) estimated 0.61 and 0.30 for farmers with and without fertiliser, respectively, for average production functions. The elasticity of output in respect of fertiliser is quite low, at 0.08. That for livestock is unexpectedly negative, but insignificantly different from zero. This insignificant result could be attributed to three factors. First, as reported above, the livestock industry has suffered chronically from low productivity; in particular, overstocking has been a major problem, adversely affecting the ability of livestock activities to contribute to output. Second, the way in which the livestock input variable is specified, with all animals grouped together, is unsatisfactory; it would have been preferable to distinguish draft animals from those raised for meat output. Third, livestock are commonly kept for prestige and security purposes, rather than for profit; hence, their productivity might be of only minor concern to peasant farmers.

In summary, the common Cobb-Douglas stochastic frontier function is considered an adequate representation of the data on all farmers in Central Ethiopia, permitting different intercepts for rainfall and soil characteristics. Results imply that the elasticities of output of equipment, cattle and land, together with the corresponding variance parameters, are equal for the two groups of farmers. Results of reasonable statistical quality were obtained despite the absence of a labour input variable from the model, with most coefficients in line with expectations or at least plausibly explained.

5.2 Technical Efficiencies of Peasant Farmers

Results of tests of hypotheses associated with the inefficiency effects in the Cobb-Douglas model are given in Table 3. These tests are obtained using the generalised likelihood-ratio statistic. The decision whether to accept the corresponding null hypothesis depends on the value of the test statistic and the appropriate χ^2 critical value applying a 5 per cent level of significance. In Table 3, the first null hypothesis that $\mu = \gamma = 0$ specifies no inefficiency effects in the frontier. This is strongly rejected by the sample data for farmers as a whole and specifically with and without fertiliser. This implies that the traditional response function is not an adequate representation of the data, given the specifications of the stochastic frontier model. Thus, inefficiencies of production cannot be assumed to be absent from the stochastic frontier production function for the given level of technology used by farmers.

The second null hypothesis in Table 3 is that $\mu = 0$, which specifies that the distribution of the inefficiency effects has half-normal distribution. This hypothesis is rejected at the 5 per cent level of significance. Since the estimates for the μ parameters are negative, there are higher probabilities of small inefficiency effects than would be indicated under the half-normal distribution.

Technical efficiencies of farmers are predicted using the common Cobb-Douglas frontier together with the separate Cobb-Douglas frontiers for farmers using and not using fertiliser. The separate frontiers enable mean technical efficiencies to be estimated for these two groups of farmers, even though it is concluded above that the two frontiers have common elasticities and variance parameters. Because of the large number of farmers involved, individual technical efficiencies are not presented.

The mean technical efficiency of all the sample farmers in Central Ethiopia is estimated to be 0.692, whereas the mean technical efficiencies of farmers using fertiliser and not using fertiliser are estimated to be 0.708 and 0.681, respectively. These latter estimates are not significantly different from each other.

The relative frequency distributions of the technical efficiencies for the three groups of farmers are presented in Figures 1 to 3. Figure 1 presents the relative frequency distribution of the technical efficiencies of all sample farmers in Central Ethiopia estimated from the common Cobb-Douglas frontier. The figure indicates that a majority of farmers have technical efficiencies in the range 0.70 to 0.85. Figure 2 presents the relative frequency distribution of the technical efficiencies of farmers using fertiliser in Central Ethiopia. In this group, about 56 per cent of farmers are in the range 0.70 to 0.85. Figure 3 presents the relative frequency distribution of the technical efficiencies of farmers using no fertiliser. About 55 per cent of farmers are in the range 0.70 to 0.85.

6. POLICY AND RESEARCH IMPLICATIONS

Three analytical results reported above have important policy implications:

(1) Substantial technical inefficiencies of production exist on peasant farms in Ethiopia, given the specifications of the stochastic frontier production functions estimated in this study. There is a therefore at least some scope for raising agricultural output through improvements in technical efficiency, without resort to improved technologies.

Figure 5.1 Relative Frequency Distribution of Technical Efficiencies for all Farmers

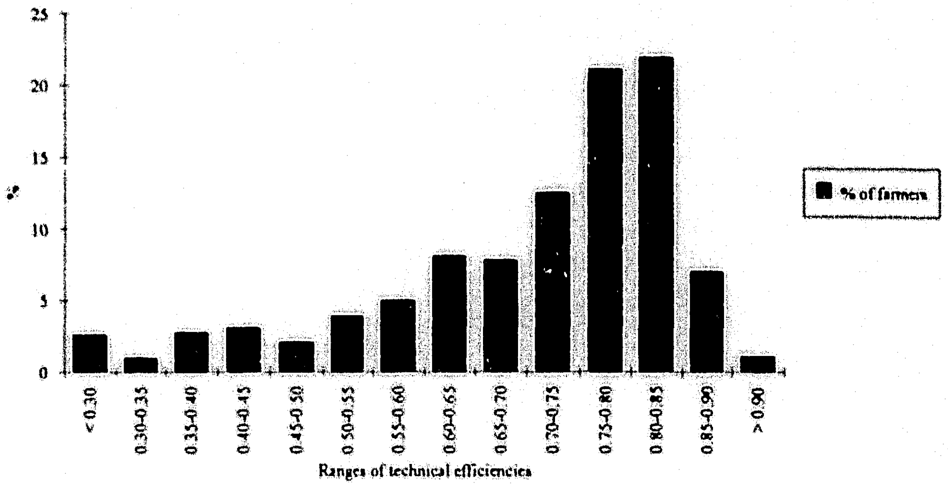


Figure 5.2 Relative Frequency Distribution of Technical Efficiencies for Farmers Using Fertiliser

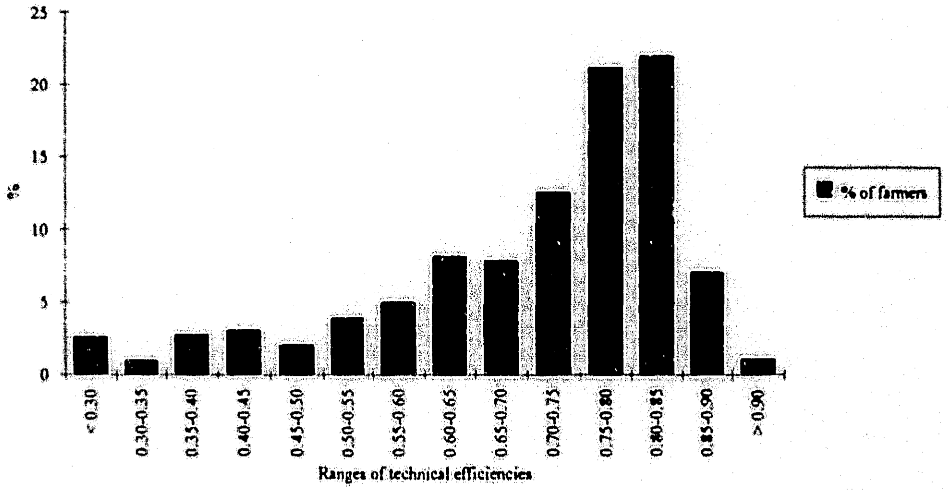
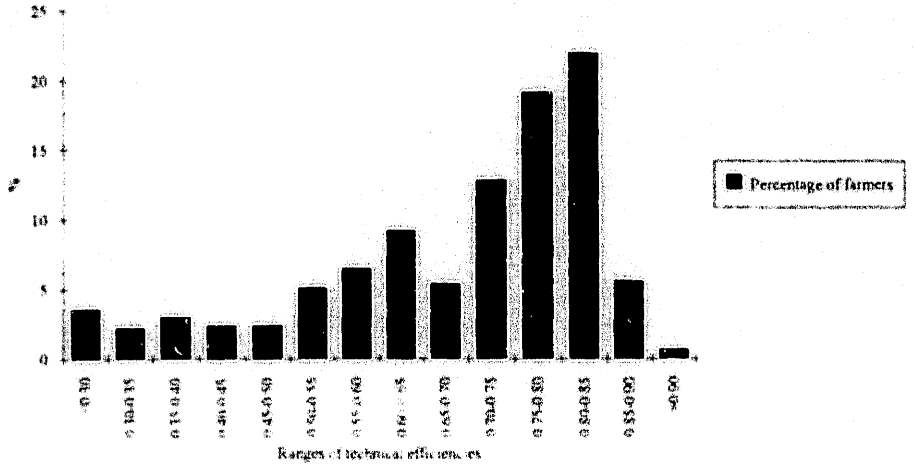


Figure 5.3 Relative Frequency Distribution of Technical Efficiencies for Farmers Not Using Fertiliser



(2) Since land remains a key input in Ethiopian agriculture, especially for production on the frontier, its fragmentation and insecure tenurial arrangements are likely to have contributed to technical inefficiency. Land tenure policy therefore remains critical to improving technical efficiency. Current arrangements inherited from the 1975 land reform where land is ultimately owned by the state - meaning that farmers cannot own land but only inherit rights to work or lease it - are inimical to small farm development (Anon 1995)

(3) The importance of fertiliser in the development of peasant agriculture in Ethiopia can be overstated, *given current application methods*. The mean technical efficiency of farmers who apply fertiliser is not significantly different from that for farmers who do not. Furthermore, the partial elasticity of output with respect to fertiliser is low. Use of fertiliser does not distinguish technically more efficient peasants from technically less efficient ones.

Four important research issues remain. One outcome of the study is that it has been shown possible to undertake an analysis of technical inefficiency in peasant agriculture despite the absence of data on the key input of labour. In light of the extreme difficulties often faced in gathering accurate labour data for such analysis, this is a positive result. Nevertheless, it does mean some loss of information about production relations and technical inefficiency, and any future analysis of technical inefficiency in peasant agricultural production should ideally incorporate labour input data.

Second, the current study excludes a number of non-traditional variables which help explain agricultural output because data were not available. It would be useful to examine technical efficiency more rigorously by incorporating such relevant explanatory factors in the stochastic production function analysis. Factors which have been found to influence the level of technical inefficiency of production in other studies include age, education and experience of farmers, access to credit and infrastructure. Management procedures, access to extension advice and marketing arrangements for agricultural products might also be relevant variables. The model proposed by Battese and Coelli (1993) may be useful as a framework for incorporating these variables.

Third, aspects of efficiency other than technical ones, notably allocative, size and technological efficiency, have not been addressed in this paper. Policy analysts would benefit from study results in these areas to the extent that progress in exploiting these efficiencies can also play a role in developing peasant agriculture in Ethiopia. In particular, it would be interesting to trace improvements in allocative efficiency over the past few years to determine the impact of liberalisation of agricultural markets.

Finally, this study represents a snapshot of technical inefficiency in peasant agriculture. A study which uses panel data would be useful in tracking changes in technical efficiency over time, especially given the quite momentous changes which have been taking place in the agricultural economy in Ethiopia since the data used in this study were collected in 1990.

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