ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

AN APPLICATION OF STOCHASTIC FRONTIER IN ESTIMATING THE TECHNICAL EFFICIENCY OF SMALLHOLDER CEREAL CROP PRODUCERS: *THE CASE OF SEVEN PEASANT ASSOCIATIONS (PAs) IN THE AMHARA REGION*

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Economics (Economic Policy Analysis)

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study tried to predict the technical efficiency levels of farmers over time and the factors that are responsible to the variation in technical efficiencies among farmers. We considered seven peasant associations (PAs) in Amhara region from the four year agricultural households survey panel data that has been conducted by the Department of Economics (Addis Ababa University). Parameters from the stochastic frontier and the technical inefficiency effects model have been estimated simultaneously. A more flexible stochastic frontier production functional form, i.e., the translog, for farmers in Milki, Karafino, Bokafya and Shumsheha and the Cobb-Douglas stochastic frontier production functional form for farmers in other PAs have been found to be appropriate production technologies in estimating the farm level technical efficiencies. The hypothesis that farmers are fully technically efficient so that the conventional (average) production function is adequate has been rejected for all PAs. For two of the PAs (Milki and Shumsheha), appropriate technical efficiency predictions have been obtained based on a truncated normal distribution of the inefficiency term whereas a half normal distribution of the inefficiency term gave good predictions of farm level technical efficiencies for the rest of the PAs. The results in all PAs show the existence of technical inefficiency implying that there is a hope, at least for a short run, to increase agricultural production only by improving the technical efficiency of farmers.

In general, education, credit, experience, family size, sex occupation, the size of livestock holding and incomes generated from off-farm activities have been fond to be important variables in explaining the variation in technical efficiency among farmers. To enhance technical efficiencies, therefore, the regional government should have a prime responsibility for its increased provision of education, micro-enterprises to assist farmers in terms of financial support and creation of off-farm job opportunities. Special attention towards female-led households, for instance, giving priorities to make them as "model farms", should also be included in the agenda of the region's agricultural policy. Moreover, the regional government should also give priorities for agricultural households with relatively younger and older household heads in the provision of credit, access to education and other technical assistance. The long-run plan should, however, involve in introducing new technologies, improving institutional structures and building infrastructure to push the production function outward and create new production horizon.

CHAPTER I: INTRODUCTION

1.1 Background

Ethiopia is one of the poorest countries whose economy's fate is almost determined by agriculture. The agricultural sector contributes enormously to the Ethiopian economy. It accounts for about 50 per cent of the gross domestic product (GDP), provides employment for 85 per cent of the population, generates about 90 per cent of the export earnings, and supplies about 70 per cent of the country's raw material requirement for large and medium sized agri-based industries (MEDaC, 1999: 145). Given the existing structure of employment and the economy at large, agriculture remains to be the basis of the Ethiopian economy.

In spite of the existence of potentials for agricultural development, the growth in production in the sector has not been able to cope with the demand, particularly over the last three decades (Assefa and Franz, 1996: 18). In general, despite agriculture's importance to the Ethiopian economy, it has been performing below its potential.

The rapid growth of population, natural hazards and mis-directed policies contributed to the deteriorating food security situation for the majority of the population. The poor performance of the sector is also reflected through its insufficient provision of raw materials for the limited number of local industries. Had the sector performed well, it could have supplied raw materials to local industries and provided food for the growing population more than what it does today.

As a result of the poor performance of the agricultural sector, the country has been obliged to import increasing quantities of its basic food items. According to FAO's (1996) report, during the early 1980's, domestic production met only about 70 per cent of the recommended minimum caloric intake. This evidence can be complemented by the report on Food Aid to Ethiopia (1988). According to this report, in mid-1980's, the country, in absolute magnitude, emerged as the fifth largest food aid recipient in the world, being preceded by Egypt, Bangladesh, Sri Lanka and Pakistan. For instance, cereal aid to Ethiopia rose from 1,800 MT in 1972 to over 1 million MT in 1985 (Alemayehu, 1988: 60). As a result, the country's food self-sufficiency in 1985 was only 59 per cent (IGADD, 2000: 35). Further, Croppenstedt and Mulat (1997) indicated that cereal imports and food aid reached to 1045 and 963 thousand metric tons, respectively in 1992.

Regardless of efforts made to meet the demand for food through domestic production, imports and aids, the available supply from all these sources has remained below the biological minimum requirements. According to the National Nutrition Survey (CSA, 1993:28), among children below the age of five years, 64 per cent are stunted (low height-for-age), 8 per cent are wasted (low weight-for-height) and about 47 per cent are underweight (low weight-for-age). The report emphasized that these figures are alarming by all standards.

To all appearances, the position of the Ethiopian agricultural sector, as stated above, is below what it should have been. Hence, improving the agricultural sector's performance in Ethiopia, for instance, by increasing the efficiency of producers, is of crucial importance.

It is clear that the bulk of the Ethiopian agricultural output comes from smallholders. Smallholder farmers on the average account for 95 per cent of the total area under cultivation and for more than 90 per cent of the total agricultural output. Moreover, 94 per cent of the food crops is produced by small-scale farmers (MEDaC, 1999: 145). Despite such contributions of smallholder farmers, they have been adopting low input and low output rain-fed mixed farming with traditional technologies. The arable land holding size of smallholder farmers is also diminishing primarily due to demographic dynamics and the absence of development in other economic sectors, which could have absorbed the growing rural population. The average national arable land holding size per household is estimated to be 1.0 hectare (CSA, 1999/00:77). This minuscule size of land holding needs either the farmers' efficient utilization with the existing technology or a further innovation of technology.

The overriding objective of economic development in Ethiopia should be enhancing the productivity of the peasant sector. To this effect, the current government has taken measures. Market liberalization and price incentives, provision of modern inputs, extension services and improved technology are among the measures. In the presence of shortage of land and rapid population growth, this kind of government attention to the agricultural sector seems to be a good beginning (Abrar, 1996: 1-2). Of course, much remains to be done. The frequent occurrence of famine in different regions of the country is a clear indication of the low level of agricultural production and the magnitude of the problems in which the country finds itself.

Cereals are the preponderance in the cropping pattern of peasant agriculture. It is also common knowledge that these crops are the major food crops produced in Ethiopia. The major cereals produced are teff, wheat, barely, sorghum, and maize. Millet and oats are also among cereals which are cultivated rarely.

According to the annual agricultural sample survey of CSA (1979/80–1999/00), the main (Meher) season harvest, at national level, indicate that cereals in each year under consideration had the highest percentage share both in total crop area and production compared to pulses and other crops. On the average, they accounted for about 83 and 88 per cent of total crop area and production, respectively. The remaining was accounted for by pulses and other crops in that order. However, the productivity (yield) of these major crops has been virtually stagnant.

1.2 Statement of the Problem

It is apparent that the Ethiopian economy is dominated by agriculture sector. Thus, the performance of the overall economy is determined by this sector. Food production and the provision of raw materials for the agri-based industries are among the contributions of the sector. But the sector fails to provide the above contributions sufficiently. This is undoubtedly due to the low level of development in the agricultural sector. The poor use of modern inputs such as fertilizers, improved seeds and extension services partly explain the low productivity of the sector. Apart from this, the internal inefficiency of farmers has its own contribution to the poor performance of the sector.

This study focuses on seven PAs in region three. The region is one of the major cereal crop producing regions in the country. However, the growing population of the region is followed by scarcity of arable land. The recent redistribution of land in the region seems to be a response to the problem. Furthermore, the decreasing trend of production in the region is another problem. As a result of these problems, many of the farmers migrate to other regions where either land, relatively, is not scarce or off-farm activity is available (own observation). Therefore, the region, other than the distribution of land, needs some kind of attention to improve the agricultural sector. Assessing the efficiency of farmers may be one of the ways that helps improving the sector in the region.

Although a number of studies in Ethiopia have been undertaken to assess the efficiency of smallholder producers, no study that specifically refers to the region concerning the technical efficiency of smallholders has been undertaken. In fact, many of the studies in Ethiopia used cross–sectional data and their findings indicate the efficiency or inefficiency of farmers at a point in time. But technical efficiency is better studied with panel data.

The Department of Economics (Addis Ababa University) in collaboration with Center for the Study of African Economics, Oxford University; United Kingdom, and USAID, has completed the fifth round of Ethiopian Rural Household Survey. This enables one to use panel data in investigating the technical efficiency of farmers. Therefore, the availability of this survey, which in aggregation gives 4 years agricultural household panel data, and the scarcity of arable land and low level of agricultural output in the region inspired me to take up the study to shade some light on filling the gap in the technical efficiency of farmers over a period of time.

1.3 Objectives of the Study

As the population of the country increases and land becomes less and less available, growth in agriculture depends more and more on yield increasing technological change. It is also possible to increase output given the existing technology, for instance only by reducing the leisure time of farmers, without injecting new and additional resources into the farm. This is a potential choice for a country like Ethiopia where resources are limited to further new technologies.

Therefore, under such rapid population growth and limited resources, it is imperative to investigate whether most farmers obtain the maximum possible output given the existing inputs and technologies so that new investments should be designed to promote production or some farmers produce less than what others produce and hence there may be considerable scope for increasing output without major investment. At the same time it is also important to see whether farmers can learn, after a period of time, from the extent of their inefficiency and do a way with inputs and other factors that may contribute to their inefficiency. Therefore, the main objective of the study is to address the above issues.

The specific objectives of the study are:

- To investigate the efficiency of the sampled smallholder farmers, (agricultural households) in the selected PAs in the region,

- To assess whether the sampled farmers in the PAs improved their technical efficiency over time and
- To assess the determinants of technical [in]efficiency.

1.4 Significance of the Study

The agricultural sector is not a thing to be left to the market forces. It is mainly characterized by subsistence farming. It usually consists of a large number of small-scale peasant producers who operate on fragmented plots in remote areas. The producers are highly dependent on infrastructure, marketing support, and extension services. The risk-adverse small-scale farmers lack the resources to invest in technological innovations, improvements and other long-term strategies which can help maximize production. Furthermore, malnutrition, poor access to rural health and educational facilities combined with other problems can all restrict the small farmers' ability to increase agricultural output. Therefore, the very unique nature of the sector needs some kind of intervention so as to promote it. Appropriate measures that will be taken are important in overcoming the problem of starvation that frequently hits every corner of the country and is fomented by natural calamities and ill-designed policies.

Improving the efficiency of smallholder producers, given the level of technology and inputs, is one of the strategies in the promotion of the agricultural sector.

Analyzing the technical efficiency of farmers, as one form of rating efficiency, gives empirical evidence in the assessment of their performance.

The present social, political and economic structures of the country are almost regional-based. Each region has been given an authority in deciding on the promotion or improvement of some forms of social, political or economic structures of the region in question. To take some kind of action in such areas, statistical or empirical evidence is important.

Thus, providing empirical evidences on the degree of smallholder producers' technical efficiency and factors influencing such efficiency of farmers found in areas under consideration would help indicating the direction that regional policy makers ought to take concerning the improvement of smallholder farmers in the region.

Therefore, this study, using panel data in assessing the efficiency of farmers over time, may provide ideas for policy makers to take sound policies. Further, the study may motivate other researchers to undertake other complex design studies in regions extensively or at a country level.

1.5 Hypotheses

The nature of smallholder farmers is diversified. Some of them operate in a favorable environment and others do not. They are endowed with various resources and units of production. The assumption that farmers produce the same level of output, given the same level of inputs and technology, seems to be unrealistic. This is because some of the farmers produce a higher level of output with the given technology and inputs and others produce less than this level.

Therefore, in this study the hypotheses to be tested are:

- Smallholder farmers in the selected PAs are inefficient and hence the Conventional (average) production function may not be an appropriate production function.
- Their inefficiency is attributable to their specific characteristics.

1.6 Scope and Limitation of the Study

The areas under study produce a variety of crops ranging from temporary to permanent food and cash crops. Cereals, among food grains, are the dominant ones[1]. Therefore, this study focuses only on cereal crops. At the same time,

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[1] For details, see Ethiopian Village Studies-designed and edited by Philippa Bevan and Alula Pankhurst (1995 and 1996) which are available at the documentation Centre of the Department of Economics, A.A.U

although the majority of the sites have bimodal production, only the 'Meher' (main) season cereal production, so as not to create a gap in production magnitudes, is considered.

The nature of the survey constrained us to consider some of the variables that are specifically utilized to cereal production separately. For instance, information on labor was collected on aggregate. Since there is no way to isolate the labor used only for cereal cultivation, the overall labor is considered. Furthermore, conversion factors used for each household are based on the conversion factors available at *wereda* level. Obviously, local units not only differ from region to region, *wereda to wereda,* or PA to PA but they also differ from household to household. The need to have a balanced panel data and the existence of many missing and unbelievable figures forced us to come up with a small sample size. For instance, in testing of sample selectivity bias, only 716 observations were used out of the total 1890 observations. Furthermore, in some of the PAs, especially in *Yetmen,* the problem of the data made us arrive at small sample sizes. Thus, these limitations may adversely affect the robustness of the results.

1.7 Organization of the Study

The introductory part of the study has been discussed in the previous sections. The rest of the paper is organized as follows: In Chapter 2 and 3, we present about the Amhara region agro-climatic conditions and some socio-economic characteristics of the study sites, and the review of literature, respectively. In Chapter 4, the methodology part of the study is discussed. The last two chapters, i.e., Chapter 5 and Chapter 6, present source of data, definition of variables, results & discussions and conclusion, policy recommendation and possible indication for future research, respectively.

CHAPTER II: AGRO-CLIMATIC CONDITIONS OF THE AMHARA REGION AND SOME SOCIO-ECONOMIC CHARACTERISTICS OF THE STUDY SITES

2.1 Agro-Climatic Conditions of the Amhara Region

Our study is undertaken by considering smallholders in region three, in referring to the seven PAs (Dinki, Milki, Koremargefia, Karafino, Bokafya, Yetmen and Shumsheha) located in Ankober, Debre Birhan, Enemay and Lalibela werdas. These areas have been covered by the Ethiopian Rural Household Survey conducted by the Department of Economics (Addis Ababa University) in collaboration with different overseas research institutions.

The region has an area of 166, 100 sq kms. It consists of ten zones and one special zone, Bahir Dar; 106 Weredas and 208 towns. There are 4,980 peasant associations (PAs) and 337 Kebeles in the rural and urban parts of the region, respectively (CSA, 1995: 1).

There are four agro-climatic zones in the region: the "*Kolla*", the "*Woina Dega*", the "*Dega*", and the "*Kur*" or "*Wirch*" zones. The "*Kolla*" zone with an altitude of less than 1500 meters above sea level and temperature of 20-25 degree centigrade comprises about 31 per cent of the total area of the region. The *"woina Dega"* zone with altitude ranging between 1500-2500 meters above sea level and annual temperature of 15-20 degree centigrade comprises about 44 per cent of the region. The *"Dega"* zone has altitude extending between 2500-3500 meters above sea level and annual average temperature of 10-15 degree centigrade. It forms about 21 per cent of the total area of the region. The *"Wirch"* zone found above 3500 meters above sea level with a mean annual temperature of less than 10 degree centigrade and covers around 4 per cent of the region's area. The *"Kolla"*, the *"Woina Dega"* and the *"Dega"* zones receive rainfall ranging between 500-900 mms, 1000-1200 mms and 1500 mms, respectively (Theodros, 1998: 40-41).

According to the 1994 census report of CSA, the region's population was about 13.8 million. Of this, about 50.2 per cent were males and about 49.8 per cent were females. The result of the census also shows that, out of the total population in the region, some 1.3 million are urban and the remaining are rural population.

Under different assumptions, the projected population of the region for the year 2000 is calculated to be about 15.9 million of which about 1.6 million are urban population and the remaining reside in rural areas. About 93 per cent of the economically active population of the region were reported to be engaged in the agricultural sector and 87.8 per cent were illiterate.

Agriculture, which is the main stay of the region, suffers from low productivity and low utilization of farm inputs. Farmers have low financial capacity for the purchase of inputs. This points to the importance of credit in increasing the capacity of farmers to use inputs. The availability of credit in the region however is much to be desired. For instance, the total amount of loan made available in 1995/96 for the purchase of inputs barely amounted to 40 per cent of the demand. The absence of sufficient and effective provision of extension service is also a major problem encountering the agricultural sector (Theodros, 1998: 40-41).

Despite all these constraints, the region remains among the major food crop producing regions. In particular, although we did not present regional comparison, the history of various agricultural sample survey results of CSA, indicates that the region is the second largest cereal crop producing region being preceded by the Orimia region.

But this does not mean that the region is devoid of problems. Significant parts of the region faced frequent food shortage due to natural and man made disasters. The frequent food shortage in Wello, Northern parts of Gondar and in some parts of North Shewa can be cited as an example. The early warning system report of Disaster Prevention and Preparedness Commission (DPPC) (1999:8), for instance, shows that the needy rural population was estimated to be about 5 per cent of the 1999 projected rural population (14 million). South Wello, North Wello and North

Shewa are highly affected zones which accounted for 63 per cent of the total rural needy population in the region. To overcome this situation, the total relief food requirement of the region was estimated at 65, 432 MT. (See Table 2.1 below for details).

Table 2.1 Affected Population and Food Requirement in Amhara Region in 1999

Region/Zone	Assistance due to			Total Food Requirement
	Natural Causes	Man Made Causes	Total	in MT. For Victims
Amhara	-	15,382*	15,382	2,077
N.Wello	146,170	-	146,170	14,891
Wag Hamra	66,980	-	66,980	5,149
S.Gondar	59,430	-	59,430	4,690
N. Gondar	76,340	-	76,340	3,658
Oromia	65,520	-	65,520	4,780
S.Wello	224,600	-	224,600	20,214
N.Shewa	111,210	-	111,210	9,973
Total	**750,250**	**15,382**	**765,632**	**65,432**

Source: DPPC (1999), Food Supply Prospect Early Warning System Report

* Displaced Population

Unlike other regions, the region lacks cash crops and hence it highly depends on cereal crops to subsidize its population in all circumstances. Therefore, enhancing the efficiency of producing these crops, at least to secure the population in food, is important.

Table 2.2 Area, Production, and Yield of Major Crops (Main Season) in Amhara Region for Private Peasant Holdings, 1990/1991-1999/00

	AREA (' 000ha)				PRODUCTION (' 000qt)				YIELD (qt/ha)			
Year	Cereals	Pulses	Oilseeds	Total	Cereals	Pulses	Oilseeds	Total	Cereals	Pulses	Oilseeds	Total
1990/91*	1271.5	273.7	122.6	1667.8	17297.0	3930.9	1474.0	22701.9	13.6	14.4	12.0	13.6
1991/92	1508.8	344.7	114.1	1967.6	15795.7	2856.9	448.4	19101.0	10.5	8.3	3.9	9.7
1992/93**	1586.2	347.9	113.5	2047.6	17654.8	2825.4	347.8	20828.0	11.1	8.1	3.1	10.2
1993/94**	2795.0	683.3	235.3	3713.6	21347.8	3891.3	909.5	26148.6	7.6	5.7	3.9	7.0
1994/95	2055.8	409.6	142.9	2608.3	19912.1	3560.7	373.3	23846.1	9.7	8.7	2.6	9.1
1995/96	2380.4	382.0	170.8	2933.2	24774.2	3075.8	762.9	28612.9	10.4	8.1	4.5	9.8
1996/97	2487.4	386.1	207.7	3081.2	27266.3	3271.7	888.6	31426.6	11.0	8.5	4.3	10.2
1997/98	1907.7	385.8	164.3	2457.8	18249.5	2899.6	639.6	21788.7	9.6	7.5	3.9	8.9
1998/99	2395.4	402.0	188.4	2985.8	24480.6	3270.1	781.8	28532.5	10.2	8.1	4.2	9.6
1999/00	2368.7	504.1	201.5	3074.3	23286.0	4691.7	829.5	28807.2	9.8	9.3	4.1	9.4
Average	**2075.7**	**411.9**	**166.1**	**2653.7**	**21006.4**	**3427.4**	**745.5**	**25179.4**	**10.1**	**8.3**	**4.5**	**9.5**

Source: CSA, Report on Area and Production of Major Crops (Main Season) for Private Peasant Holdings (1990/91-1999/00)
** MOA/CSA, Crop Assessment. Report on Area, Production and Yield of Crops, Private Peasant Holdings (Main Season).

* Excluding North Wolo.

Table 2.3 Estimate of Improved Seed, Irrigation, Pesticide and Fertilizer Applied Area (Main Season) in Amhara Region by Private Peasant Holdings, 1990/91-1999/00

(' 000ha)

Year	Total Cropped Area	Improved seed Applied Area	Irrigation Applied Area	Pesticide Applied Area	Fertilizer Applied Area
1990/91*	1667.9	4.9	19.6	8.7	422.1
1991/92	2025.6	9.8	13.4	50.4	443.7
1992/93	NA	NA	NA	NA	NA
1993/94	NA	NA	NA	NA	NA
1994/95	2688.7	10.4	31.0	333.8	1165.6
1995/96	3010.7	13.7	25.3	103.2	751.1
1996/97	3154.8	50.9	23.5	42.9	797.3
1997/98	2534.3	38.2	20.0	25.9	612.8
1998/99	3078.2	50.5	13.0	28.7	898.7
1999/00	3167.8	81.9	26.4	60.9	954.1
Average	**2666.0**	**32.5**	**21.5**	**81.8**	**755.7**

Source: CSA, Report on Farm Management Practices (Main Season) for Private Peasant Holdings (1990/91-1999/00)

* Excluding North Wolo.

NA= Not Available

For the last 10 years, the region's major food crops production was on the average 25 million quintals (Table 2.2). Given this quantity and the 13.83 million population of the region, a rough estimate of 182 kgs of major crops production per capita indicates the region's insufficient food crops production. This is ascribed to a lump sum of many constraints. Inappropriate policies that fail to fit the region's agricultural activities may take the first responsibility. The impact of drought and other natural calamities is also among the factors. A low level of input utilization also accounts a lot. As indicated in Table 2.3, improved seed was applied only on an average of 32.5 thousand hectares (or 1.2 %) of the total cultivated area. Similarly, irrigation, pesticide and fertilizer were applied, respectively, only on 21.5, 81.8 and 755.7 thousand hectares (or 0.8 %, 3.1% and 28.3 %) of the total cropped land area. As a result of these, major crops productivity stagnated at an average of 7.6 quintals per hectare between 1990/91 and 1999/00 (Table 2.2).

To these must be added the rapid increase of the region's population, which resulted in the fragmentation of arable land-an average of 1.1 hectare per household (CSA, 1999/00:81). The average productivity of major crops, which is about 10 quintals per hectare (Table 2.3), seems to be inadequate for feeding a family with approximately 5 persons (CSA, 1995:19). Under such circumstances, either introducing new technology or increasing internal efficiency of producers or both is crucial.

In fact, in addition to policy influences and natural calamities that restrain agricultural output, be it at national or regional level, it is always questionable whether the producers use efficiently the available technology in the way it has to be used to realize the maximum output level. Chapter 3 presents some arguments on this issue.

2.2 Some Socio-Economic Characteristics of the Study Sites

(a) Dinki

This peasant association is found in North Shewa zone, near *Ankober.* The site is about 48 kms far from Debre Birhan. According to the 1994 population and housing census result of Ethiopia, its population was calculated to be 587, out of which 297 were males and 290 were females. Of the total population, almost three-quarters were Muslims and the rest were Orthodox Christians.

Since the site is located in the lowland region of North shewa, its climate can be classified as "*Kolla".* The area has two rainy seasons, "*Meher*" and "*Belg*", the former being the longer rainy season which lasts from June to September and the latter has short rainy season from January to April. It is on the "*Meher*" (main) season that crop production in the area highly depends.

The economic activity of the people in the area is virtually agriculture which involves traditional ploughing technology. The main crops grown in the area include sorghum, "*teff*", maize, soyabeans, chickpeas, sunflower, sesame, cotton, and nigerseed. Vegetables and fruits (papaya, banana, sugar cane, tomato, potato, onion) and cash crops such as coffee, "*chat*", and "*gesho*" are also cultivated. Most vegetables and fruits are cultivated using irrigation.

In the years 1954, 1958, 1985 and 1994, the area was affected by famine-locally known as "*shenkute*" and "*dubalech*". At present *Dinki* and the surrounding peasant associations are at the level of under production. Food aid and food for work programs are assumed to be the consequences of under production. It seems that individuals in the area tended to be non-productive because of the presence of these programs. For instance, even during peak periods (harvesting/threshing periods), farmers in the area are looking for food aid. This observation indicates that the farmers in the area are not operating at the level that they should operate.

Weaving is another major economic activity in the PA, probably the second most important activity next to agriculture. This may be due to the dominance of Muslims in the area. Due to the absence of nearby schools, the conservative culture of the people in the area and some natural barriers (e.g., difficulties to cross-rivers) constrained parents to send their children to school.

In general, the non-productive nature of the society due to the provision of aid through various NGOs, since 1984, coupled with the frequent lack of rainfall and the bad nature of the landscape for agricultural activities made the site among the poorest areas.

(b) Milki, Koremargefia, Karafino and *Bokafya.*

The results of the 1994 population and housing census of Ethiopia show that the population size of the four sites is calculated to be 3576 of which 1809 are males and the remaining are females (CSA, 1995:105).

From village studies, documented in the Department of Economics of Addis Ababa University, no information is available for individual sites. What is documented is about Debre Birhan, where these PAs are located around it. Therefore, the description given to these PAs is based on that of Debre Birhan.

Debre Birhan enjoys with two rainy seasons, namely "*meher*" (main) which refers to the long rainy season, usually lasting from June to the beginning of September and the "*belg*" season, which refers to the short rainy season, usually falls between January and April. "*Belg*" production is very important in high altitudes of the area. However, the "*belg*" season being characterized by variability and delay or absence of rain fall, is highly unreliable and thus most producers in the areas spend more of their time during the main season.

In the highlands of the areas, mixed farming, i.e., crop production and animal husbandry, is a common practice. The main crops grown around the areas include barely, wheat, horsebeans, chickpeas, *temej* and linseed. While most of the produce in the area is for consumption, a very small proportion of it is marketed. The areas in general are self-supporting in crop production. But in 1994, the areas were highly affected by food shortage due to frost that has occurred during the production season. During this disaster, households in the areas were forced to sell even their oxen to overcome the problem.

The technology that is used for agricultural production is traditional implements pulled by oxen. The only modern input farmers use in these areas is fertilizer. The fast growing population in the areas brought high deforestation, which in turn resulted in a declining of soil fertility over time (Philippa and Alula (eds.), 1995, 1996). As a result, agricultural outputs show decreasing trends.

Because people in the areas are highly attached to church, they spend half of the day in church where there is a religious holiday. There are a number of religious holidays in a month which people in the areas celebrate. As a result of this, most people spend their time without work.

Off-farm activities such as weaving, tanning, selling of local drinks and pottery are other sources of income for the households in the PAs.

(c) *Yetmen*

Yetmen is located in *enemay wereda* of east Gojam zone. The site is endowed with all weather-road to major towns. According to the 1994 population and housing census of Ethiopia, the population of *Yetmen* is calculated to be 1399. From the total population of the area, 718 and 681 were found to be male and female, respectively. Orthodox Christianity is the dominant religion in the area.

The climate of *Yetmen* is classified as "*Woina-Dega*" (temperate climate) and it is generally suitable to agriculture. There is no as such significant soil erosion in the area-since it is located in a flat plain. In fact, the soil is losing its fertility over time.

Using traditional farm implements pulled by oxen, a variety of crops such as sorghum, wheat, "teff", barely, chickpeas and others are cultivated, where "teff" and wheat account for 55 per cent of the total cultivated area. The rainy season in the area is bounded in between early June and mid-September during which most crops are grown. This period determines the "Meher" (main) season production. Labor input (in local exchange, hiring and family labor) in this PA is available and people in the area have become cognizant of using modern agricultural inputs, such as fertilizer. It has been reported that, except for the 1985 drought which affected few households, no drought has occurred in the PA for the last 30 years.

Off-farm activities such as involvement of women in selling of local drinks serve as sources of income to subsidizing their family.

(d) *Shumsheha*

Shumsheha is one of the PAs in *Bugna werda* of North *Wollo* zone. It is about 12kms far away from *Lalibela* and situated at an altitude of between 1500ms and 2000ms above sea level. The PA is located on a plain surrounded by a chain of mountains that are bare and devoid of plant life. As a result, about 75 per cent of the PA is *Kolla*. Moreover, it is one of the areas located in drought prone area in the country. Information from village studies indicates that the total population of the site in 1993 was estimated to be 2,583.

Agricultural activity is virtually the only economic activity of the area. In this PA, "*Meher*" (Main) season is the major harvesting season during which "*teff*", sourghum, barely, wheat and others are cultivated. Because of frequent rain failures, there exists a serious food deficit in the area. Besides, the land is highly eroded and the quality of the land which is classified as "*teuf*" (infertile) might have contributed to the low level of agricultural output. About 40 per cent of the total land of the *wereda,* where *Shumsheha* is found, is estimated to be inconvenient for agricultural activities. Of the estimated arable land of the *wereda*, only 10 per cent is cultivated.

The producers in this site sell insignificant part of their produce, usually less than 10 per cent of total production. The area lacks roads that link it to towns. For instance, the people have to go to about 120kms on foot to reach to the nearest big town-*Woldia*.

Although the above problems exist in the area, the farmers use traditional farming system and the use of modern inputs is very low. Apart from this, a number of religious holidays, whose observance is mandatory, contribute to the dwindling of agricultural production over time (Philippa and Alula (eds.), 1995, 1996). This rendered the population prone to chronic food shortage.

CHAPTER III: LITERATURE REVIEW

3.1 Theoretical Background

3.1.1 Efficiency Hypothesis

The concept of maximization behavior of economic agents lies at the centre of economic theory. For instance, a consumer wants to maximize his utility subject to his income constraint, while a producer strives to maximize his profit within the constraints of input and output pricing and the state of technology. A number of studies have tried to determine whether this working hypothesis can be realized in the context of real economic activities or not.

Considering the vast number of economic variables, one can find many reasons to explain the failure of the maximization behavior process. For instance, in the scenario of producers, Mulat (1989) mentions two ways in which the maximization behavior process might fail:

> " First, the marginal revenue products of some or all factors might not be equal to their marginal costs, and firms with such a problem are said to be allocatively inefficient. Second, production may occur on the interior of the production possibilities set and this problem is referred to as technical inefficiency" (Mulat, 1989: 107).

Different views have been entertained in applying the maximization behavior process to an evaluation of smallholder farmers. Prior to Schultz (1964), the literature on "traditional" agriculture emphasized the laziness, lack of motivation or irrationality of peasants. Schultz's (1964) hypothesis was the point of departure for taking a much more serious look at the logic behind peasant farm systems; and, for seeking to discover the underlying logic of peasant farm practices instead of dismissing it out of hand (Ellis, 1988: 74).

The belief that traditional farmers are "efficient but poor" as hypothesized by Schultz (1964) is based on the assumption that peasants are profit maximizers. This has attracted the attention of a number of development economists and it was assumed that farmers, by maximizing utility, prevent any major inefficiency in the allocation of traditional factors and were operating on the most superior production function available to them (Ellis, 1988: 65).

To examine the profit-maximizing behavior of farmers, Schultz (1964) hypothesized that:

> "There are comparatively few significant inefficiencies in the allocation of the factors of production in traditional agriculture" (Schultz, 1964: 37).

If this proposition is valid it follows that there is little scope for increasing farmers' decision-making with the existing production functions. Schultz's (1964) statement explicitly refers to allocative efficiency suggesting that peasants optimally use the combination of inputs to maximize their profits by equating marginal value product (MVP) to marginal factor costs (MFC); and implicitly to technical efficiency suggesting that the same amount of inputs are combined in order to maximize output.

The principal implication of this hypothesis is that no significant increase in agricultural production is to be made by reallocating factors at the disposal of farmers who are bounded by traditional agriculture. This means that the combination of crops grown, the number of times and depth of cultivation, the time of planting, watering, and harvesting, the combination of hand tools, draft animals and other simple equipment are all used correctly in regarding to marginal costs and returns (Schultz, 1964: 39).

Another implication that can be driven from the hypothesis is that any outside expert who is skilled in farm management will not discover any major inefficiency in the allocation of factors.

The notion of Schultz's (1964) hypothesis led to the conclusion that farmers in developing agriculture have low incomes, not because they use their resources inefficiently, but because they lack the technology and resources they need to realize higher productivity and, thus, higher income (Antle et al, 1990: 517). Therefore, according to this view, the possible strategy to promote farmers to a higher efficiency level is through investment. As a result, this has influenced policy makers' decisions to introduce new investments and technological inputs from outside instead of improving farm internal efficiencies (Assefa, 1995: 67).

The art to be efficient may involve some kind of risk. But producers, particularly subsistence farmers, do not dear to take much risk. As a result, they may not be as efficient as Schultz (1964) hypothesized. This means, the fact that Schultz's (1964) hypothesis is contrary to the real world, the hypothesis had fallen under a cloud of doubt. For instance, Lipton (1968), in an extensive criticism of Schultz's (1964) thesis, pointed out that the variability of production from year to year, due in part to changes in the quantity and distribution of rainfall, implies that economic efficiency is equivalent to maximizing the mean income over some time period. However, this criterion may increase the probability that a farmer will have to sell some land to repay outstanding debts after a bad harvest. The continuation of the farmer's control over his land is an important consideration, as it represents the primary means for sustaining his family in the future. Consequently, a farmer will choose a lower mean income in conjunction with less variability of income to ensure a higher probability of keeping his land and therefore farmers do not maximize profits, as high income levels are associated with too much risk (Lipton, 1968: 330-332).

Rao (1986) referring the works of Boserup (1965), Chayanov (1966) and Perkins (1969), also criticized Schultz's (1964) position. Rao (1986), in his criticism pointed out that absence of developed labor market in a peasant economy makes resource allocation subject to entirely different mechanisms than the ones entertained by

Schultz (1964). He also added that population growth in traditional agriculture is often accompanied by the search for new technology or faster diffusion of known technology. Therefore, unlike Schultz's (1964) belief, neither population nor technology need be stationary. Rao (1986) further extended his criticism from the fact that because of many reasons, resource ratios will not be equalized everywhere. For instance, a feudal elite may be content to extract limited surplus from cultivators rather than maximize it. From these viewpoints, Rao (1986) concluded that traditional agriculture may be poor but neither stationary nor efficient (Rao, 1986: 47-48).

It is important to note that the notion "poor but efficient" overlooks inefficiencies that result from operation on an interior production function. In effect the profit maximization model emphasizes only one aspect of efficiency, which is the adjustment of output and inputs to their relative prices (Ellis, 1988: 65).

To increase productivity or to be efficient, specialization in the production process is necessary. In the case of peasant smallholders, there is no clear specialization. The "risk-averse" peasant theory argues that smallholder farmers experience a lot of uncertainty. Therefore, they are risk-averse in their decision making and give priority to family security by producing a diversity of consumer goods instead of following a strategy that only maximizes output or profit. For instance, Kamarck (1971) argued that:

> "...specialization in both cash export and local food crops in small-scale farmers is prevented or hindered-hence, productivity all around is held down" (Kamarck, 1971: 140).

As a result, the maximizing behavior of smallholder farmers may not be an appropriate behavioral assumption with regard to efficiency of output or maximization of profits.

In this regard, Ellis (1988) stressed that:

> "...the proposition that peasant farmers are efficient in a pure neoclassical profit maximizing sense is neither proven as a general hypothesis, nor is it insightful of variation and its causes in the peasant economy and hence none of the theories assume or predict that peasant farmers are uniformly technically efficient, i.e., they all operate on the same 'best' production function. The simple conclusion to draw from this is that varying technical efficiency amongst peasant farms is always worth investigating irrespective of the microeconomic theory of the farm household" (Ellis, 1988: 73 and 160).

3.1.2 Components and Meaning of Efficiency

3.1.2.1 Background

The neoclassical theory of production is based on the notion of efficiency, i.e., firms are efficient and whatever inefficiency comes in the process of production is due to external "shocks" or statistical "noise" which is entirely beyond their control. This idea is emphasized in the textbook definition of a production function which gives the maximum possible output for given quantities of inputs. One problem with the notion of maximum is that nobody can recognize it simply by observing the actual level of output unless the observed output is assumed to be the maximum. Such an assumption is not realistic since different producers do produce different levels of output even if they use the same level of every observed input. One way of explaining the difference in observed outputs among producers is through differences in productive efficiency.

Although the concept of efficiency in economics is a complex and difficult one, production efficiency has received considerable attention in economic literature in recent years. When we say efficiency, basically we do mean something that is related to production function. As Ali *et al* (1996:271) emphasized, much of the literature on efficiency is based, directly or indirectly, on the seminal work of Farrell (1957), who argued that efficiency could only meaningfully be gauged in a relative sense, as a deviation from the best practice of a representative group of producers. Therefore, Farrell's consideration led to deviate from estimating "average" production functions to frontier production functions.

3.1.2.2 Conceptual Framework

Producers that achieve different output-input ratios may actually face different technologies, or the differences may arise from random disturbances, or some producers may be more successful than others in exploiting the same technology. In the first two cases, there is no difference in efficiency; only in the third situation does efficiency play a role (Shaprio and Müller, 1977: 294-295).

The failure of producers facing the same set of prices and production function to achieve the same level of efficiency arises from two sources: (1) the failure of some to avoid waste by producing as much output as input usage allows or by using as little input as output production allows, i.e., the failure to operate on the technically efficient production function, and (2) the failure of some to combine inputs and outputs in optimal proportions in light of prevailing prices, i.e., the failure to apply the level of inputs that maximize profits. The above two points enable one to identify technical inefficiency and allocative or price inefficiency. Herdt and Mandac (1981:376) pointed out that it was Farrell (1957) who first identified technical efficiency and allocative efficiency as two components of economic efficiency. The failure to operate on the production function is technical inefficiency. Whereas the failure of producers to utilize the profit maximizing level of inputs is defined as allocative or price inefficiency. The total of technical and allocative inefficiency is what the literature characterizes as economic inefficiency (Herdt and Mandac, 1981: 376-377). To conceptualize allocative and technical efficiency, the following figure is considered.

Consider a sample of firms whose production activities give rise to the scatter of points as shown in figure 1. Assuming constant returns to scale, the production function can be specified in the form of a unit isoquant (SS'). This isoquant represents points indicating the minimum quantities of the factors of production required to produce one unit of output with varying factor proportions. An estimate of SS′ is derived by fitting an envelope from below to a set of observations on productive activities for which factor utilization data (X_1 and X_2) are divided by output (Y).

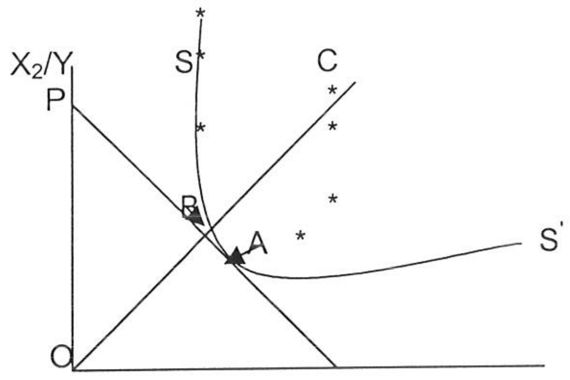

Fig. 1- Theoretical model of technical and allocative efficiency in one output and two variable input case.

According to Farrell's terms, as mentioned in Seitz (1970:503), the curve SS′ is a conservative estimate of a theoretical efficient unit isoquant. Physical or technical efficiency (TE) of observation C is defined as the ratio of the distance between the origin and point B to the distance between the origin and point C. Points C and B are on the same ray from the origin and thus represent identical factor proportions. Allocative efficiency (AE) of point C is estimated by defininig the lowest possible isocost line touching the efficient unit cost, in our case PP′, and finding the ratio of the cost implied by this isocost line to the cost at point B. The measure of allocative efficiency is therefore determined as the ratio of the minimum cost given efficient utilization of the optimum factor proportions.

From figure 1,the ratio of distance, $\frac{OB}{OC}$, which measures firm C's relative technical efficiency, indicates that firm C could reduce its use of inputs X_1 and X_2 to $\frac{OB}{OC}$ of present levels and still maintain the same output if it became as efficient as B. Only those firms on the frontier isoquant have an efficiency rating of 1.00.

The product of TE, $\left(\frac{OB}{OC}\right)$, and AE, $\left(\frac{OA}{OB}\right)$, is an estimate of economic efficiency (EE).

That is, EE = $\left(\frac{OB}{OC}\right)*\left(\frac{OA}{OB}\right)=\frac{OA}{OC}$ (the ratio of minimum to actual unit cost).

Having the idea of efficiency as described above, now it is important to present the two components of economic efficiency independently although the main concern of this study is technical efficiency.

3.1.2.3 Allocative Efficiency

The concept of allocative efficiency refers to the adjustment of inputs and outputs to reflect prices. In this sense, the term price efficiency is sometimes used to describe allocative efficiency. As it is mentioned in many literatures, Farrell's (1957) definition of allocative efficiency leads to measure it with respect to the frontier rather than a farmer-specific production function.

The approach of others, Herdt and Mandac (1981:377), for instance, is to measure allocative efficiency from a different direction. They argued that if farmers maximize profit, a measure of their allocative efficiency can be obtained by comparing the maximum profit for a given farmer specific production function and market prices with the predicted profit at the level of inputs equally used.

The empirical conformation to the measure of allocative efficiency is the mechanics of profit maximization. To say that producers are allocatively efficient, the marginal value product (MVP) should be equal to the marginal factor cost (MFC) for any single variable input, and that MVP per unit of an input should be equal across different outputs (the principle of equimarginal returns) (Ellis, 1988: 66). This follows from individual utility maximization only under perfect competition. In particular, a perfect market in factors and products must exist, and each farmer must be able to predict, with reasonable confidence, the outcome of each array of production, consumption and sale decisions at his disposal.

Ekayanake (1986:511) emphasized that, the definition of allocative efficiency given by Herdt and Mandac (1981) is preferred to that of Farrell's (1957) by virtue of its explicitness in separating allocative efficiency from technical efficiency and permits a farmer to be allocatively efficient even if he is technically inefficient.

The notion of allocative efficiency is clearly goal-oriented, in the sense that different goals generate allocative efficiency requirements, unlike technical efficiency in which a producer is technically efficient or otherwise regardless of the producers' behavioral goals.

Farmer specific production functions (Y_i) can be obtained by transforming the estimated production frontier by the level of technical efficiency of the farmer. Assuming a Cobb-Douglas technology, Y_i is given by:

$$Y_i = A\prod_{i=1}^{m} X_i^{b_i} \prod_{j=m+1}^{n} X_j^{b_j} e^{u_i} \quad \text{-- (1)}$$

Where, X_1 to X_m are variable inputs, X_{m+1} to X_n are fixed inputs, $A, b_i,$ and b_j are estimated coefficients of the frontier and u_i is farm specific technical inefficiency.

We assume that farmers maximize profits with respect to their variable inputs given the fixed inputs such as land in the short run. Therefore, the first order conditions for profit maximization with respect to variable inputs are given by:

$$P_i = \left(P_y \frac{b_i Y}{X_i} \right) K_i \quad \text{--- (2)}$$

where i= 1, 2, 3, ..., n; P_y denotes price of output; P_i represents input prices and X_i s are input quantities. K is a factor which measures deviations from the allocative efficiency input level.

In other words, the i-th farmer allocative efficiency in the use of variable input j is:

$$AE_{ij} = \frac{MPO_i}{OPU_{ij}} \quad \text{--} \quad (3)$$

where AE_{ij} = farm specific allocative efficiency using the variable input j;

MPO_i = maximum possible output of farm i; and

OPU_{ij} = output at the optimum level of the j-th input with all other inputs remaining at the level at which they were used by the i-th farmer.

The over all allocative efficiency (AE_i) of all inputs on the i-th farm is estimated by:

$$AE_i = \frac{MPO_i}{OPU_i} \quad \text{--} \quad (4)$$

where MPO_i is the i-th farmer maximum possible output at all variable inputs and OPU_i is the i-th farmer output at the optimum level of all variable inputs.

Testing the following ratios help judge whether the farmer is allocatively efficient or not.

$\frac{MVP}{MFC} > 1 \Rightarrow$ Underuse of resources

$\frac{MVP}{MFC} = 1 \Rightarrow$ Optimum use of resources (allocatively efficient)

$\frac{MVP}{MFC} < 1 \Rightarrow$ Excess use of resources

3.1.2.4 Technical Efficiency

As with allocative efficiency, if not more so, policy makers' conception to technical efficiency in peasant agriculture may influence the shape of development strategies (Shapiro, 1983: 186). Technical efficiency, which can have an output augmenting orientation or an input conserving orientation, is the measure of a firm's success in producing maximum output from a given set of inputs. A producer is said to be technically efficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output. Thus a technical inefficienct producer could produce the same outputs with less of at least one input, or could use the same inputs to produce more of at least one output.

In measuring technical efficiency, one should use the true production frontiers (not average production functions). This is because the estimator of the intercept which is obtained from the average production function is downward biased, and therefore the resulting estimate is not efficient.

Suppose producers use inputs $X \in R_{+}^{k}$ to produce scalar output $Y \in R_{+}$ with technology:

$$Y_i = f(X_i;\alpha)EXP\{V_i - U_i\} \text{ -- } (5)$$

where α is a vector of technology parameters to be estimated and i = 1,..., N indexes producers. The random disturbance term V_i is intended to capture the effects of statistical noise and is assumed to be independently and identically distributed as $N(0,\sigma_v^2)$. The disturbance term U_i is assumed to be distributed independently of V_i and to satisfy $U_i \geq 0$. The deterministic production frontier is $f(X_i;\alpha)$ and the stochastic production frontier, which represents the maximum feasible output, is $f(X_i;\alpha)EXP\{V_i\}$. The non-negative error component U_i represents technical inefficiency attributed to farm specific factors that make it operate below the maximum level of production.

The relative technical efficiency can be expressed as:

$$TE_i = \frac{Y_i}{f(X_i;\alpha)EXP\{V_i\}} = EXP(-U_i) \text{ -- } (6)$$

where Y_i is the observed output given by (5) and $f(X_i;\alpha)EXP\{V_i\}$ is the corresponding frontier output obtained by setting the inefficiency term, U_i, zero.

3.1.3 Techniques for Efficiency Measurement

To evaluate production units in terms of technical or allocative efficiency, researchers have used different approaches. According to literature, four major models can be applied in examining the efficiency of farmers: partial and total productivity measures, production functions, profit functions and frontier approaches.

3.1.3.1 Partial and Total Productivity

The measure of partial productivity assumes homogeneity, i.e., it assumes that all farmers face similar input and output prices. Based on this assumption input and output are valued at market prices or opportunity costs and the ratio of output to input provides an efficiency index. But the assumption of homogeneity seems a deviation from the real world. In this approach, the use of only one input does imply that a large or excessive amount of other inputs can be used to increase the productivity of the single input under consideration (Mulat, 1989: 145-146).

Efficiency can also be measured by total productivity. In measuring total productivity, the computation is easy if the production unit uses a single input to produce a single output. In the more likely event that the unit uses several inputs to produce several outputs, the outputs in the numerator must be aggregated in some economically sensible fashion, as must the inputs in the denominator, so that the total productivity remains the ratio of the two scalars (Lovell *et al*, 1993:3).

The arithmetic index of productivity, which expresses all variables of an underlying production function as index numbers with a common base period and appropriate weight, and the geometric index of productivity, which allows input prices and marginal products to vary, are the two alternative approaches to measure total productivity index instead of partial productivity. However, both approaches provide absolute figures and it is not possible to identify individual farms operating at or underneath the optimum level of production (Mulat, 1989: 146).

In general, the partial productivity approach to measure efficiency in comparing the productivity of one factor without allowing the differences in technologies and other input combinations may give misleading results. Further, the measure of efficiency using partial productivity fails to specify the optimum level of production. Therefore, these two drawbacks force one to look for another approach.

3.1.3.2 Production Function

For over 60 years, at least since Cobb and Douglas started running regressions, conventional production functions measure the output of firms in general in terms of averages by employing ordinary least squares (OLS) methods by which estimated functions of interest pass through the data (Lovell *et al*, 1993 :18). In the school of

OLS methods, regression analysis assumes implicitly that all firms are successful in reaching a maximum output level and indicate "average" production functions, associated with mean outputs, for given input levels. But it is clear that farmers are endowed with different resources and managerial skills that would allow any individual farmer to possibly operate at a different production level from another farmer and hence the "average" relationship may not reflect the maximum production level.

Furthermore, the meaning of such an "average" function is not necessarily clear. In this regard Aigner and Chu (1968), for instance, questioned as:

> "... average in the sense of what? a conditional median? a mean? or, a mode? More importantly, average about what? about output? about some input? about technology? or about something else?" (Aigner and Chu, 1968: 829).

Some economists refer to "average" production function as the function for a "firm of average size." Aigner and Chu (1968) condemned this interpretation unless it is assumed that the parameters of the function are random variables and have their expectations equal to those of the firm of "average size." Others seem to refer to it as reflecting some sort of "average technology." But same scholars argued that it would be infeasible to assume that a firm which possesses "average technology" with respect to some inputs, for example capital, also has an average technology, with respect to some other inputs, for example labor.

An average function is more meaningful in a random coefficient model. Therefore, it can be defined as the function obtained when the random coefficients obtain their expected values. In this function, one is not able to estimate the frontier for individual firms, but only on average. This is in line with the conventional microeconomic theory which assumes that all production units are efficient in the process of measuring and explaining productivity.

From a more practical standpoint, if, for example one wishes to estimate how much output on the average, could be obtained with a certain set of inputs; or, when we want to approximate the aggregate production function when data are available only at firm level; or when we want to approximate the firm's average production function when we have data only on aggregates, then the "average" concept would obviously be the correct one to employ.

Although some econometricians adopt the "average" function as the correct conceptual construct with persuasive arguments about "sustained" versus "unusual" output, the necessary theoretical development which derives from this construct has not been forthcoming (Aigner and Chu, 1968: 827). This approach is basically criticized from the fact that its criterion relies on the "average" as opposed to the "best" practice firm conditions thereby not showing the different levels of technical competence between farmers (Abdulhamid, 1992: 59). Aigner and Chu (1968), therefore, argued that the frontier production function presently forms the core of producers' theory.

3.1.3.3 Profit Functions

Perfect competition is the basic assumption in the estimation of farmers' efficiency using profit functions. This assumption leads to the conclusion that inefficient farmers will be out of the market, or become competitive by improving efficiency (Abdulhamid, 1992: 58). As argued by Aigner, Lovel and Schmidet (1977:22), such functions do not allow for the estimation of farm specific efficiency levels. These considerations led to the concept of frontier production functions.

3.1.3.4 Frontier Approaches

The development of frontier approach opened a wide range in the area of the measure of efficiency (Forsund et al., 1980: 5). The word *frontier* may meaningfully be applied either to the *maximum* possible output which can be produced from given quantities of a set of inputs or the *minimum* level of cost at which it is possible to produce some level of output, given input prices or the *maximum* profit that can be attained, given output price and input prices. Currently, the frontier function is widely utilized to analyze efficiency for a variety of reasons. First, it is consistent with the underlying economic theory of optimizing behavior. Second, deviations from a frontier have a natural interpretation as a measure of the level of efficiency with which economic units pursue their technical or behavioral objectives. Finally, information about the structure of the frontier and about the relative efficiency of economic units has many policy implications (Bauer, 1990: 39).

In general, there are two frontier approaches: deterministic and stochastic. Further, deterministic frontiers are divided into non-parametric, parametric and statistical frontiers.

(a) Deterministic Non-Parametric Frontiers

Forsund et al (1980:8) pointed out that the beginning point for any discussion of frontiers and efficiency measurement is the pioneering work of Farrell (1957). Farrell's non-parametric estimation procedure was based on linear programming techniques to construct a non-parametric frontier. The technical inefficiency of an observation is then measured relative to this frontier. This approach has not been found plausible. The restrictive assumption of constant returns to scale was one of its disadvantages. The non-parametric frontier does not assume any functional form and efficiency ratios are estimated from sample observations. Hence, it is sensitive to extreme observations, random "shocks", measurement errors, etc. As a result, his approach has been extended, proved and applied by Farrell and Fieldhouse (1962), Seitz (1970, 1971), Todd (1971), Afriat (1972), Dugger (1974) and Meller (1976) (cited in Forsund et al, 1980: 9).

(b) Deterministic Parametric Frontiers

Although the first Farrell's non-parametric approach has won few adherents, a second approach proposed by him has proved more fruitful. Farrell proposed computing a parametric convex hull of the observed input-output ratios to determine a production function that obeys constant returns to scale. He recommended the Cobb-Douglas form for the sake of expressing the frontier in a simple mathematical form. Although the mathematical expression of the Cobb-Douglas form is simple, Farrell was aware of the unnecessary assumption of constant returns to scale. Unfortunately Farrell did not follow his own suggestions to motivate himself and extend to further improvements in the frontier production function estimation.

Aigner and Chu (1968:830) were the first to follow Farrell's suggestion to contribute a methodological development in frontier production function estimation. They specified a homogeneous Cobb-Douglas production frontier. Their model may be written as follows.

$$\ln Y_i = \ln f(X_i;\alpha) - U_i \quad \text{--} \quad (7)$$

$$= \alpha_o + \sum_{i=1}^{n} \alpha_i \ln X_i - U_i$$

where Y_i is the i-th firm output level; $f(X_i;\alpha)$ is a suitable functional form (e.g. Cobb-Douglas or Translog) of inputs vector X_i for the i-th observation and a vector of α of unknown parameters, and U_i 0 is as defined in (1).

The elements of the parameter vector $\alpha = (\alpha_o, \alpha_1, \alpha_2, ..., \alpha_n)'$ may be estimated either by linear programming (minimizing the sum of the absolute values of the residual, subject to the constraint that each residual be non-positive) or by quadratic programming (minimizing the sum of squared residuals, subject to the same constraint). Therefore, technical efficiency of each observation can be computed directly from the vector of residuals, since U represents technical inefficiency.

The ability to characterize frontier technology in a simple mathematical form, which the non-parametric approach lacks, is the advantage of the parametric approach. The parametric approach also relaxes the assumption of constant returns to scale.

In fact, the parametric approach is not devoid of limitations. It imposes a limitation on the number of observations that can be technically efficient. For instance, when the linear programming algorithm is used in the homogenous Cobb-Douglas case, there will in general be only as many technical efficient observations as there are parameters to be estimated. The absence of statistical properties of the estimates produced by this approach is also another problem. The estimates are without standard errors and hence it is not possible to get t-ratios. As a result, since no statistical assumptions are made about the regression or the disturbances in (7), inferential results cannot be obtained (Forsund et al., 1980: 8-10).

(c) Deterministic Statistical Frontiers

As it is stated in Forsund *et al* (1980:11), it was Afriat (1972) who first explicitly proposed these models. Unlike the deterministic parametric frontiers, the deterministic statistical frontiers use statistical techniques for frontier and efficiency level. The deterministic statistical models can be expressed as:

$$Y_i = f(X_i;\alpha)e^{-U_i} \text{ -- } (8)$$

$$\Rightarrow \ln Y_i = \ln\left[f(X_i;\alpha)\right] - U_i$$

where $Y_i; f(X_i;\alpha); X_i;\alpha,$ and $U_i \geq 0$ are as defined in (5).

From $U_i \geq 0$, it follows that $0 \leq e^{-U_i} \leq 1$.

This model, to be statistically estimable, imposes basic assumption on X and U. The $U_{i's}$ are assumed to be independently and identically distributed and X is assumed to be exogenous (independent of U_i).

Different distributions for U have been proposed. For instance, Afriat (1972) proposing a beta distribution for U suggested a maximum likelihood estimation of the parameters of the model (cited in Forsund *et al,* 1980:11). The choice of a distribution for U is important since the maximum likelihood estimates (MLE) depend on it.

Assefa (1995), referring the work of Green (1990), has pointed out that an alternative method of estimation of the parameters called corrected ordinary least squares (COLS) provides consistent estimates by shifting the COLS constant parameter estimate upward until no residual is positive (Assefa, 1995: 76). The difficulty in this estimation is that these residuals may unfortunately be above the estimated frontier function. The stochastic frontier approach (discussed below) takes care of this difficulty.

Besides the estimation difficulties mentioned in the preceded paragraph, deterministic frontiers assume that all firms share a common family of production, cost and profit frontiers. This means that they include the effects of the symmetrically distributed error terms into a one-sided error term and designate the mixture as simply inefficiency. Hence, all variation in firm performance is attributed to variation in firm efficiencies relative to the common family of frontiers. Therefore, the lump of the two errors into a single term error term made the non-stochastic frontier approaches somewhat questionable.

In general, the common feature of the deterministic frontiers is that they include the effects of the symmetrically distributed error terms into a one-sided error term and designate the mixture as simply inefficiency. This implies that these models ignore the farmer's performance that can be affected by factors entirely outside his/her control.

(d) Stochastic Frontiers

In recent studies, a measure of efficiency using a "stochastic" frontier has received more emphasize. The essential idea behind the stochastic frontier model is that the error term is composed of two parts: (1) a systematic component which captures the effects of measurement error, other statistical "noise" and random "shocks" outside the control of the production unit; and (2) a one-sided component which captures the effects of inefficiency relative to the "best" stochastic frontier.

A stochastic production frontier model which was first proposed by Aigner et al (1977:24) and Meeusen and Van den Broeck (in Forsund et al., 1980: 14) may be written as:

$$Y_i = f(X_i;\alpha)EXP(V_i - U_i) \text{ -------------------------- (9)}$$

where $Y_i; X_i; \alpha$; and $U_i \geq 0$; $f(X;\alpha)EXP(V)$ and V are as defined in (5). The presence of V in the model solves the bounded-range problem encountered by some variants of the deterministic frontier model. Technical inefficiency is captured by the one-sided error component $EXP(-U_i)$. The inequality imposed on U_i, i.e., $U_i \geq 0$, ensures that all observations lie on or below the stochastic production frontier. The basic assumption in this model is that V and U are independent and X is exogenous. Following this basic assumption, the stochastic production frontier model may be obtained by either maximum likelihood or corrected least squares methods.

Stochastic frontier models have been applied to a variety of data sets because of their advantages over the deterministic frontiers by incorporating the two error components. Furthermore, a main attraction of the stochastic frontier model is the possibility it offers for a richer specification, particularly in the case of panel data. The model also allows for, among other things, a formal statistical testing of hypotheses and the construction of confidence intervals. Because of all these aspects, this model seems most attractive. This study, using households panel data, also utilizes this approach to analyze technical efficiency.

3.1.4 Benefits of Panel Data

(a) General

Panel data, by providing sequential observations for a number of individuals, often allow us to distinguish inter-individual differences from intra-individual differences in the real world where micro-dynamism exists (Hsiao, 1986:214). The generation of a large set of points increases the degree freedom and hence reduces the collinearity among explanatory variables which this in turn improves the efficiency of econometric estimates.

(b) Advantages of Panel Data in Efficiency Estimation

The majority of earlier applications of frontier production functions involved cross-sectional data. However, as Schmidt and Sickles (1984:367) pointed out, stochastic frontier estimations currently suffer from three serious difficulties.

(1). The technical inefficiency of a particular firm (observation) can be estimated but not consistently. Of course, it is possible to estimate the whole error term for a given observation, but it contains statistical "noise" as well as technical inefficiency. The variance of the distribution of technical inefficiency, conditioned on the whole error term, does not vanish even when the sample size increases.

(2). The estimation of the model and the separation of technical inefficiency from statistical noise requires specific assumptions about the distribution of technical inefficiency (e.g., half-normal) and statistical "noise" (e.g., normal). It is not clear how robust one's results are to these assumptions. Another way to emphasize this point is to note that the evidence of technical inefficiency is skewness of the production function error, and not everyone will agree that skewness should be regarded as evidence of inefficiency.

(3). The assumption that inefficiency is independent of the regressors may not be correct. This is because if a firm knows that he is technically inefficient, there will be a possibility of input choice adjustments.

All the three problems are potentially avoidable if one has panel data sets. The technical inefficiency of a particular firm can be estimated consistently as the period of observation (T) increases. This is because adding more observations on the same firm yields information that enables to estimate firm-specific technical inefficiency consistently, not attainable by adding more firms. Second, with panel, one need not make such strong distributional assumptions as are necessary with a single cross-section. In this regard, Bauer (1990) emphasized that "unless panel data are available, an explicit distribution for the inefficiency term must be imposed in order to obtain estimates of individual firm efficiencies " (Bauer, 1990: 41).

As a result, more recently attention has been made to apply frontier production functions in the analysis of panel data on firms involved in production (Battese and Tessema, 1993:34).

3.1.5 Panel Data Models in Stochastic Production Frontier

Basically, panel data models in the stochastic production frontier literature can be divided into two main groups. The first group assumes technical inefficiency to be time-invariant. The second group allows technical inefficiency to be time-varying. Each of these two groups can further be classified into two sub-groups depending on whether any distributional assumptions are made on the error components or not.

(a) Time-Invariant Technical Inefficiency

Pitt and Lee (1981: 51) developed the following technique to measure the inefficiency using panel data. Their model is defined as:

$$Y_{it} = \beta_o + \sum_j \beta_j X_{jit} + \varepsilon_{it}, \text{-----------------------------------} (10)$$

$$\varepsilon_{it} = V_{it} - U_i$$

where i (i=1, 2, ..., N), t (t=1, 2, ..., T) and j (j= 1, 2, ..., K) indexes firm, time and input, respectively;

Y_{it} is log output, X_{it} is vector of log inputs, ε_{it} is the error component composed of the white "noise" component, V_{it}, and the non-negative time-invariant technical inefficiency, U_i.

Schmidt and Sickles (1984: 368), assuming the inefficiency to be time-invariant, specified their model as follows to measure a stochastic frontier production function using panel data.

$$Y_{it} = \beta_i + \sum_j \beta_j X_{jit} + V_{it} \text{ -- (11)}$$

$$\beta_i = \beta_o - U_i$$

This model can be estimated using the within estimator treating $U_i \geq 0$ as fixed. A dummy variable for each firm can be introduced to the model or OLS can be applied to the within transformed data. During this, the intercept will be recovered as the means of the residuals to each firm. The within estimator allows U_i and X to be correlated. The estimator of β_o then can be obtained as the $\max(\beta_i)$. From this, it is apparent that $U_i(U_i = \beta_o - \beta_i)$ will be zero at the point where $\beta_o = \beta_i$ and the corresponding firm in the sample is fully efficient.

The within estimator will not allow to provide the estimated values of time-invariant regressor coefficients. The generalized least squares (GLS) and maximum likelihood estimator (MLE) methods give the estimates assuming the U_i, with some specific distribution, are random and uncorrelated to the regressors.

(b) Time-varying Technical Inefficiency

The stochastic production frontier models are developed in a number of ways in order to include time-varying technical inefficiency in the specification. Cornwell *et al.* (1990:192), as an extension to that of Hausman and Taylor (1981) which allows time-varying technical efficiency for each firm, generalized the Schmidt and Sickles (1984) approach to relax the assumption of time-invariant on U_i. The model can be written as:

$$Y_{it} = \beta_{it} + \sum_j \beta_j X_{jit} + V_{it}, \text{ ---} (12)$$

$$\beta_{ir} = \theta_{i1} + \theta_{i2}t + \theta_{i3}t^2 .$$

Within estimator, GLS or MLE methods can be applied to estimate the model. Firm specific effects, β_{it}, are regressed on a constant, time and time-squared. Their estimates will be consistent as T gets larger.

The frontier intercept and the inefficiency level are estimated as $\hat{\beta}_t = \max(\hat{\beta}_{it})$ and $\hat{U}_{it} = \hat{\beta}_t - \hat{\beta}_{it}$, respectively. This model allows the frontier intercept to vary over time and the efficiency level to vary over firms and over time.

A more flexible formulation to Hausman and Taylor's formulation of technical inefficiency was proposed by Kumbhakar (1990: 206). It is written as:

$$Y_{it} = \beta_o + \sum_j \beta_j X_{jit} + V_{it} - U_{it} \text{ ---} (13)$$

$$U_{it} = \gamma(t)U_i = \left(1 + \exp\left(bt + ct^2\right)\right)^{-1} U_i$$

where the firm effects are represented as a product of a deterministic part, $\gamma(t)$, which is an exponential function of time and a time-invariant random effect, U_i. The MLE method gives the required estimates given appropriate distributional assumptions. This model depends on the restrictive distributional assumption on the technical inefficiency component and hence its disadvantage lies on this. Expressing firm effects as a product of exponential function of time and time-invariant, U_i, Battese and Coelli (1992: 160) presented a stochastic frontier production function model for panel data as:

$$Y_{it} = \beta_o + \sum_j \beta_j X_{jit} + V_{it} - U_{it} \quad \text{--} (14)$$

$$U_{it} = \eta_{it} U_i = (\exp(-\eta(t-T)))U_i$$

where η is a parameter to be estimated.

Further, Battese and Coelli (1995: 329) defined U_{it} by

$$U_{it} = Z_{it}\delta + W_{it}$$

where Z_{it} is a $(1 \times M)$ vector of explanatory variables, including possibly time, associated with technical inefficiency effects;

δ is an $(1 \times M)$ vector of unknown parameters to be estimated; and the W_{it}s are unobservable random variables, which are assumed to be independently distributed, obtained by truncation of the normal distribution with mean zero and variance, σ^2, such that U_{it} is non-negative (i.e., $W_{it} \geq -Z_{it}\delta$).

A number of alternative models to specify the behavior of the firm effects, U_{it}, over time are being investigated. But only the specification of U_{it} given by Battese and Coelli (1992, 1995), although the specifications are rigid parameterizations, have programming algorithms that enable to estimate the parameters easily (Battese and Tessema, 1993:320).

The parameter η from the above parameterization of U_{it} is estimated if we are estimating the error component model. But the objective of this paper is to apply the technical inefficiency effects model, which basically estimates the stochastic frontier production function and the relation between U_{it} and the farm socio-economic variables simultaneously. Therefore, to observe the behavior of U_{it} over time and its relationship to firm specific variables, we used the model specified by Battese and Coelli (1995).

3.1.6 Factors Affecting Technical Efficiency

Given a particular technology to transform physical inputs into outputs, some farmers able to achieve maximum output while others produce below this level and therefore considered as technically inefficient. At this point, it is imperative to raise the question 'why they are technically inefficient?' It is the answer of this question that guides policy makers to assist those inefficient farmers (to minimize and avoid their inefficiency by using the available resource more efficiently under the current technology).

Differences among farmers in education, experience, etc, might be a reason for differences in farm management and consequently these differences in farm management can cause differences in efficiency among farmers. So the relation between technical inefficiency and various socio-economic characteristics of farmers needs to be investigated.

Two approaches can be utilized in this investigation: a simple correlation analysis and a regression model approach. In this study, the interdependence between technical inefficiency and socio-economic variables has been examined using the latter approach. This method is a two step procedure in the sense that in the first step the level of farm specific technical efficiency is measured and in the second step the regression model is estimated where the inefficiency measure is expressed as the function of socio-economic variables. In fact, though some argue that the variables should be injected directly in the production frontier model, believing that they have a direct effect on efficiency, others, as Assefa (1995) emphasized by mentioning the argument by Kalirajan (1991), try to nullify this by arguing that these variables have a roundabout effect on efficiency levels (Assefa, 1995:146). Moreover, Assefa (1995), after stating the possibility of separating inputs in production into essentials and non-essentials, added that it is the essential inputs that are typically included in production function while the later could be used to explain the variation in efficiency. In line with this, Montaner *et al* (1996: 4-5) after fitting a stochastic production frontier to estimate farm-level technical efficiency (by treating the total value of crop production as a dependent variable, the area of land, labor and fertilizer as independent variables), tried to observe technical efficiency differential among farmers by regressing efficiency levels against education, age, amount of credit and off-farm income.

So, in this study, although it is not possible to include all socio-economic variables in the analysis, some factors that are available in the survey data and believed to affect technical inefficiency are regressed against farm level technical inefficiencies.

3.2 Empirical Evidence

3.2.1 General

A number of studies, testing the hypothesis that peasants are profit maximizers, reached conflicting conclusions. For instance, studies in India in the 1960s (e.g., Hopper 1965; Chennareddy, 1967; Sahota, 1968: Saini 1968) and studies on Africa by Norman (1974; 1977) reached the conclusion that farmers are allocatively efficient since they tend, on average, to equate the marginal value product of each variable input to its market price (cited in Ellis, 1988: 71).

Others argued that these studies had mistakenly concluded that peasants were efficient because of a mistake in the method of calculating the allocative efficiency ratio. For instance, Shapiro (1983:179) pointed out that a re-examination of many of the above studies found that marginal value of products differed on the average, by more than 40 per cent from the factor prices to which they were supposed to be equated. Moreover, other researchers have come up with different results. For instance, the study by Bliss and Stern (1982) (in Ellis, 1988:71) based on wheat producing villages in India found that marginal value of productivities for three wheat production inputs to be more than three times above their market prices. These two results indicate that farmers are not being the most productive or efficient.

Shapiro (1983:179-190), in his study of peasant cotton farms in Tanzania, applying linear programming, found that the output of all sample farms could have been 51 per cent higher if all farms had achieved the technical efficiency level of the best farms in the sample.

Battese and Coelli (1988:387-399) in their study of dairy farms in Australia found that technical inefficiencies ranged from 0.073 to 0.452 between farms. The study also concluded that the traditional (average) Cobb–Douglas production function is not a suitable model for the farms under study.

Again Battese and Coelli (1995:325-332), using 10 years data across 14 paddy farmers from the village of Aurepalle in India found that years of schooling and years of observation were negatively related to inefficiency, whereas, age of the farmers was positively related. This would indicate that because smallholders are subsistence in nature, they do not reach the "frontier" because of socioeconomic, demographic and environmental factors which are inclined to generate inefficiencies.

Ali, Parikh and Shah (1996:271-287), in their study of economic efficiency of Pakistan farms, using the behavioral and stochastic cost frontier approach found that the size of holding, fragmentation of land, subsistence needs, and higher age of farmers contribute positively to inefficiency. Their conclusion asserts that there is less than optimum use of inputs and this non-optimum use is explained by size of holding, education, credit and subsistence needs.

Dawson et al (1991:1098-1104) calculated single measures of farm-specific technical efficiency over time for twenty-two rice farms in central Luzon, in the Philippines, from the residuals of a stochastic frontier production function. The results of panel data for the years 1970,1974,1979,1982 and 1984 showed a narrow spread in the range of efficiency, i.e., the best farm achieving over 95 per cent efficiency while the worst was only 84 percent. They concluded that there was limited impact on increasing output by resource allocation.

Ali and Chaudry (1990:62-74) attempted to measure technical, allocative and economic efficiencies in four irrigated cropping regions of the Punjab province of Pakistan by estimating a deterministic and probabilistic frontier production function using farm survey data for the year 1984 and 1985. The average technical efficiency ranged from 0.80 in the rice region to 0.87 in the sugar cane region, and implies a potential for a 13-20 per cent increase of farmer's income at their present level of resources. No significant difference in technical efficiency was found across the regions. The study further revealed that economic efficiency was similar across all cropping regions expect in the cotton region, which had significantly lower economic efficiency due to higher allocative inefficiency, ranging from 30 to 47 per cent.

In the estimation of profit efficiency among Basmati rice producers in Pakistan Punjab, Ali and Flinn (1989:303-310) found a 28 per cent mean level of inefficiency at farm resource and price levels (ranging from 5% - 87%). The farm household's education, nonagricultural employment, and credit constraints were among the socioeconomic factors found to relate to profit inefficiencies.

Bravo and Evenson (1994:27-37), using a stochastic efficiency decomposition methodology to derive technical, allocative and economic efficiency for cotton and cassava producers of peasant farmers from Eastern Paraguay, obtained an average technical and allocative efficiency of 58.2 per cent and 70.1 per cent, respectively for cotton and of 58.7 per cent and 88.9 per cent for cassava. From the study an overall or economic efficiency of 40.7 per cent for cotton and of 52.3 per cent for cassava have been derived. The results suggest considerable room for productive gains for the farms in the sample through better use of available resources given the state of technology. The researchers pointed out that no clear strategy to improve farm productivity could be suggested from an examination of the relationship between efficiency and various socioeconomic variables. One possible explanation addressed by them is the existence of a stage of development threshold below which there is no consistent relationship between socioeconomic variables and productivity. Therefore, they suggested the need to have improvements in educational and extension services as a first strategy to increase the efficiency of producers and then investments to gain a further improvement.

Battese and Tessema (1993: 313-333), using panel data of households engaged in agricultural production from three villages in India, estimated a stochastic frontier production function with time-varying technical efficiencies. They found that the traditional response function is an adequate representation of the data for only one village. This shows the existence of farmers' technical inefficiency in the two villages. Further, the result of the two villages showed time-varying technical efficiency and also the hypothesis of time invariant elasticities of the input variables is rejected for two of the three villages. The technical efficiencies of individual farms exhibited considerable variation in the two villages with either time-invariant or time-varying technical efficiencies.

Shapiro and Muller (1977: 293-310) have considered the roles of modernization and information, in identifying sources of technical efficiency on cotton farms in Tanzania. The conventional OLS estimation technique and a linear programming frontier were employed. The result revealed that modernization and information have significant roles to shift to greater technical efficiency. According to the result, the role of modernization and information is reflected through the proper application of labor, planting and weeding at the right time.

3.2.2 Empirical Evidence on Ethiopian Farms

Empirical evidences on the agricultural efficiency in Ethiopia are also available. Abrar (1995a: 47-66) found substantial technical inefficiency by Ethiopia smallholders using linear programming approach (Data Envelopment Analysis).

Applying stochastic frontier on fertilized farms to measure technical efficiency, Abrar (1996: 1-30), using cross sectional data from three villages in Ethiopia, has obtained results that indicate room to expand the output of the average farmer by more than 40 per cent, if appropriate measures are employed to improve internal efficiencies. The results of his investigation enabled him to reach to two basic conclusions. First, the traditional Cobb-Douglas production function is not a suitable model to explain the production behavior of the farmers under consideration. This means that technical inefficiency is one of the main characteristics of agricultural production for these farmers. Second, technical inefficiency not only varies between villages but there is also a high variation across farmers within a village.

In a study of technical efficiency of smallholders, applying a stochastic frontier, in the central highlands of Ethiopia by Assefa and Franz (1996: 18-37), the results show that the discrepancies between the actual and the frontier output levels are due more to technical inefficiency rather than external "shocks" which are beyond the farmer's control. The study tried to determine the efficiency level of fertilized farms and unfertilized farms independently. The discrepancy parameter indicates that more than 90 per cent of the variation in output is accounted for by technical inefficiency for fertilized farms. In the case of unfertilized farms the picture is more or less the same. The results further indicate that there is a possibility of increasing the efficiency of fertilized farms by about 8 per cent using existing technology without additional financial cost to the farmer and by about 13 per cent on unfertilized farms if existing technology were used.

Sisay (1983: 103-132), applying non-frontier programming methods on data from four Ethiopian villages, and Alemayehu (1989:12), using the conventional OLS method to fit a non-frontier Cobb–Douglas production function on data from two villages in central Ethiopia, found that there is significant inefficiency in the resources used by the sample farmers.

For the assessment of the impact of education on allocative and technical efficiency of the Ethiopian smallholder farmers, Abay and Assefa (1996:1-26), using a frontier profit function approach found that there are considerable deviations from the optimal profit efficiency level. Specifically, the results indicate that the mean level of profit efficiency for sampled farmers is 54.0 per cent suggesting that the level of profit inefficiency could be as high as 46 per cent. Moreover, in the study, the hypothesis of equal allocative and technical efficiency of educated and illiterate farmers was tested and the result revealed that educated farmers are more efficient than illiterate farmers.

Croppenstedt and Abbi (1996:39-61) measured the degree of technical efficiency of 249 farmers growing cereals, from five sites of three regions of Ethiopia in 1993 and 1994, using maximum likelihood method to estimate Cobb-Douglas stochastic frontier production function. The dependent variable considered in their estimation was ratio of total value of grain output in 'meher' (Main) season to output price index and; land, total number of person days in ploughing and weeding, amount of fertilizer applied, number of oxen owned, quality of land, age, and region (dummy) were included as independent variables. The result indicated that 41 per cent of the sampled farmers achieved 70 to 79 per cent technical efficiency with overall average technical efficiency of 72 per cent, implying that farmers under consideration were 28 per cent technically inefficient or below the frontier. It was further noted that land quality and average age of household members were significant variables in explaining output variations among farmers.

A reasonable conclusion that can be made from the literature is that at the existing level of factor endowments and technology, there is a potential to increase agricultural output by improving the internal efficiency of farmers; for instance, through education as only a single example.

CHAPTER IV: METHODOLOGY

4.1 Methods of Analysis

In the analysis of the data, both descriptive and analytical methods are employed. In the descriptive part, simple measures of central tendency, frequency, total and percentages are used. With respect to analytical method, a stochastic frontier approach is used to estimate farm level technical efficiencies and the relation between farm socio-economic variables and inefficiencies.

4.2 The Basic Model and Estimation Procedure

This study considered agricultural households who used fertilizer and who have oxen/bulls (to assume that they are operating on a similar technology and endowed with the same vehicle for ploughing). Under such criteria, a non-random sample selection bias would result (Heckman, 1979:154 and Green, 1981:795). To overcome this problem, we applied Heckman's two-stage estimation method in estimating the production function. Heckman's two-stage estimation is a simple least squares regression method which treats the bias from the non-randomly selected samples as an ordinary specification bias that arises because of missing data. In this method, it is possible to estimate the parameter values of the variables, which are in the non-selected sample (those who did not apply chemical fertilizer and those who did not have oxen/bulls). The estimated values of the omitted variables can be used as regressors so that the production functions of both farmers can be estimated. In the first step, a probit model (by formulating a dichotomous dependent variable, i.e 1 for those who applied chemical fertilizer and had oxen/bulls, and 0 otherwise) is estimated, followed by application of ordinary least squares to the production function of the farmers who used fertilizer and who have oxen/bulls augmented by a constructed regressor, λ_i, which accounts for the bias. The latter function is:

$$Q_{it} = X_{it}\phi + \lambda_i C + \mu_i \qquad (15)$$

where Q_{it} is the natural logarithm of output for farm i at time t, X_{it} is a vector of the natural logarithm of input variables such as land, labor, fertilizer and oxen/bulls and other demographic variables for farm i at time t, ϕ is a vector of parameters to be estimated, λ_i is an additional variable (a constructed regressor), and $\mu_i \sim N(0,\Sigma)$. If the selection of farmers who used fertilizer and who had oxen/bulls were totally random, then the covariance (C) between the error term in the probit function and the production function without lambda is zero, and then the usual formula for least squares coefficients is appropriate. When $C \neq 0$, the asymptotic variance-covariance matrix (Σ) is used in calculation of the standard errors for the estimated coefficients. Otherwise, we will get incorrect measure of the true value. λ_i adjusts the bias and enables us to obtain a consistent estimate of the production function. If the estimated value of λ_i is significant, sample selection bias is apparent. Otherwise, the conclusion we draw from those farmers who used fertilizer and had oxen/bulls will be valid for the unselected farmers.

Following this algorithm, we have obtained the coefficient of lambda (-0.498) to be statistically insignificant, since the probability of rejecting the hypothesis that lambda is zero or the probability of committing Type One Error is found to be 0.9255. This implies that we do not have sample selection bias and thus conclusions that can be draw from the selected sample will be valid for the unselected farmers. (See **Appendix V** for the value of lambda).

Knowing the fact that the sites under consideration have different agro-climatic conditions, it is not sound to estimate farm level technical efficiencies by pooling the whole data[2]. Hence, the study considered each site independently to estimate farm level technical efficiencies.

While the stochastic frontier production function can be specified as Cobb-Douglas (C-D), constant elasticity of substitution (CES), traslog, etc., recent advances in developing new functional forms have been dominated by efforts to conceive "flexible" forms. As a result flexible functional forms such as the translog form are usually recommended rather than the restrictive Cobb-Douglas form (Green,

2 In fact, I have tried to estimate the technical efficiency by pooling the data, but the result obtained was spurious.

1980:28) [3]. The translog function[4] is the only one of the flexible functional forms which is readily used for direct estimation of the production function.

In fact, this study did not merely depend on the explanation of the pros and cons of the two functional forms given above. Rather, the likelihood ratio test[5] is performed and the test suggested that the production technology of farmers in the three sites (*Dinki, Yetmen and Koremargefia*) is better represented by the C-D frontier production function. For farmers found in *Shumsheha, Milki, Karafino and Bokafya* the test indicated that the production technology that suits is the translog frontier production function. (See Chapter 5 for the test). Therefore, the empirical models used for the estimation of the technical efficiency of smallholders in this study are both the C-D and translog frontier production function given as follows:

$$\ln Q_{it} = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln X_{it} + E_{it} \quad \text{----------------------------------} (16)$$

$$\ln Q_{it} = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln X_{it} + \frac{1}{2}\sum_{i}\sum_{j} \beta_{ij} \ln X_{it} \ln X_{jt} + E_{it} \quad \text{-------} (17)$$

where,

Q_{it} is total cereal output (in kg) for the i-th farmer, i = 1, 2, ... , N, in the t-th year of observation, t= 1,2, ...,4;

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[3] C-D functional form assumes constant elasticity and unitary elasticity of substitution.

[4] Indeed, the translog functional form causes collinearities among variables (since it includes the quadratic form and the cross-product of the already existed variables). But when the primary purpose of the model is for prediction, as a case of efficiency prediction, multicollinearity will not be a concern (Madalla, 1992:280).

[5] A likelihood ratio test which is equal to minus two times the difference between the log-likelihood values of the C-D and the translog specification can be used to test whether the production technology is better represented by the C-D or the translog forms.

X_{it} and X_{jt} are vectors of inputs such as area in hectares, quantity of fertilizer in kgs, labor (family, hired and traditional labors) in man-days and oxen-bull, for the i-th farmer in the t-th year of observation;

α_j's and β_{ij}'s are unknown parameters to be estimated ;

E_{it} is a random variable whose distributional properties are defined by equation (18) below:

$$E_{it} = V_{it} - U_{it} \text{ --- (18)}$$

The subtraction of U_{it} from V_{it} implies that the logarithm of production is smaller than it would otherwise be if technical inefficiency did not exist.

The above parametric models are estimated in terms of the variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}$. The parameter, γ, measures the discrepancy between the frontier and observed levels of output and is interpreted as the total variation in output from the frontier attributable to technical inefficiency. It has a value between zero and one. The value of zero indicates that the non-negative random variable, U_{it}, is absent from the model while the value of one shows the absence of statistical "noise" or exogenous "shocks" from the model and hence low level of firm's production compared to the "best" practice (the maximum output) of the other firm that is totally a result of firm specific inefficiency.

More formally, to test whether technical inefficiency is absent and hence the conventional (average) production function is appropriate or not, we can use the likelihood-ratio test using the log-likelihood values of the OLS and the MLE. (See Chapter 5 for details).

Given the specification of the stochastic frontier production function, as defined by equations (16) and (17), the technical efficiency of the i-th farmer/agricultural household at the t-th period of observation is:

$$TE_{it} = EXP\left(-u_{it}\right) \text{--} \quad (19)$$

where u_{it}s are non-negative random variables, which are assumed to be independently distributed with mean μ_{it} and variance σ_u^2. μ_{it} is defined by equation (20).

To determine why some farmers are more inefficient (less efficient) than others, given similar technology and inputs, we applied the specification of Battese and Coelli (1995) as follows:

$$\mu_{it} = \delta_0 + \delta_1^{\pm} SEX_{it} + \delta_2^{-} AGE_{it} + \delta_3^{+} AGESQR + \delta_4^{-} FS_{it} + \delta_5^{-} OCC_{it} + \delta_6^{-} EDUCA_{it} + \delta_7^{-} LVSK_{it} + \delta_8^{-} CDT_{it} + \delta_9^{-} FER_{it} +$$

$$+ \delta_{10}^{-} SLP_{it} + \delta_{11}^{\pm} OFF_{it} + \delta_{12}^{\pm} TIM_{it} \text{ --} \quad (20)$$

where μ_{it} is as defined above; δis are unknown parameters to be estimated and the variables *(SEX, AGE, ..., TIM)* are as defined in section 5.2.

Expected signs are shown above the coefficients. For dummy variables, the signs refer to the ones assigned 1.

Estimating the technical inefficiency model with and without δ_0 (i.e., testing $H_0 : \mu = 0$, where μ is the mean value of U_{it}) indicates whether technical efficiency is to be estimated using a half-normal distribution of U_{it} (truncated at zero) or not. (See Chapter 5 for the log-likelihood ratio test).

The method of maximum likelihood using the computer program, FRONTIER Version 4.1c, is used for simultaneous estimation of the parameters of the stochastic frontier and the model for the technical inefficiency effects.

CHAPTER V: SOURCE OF DATA, DEFINITION OF VARIABLES, RESULTS AND DISCUSSIONS

5.1 Source of Data

In analyzing technical efficiency of smallholders, this study uses data from the five rounds of the Ethiopian Rural Household Survey, collected by the Department of Economics (Addis Ababa University) in collaboration with the Centre for the Study of African Economics, Oxford University; and funded by USAID, International Food Policy Research Institute, and SIDA, in different periods.

Although the survey had five rounds, it does not refer to a five-year data. In particular, the second and third rounds of the survey refer to the same agricultural production cycle. Hence, the relevant variables for these rounds are aggregated/refined in order to get a one-year information for each agricultural household. Consequently, we have a four-year panel data.

The survey covered around 1500 agricultural households across different agro-ecological zones. Of these, 480, 477, 467 and 466 agricultural households were covered in 1994, 1995, 1997 and 1999, respectively in the Amhara region. The survey collected information on the demographic characteristics, assets, non-agricultural incomes of the household, agricultural activities, health, women and child labor, family and marriage history, and community and public works.

the result in the second step is aggregated for each farm (or agricultural household), resulting in equivalent grain weight.

***AR** = Land under cereal cultivation.* The land variable includes the total area of land (in hectare) which each agricultural household used for cereal cropping in the main (or *Meher*) season. Land is included because it is a primary factor in the process of agricultural production and not a mere space (as in an industrial site). It receives precipitation and solar energy among other natural gifts required for biological growth of crops.

***CHFERTZ**= Chemical fertilizer (DAP+UREA) in Kg.* Without dismissing the influences of the prevailing weather condition, timely delivery and application of chemical fertilizer on production, it is always assumed that fertilizer enhances the level of output.

***LBR** = Labor in man-days.* Labor is included in the analysis because it is the driving force or the major factor of farm production. This variable includes all labor (i.e., family, traditional and hired labor) spent in the major types of activities, i.e., ploughing, weeding and harvesting. As we have already stated as a limitation, this input refers not to cereals separately but to all crops. Though number of days worked may suffer from problems of accuracy while respondents are reporting, it is the best alternative measure of labor input. However, the fact that working capacity differs on the basis of age structure and sex differentials necessitates a standardized measure for comparisons. Labor equivalent is a remedy to account for such differences. Unfortunately, the data on labor was not collected in a way that enables to differentiate the labor used by sex and age. As a result of this limitation, this study simply assumed homogeneity of farm labor and considered the total labor in man-days to be a proxy for the labor input.

OXB *= Oxen-Bulls.* Oxen and bulls are used as draught animals and main vehicles for farming in most parts of Ethiopia. Because there is no direct measure of bullocks (or oxen-bulls ploughing days), number of oxen-bulls at the disposal of agricultural households is considered as a proxy for oxen-bulls input.

SEX *= 1 if head of household is male, 0 otherwise.* This variable is included in the model to consider whether sex differential matters in technical efficiency or not.

AGE & AGESQR *= The age of the head of the household and its square.* Age is expected to be a proxy for experience in farming and endurance, as agricultural activities require strength and long-time practices on activity management and timing and thus positively related to technical efficiency. Household age square is included to allow for U-shaped relationship between age and technical efficiency in the sense that the marginal impact of increased experience diminishes over time.

FS *= Family Size.* It is expected that bigger family size puts extra pressure on farm activities to secure food and clothing and also ensures the availability of enough aggregated for each farm. It is expected that a household with a bigger size of livestock will have an opportunity to secure himself from lack of production inputs and thus improves his technical efficiency.

CDT*= Credit availability (1 if the household took loan, 0 otherwise).* Credit availability shifts the cash constraint outwards and thus enables the farmers to make timely purchases of the inputs they cannot provide otherwise from their own sources. Thus, we expect those farmers who have access to credit to be technically more efficient relative to those who do not have such access.

FER *= Soil fertility (1 if it is fertile, 0 otherwise).* Plots of land differ in fertility and this has an effect on production accordingly. Information on soil quality, whether a plot of land was *lem* (fertile), *lem-teuf* (medium-fertile) and *teuf* (infertile), was collected based on respondents' evaluation. Fertile lands are expected to contribute negatively to technical inefficiency. Although the way the data was collected was not suitable to assign a dummy to the fertility of the land at the household level, we have taken the size of the area of each plot and the frequency of information on soil quality into consideration for each household to decide whether the land under a household is fertile or not. This means that, if most plots of the household are leveled as fertile and if the area of these plots is greater than the area of other plots which are leveled different from fertile, we consider the household, on the average, as he is operating on a fertile land.

***SLP** = Topography of land (1 if it is flat, 0 otherwise).* Topography or steep nature of the land can be expressed as *medda* (flat), *dagethama* (semi flat) and *geddelama* (steeply). The nature of the land that exists in such fashion may have an adverse effect on agricultural production. Semi-flat and steeply lands may not be suitable for ploughing or they may be exposed to flooding and hence aggravate technical inefficiency of farmers. The same approach as the variable *FER* is used to decide whether the land under a household is flat or not.

***OFF** = 1 if the household got off-farm income, 0 otherwise.* Being involved in off-farm activities may have a systematic effect on the technical efficiency of farmers. This is because farmers may allocate more time to off-farm activities and thus may lag in agricultural activities. On the other hand, incomes from off-farm activities may be used as extra cash to buy agricultural inputs and thus enhance production.

***Tim** = Time.* Time (1, 2, 3 and 4) is included in equation (23) to allow for possible shifts of the frontier over time.

5. 3 Results and Discussions

5.3.1 Descriptive Statistics

Information on output, input variables and some demographic characteristics of the farmers are presented in Tables 5.1 and 5.2.

Table 5.1 Summary Statistics on Output, Input and other variables for the Panel

		Dinki			
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	50.61	1129.41	565.71	393.16
Area	Hectare	0.15	3.00	1.60	0.64
Fertilizer used	Kg/ha	16.70	180.00	39.66	28.79
Labor	Manday	21.00	170.00	72.21	45.32
Oxen/bulls	Number	1.00	4.00	1.56	0.74
Livestock (excluding oxen/bulls)	Number	0.00	9.00	2.03	2.38
Age of household head	Year	21.00	74.00	47.50	14.02
Family size	Number	1.00	12.00	6.04	2.53
		Milki			
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	85.43	1629.99	814.60	234.83
Area	Hectare	0.38	3.50	1.69	0.83
Fertilizer used	Kg/ha	14.23	200.87	53.89	34.68
Labor	Manday	18.00	198.63	98.79	53.53
Oxen/bulls	Number	1.00	5.00	2.00	1.00
Livestock (excluding oxen/bulls)	Number	0.00	17.00	3.80	0.50
Age of household head	Year	22.00	83.00	54.15	16.25
Family size	Number	1.00	10.00	5.90	2.32

Table 5.1 (cont'd)

Koremargefia					
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	64.53	969.06	485.53	356.64
Area	Hectare	0.25	3.25	1.63	0.69
Fertilizer used	Kg/ha	18.42	217.33	47.21	43.74
Labor	Manday	21.92	198.63	93.25	56.07
Oxen/bulls	Number	1.00	5.00	1.00	0.85
Livestock (excluding oxen/bulls)	Number	0.00	14.00	4.00	1.05
Age of household head	Year	18.00	85.00	51.00	17.79
Family size	Number	1.00	13.00	5.91	2.54

Karafino					
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	62.72	1096.88	693.49	413.22
Area	Hectare	0.25	3.00	1.82	0.86
Fertilizer used	Kg/ha	9.60	250.00	62.05	56.70
Labor	Manday	16.00	178.00	81.55	54.80
Oxen/bulls	Number	1.00	5.00	1.52	0.83
Livestock (excluding oxen/bulls)	Number	0.00	16.00	4.00	0.16
Age of household head	Year	35.00	77.00	53.57	10.88
Family size	Number	3.00	12.00	6.64	1.99

Bokafya					
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	94.48	1270.37	635.39	133.44
Area	Hectare	0.13	4.00	1.91	0.90
Fertilizer used	Kg/ha	12.44	155.56	61.73	37.00
Labor	Manday	21.00	211.00	112.68	62.52
Oxen/bulls	Number	1.00	4.00	2.09	1.35
Livestock (excluding oxen/bulls)	Number	0.00	19.00	5.48	1.27
Age of household head	Year	25.00	71.00	52.38	12.80
Family size	Number	2.00	13.00	6.34	2.34

Table 5.1 (cont'd)

Yetmen					
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	345.16	22081.46	1399.97	517.67
Area	Hectare	0.48	3.19	1.59	0.61
Fertilizer used	Kg/ha	25.00	312.50	102.99	60.53
Labor	Manday	21.00	300.00	139.80	52.56
Oxen/bulls	Number	1.00	3.00	1.44	0.67
Livestock (excluding oxen/bulls)	Number	0.00	11.00	1.83	1.72
Age of household head	Year	28.00	78.00	46.88	15.65
Family size	Number	3.00	11.00	5.94	2.03

Shumsheha					
Variables	Unit of measurement	Minimum	Maximum	Mean	std.deviation
Cereals output	Kg/ha	80.00	1113.63	713.42	665.96
Area	Hectare	0.13	3.95	1.48	0.69
Fertilizer used	Kg/ha	15.28	196.00	41.99	37.15
Labor	Manday	15.00	199.00	107.70	55.09
Oxen/bulls	Number	1.00	4.00	1.30	0.56
Livestock (excluding oxen/bulls)	Number	0.00	7.00	1.40	2.30
Age of household head	Year	22.00	80.00	48.05	13.07
Family size	Number	2.00	11.00	5.44	1.97

Source: Author's calculation

A close scrutiny of these tables reveal that the mean cereal output per hectare is the highest in *Yetmen* and the lowest in *Koremargefia* with an average land holding of 1.59 and 1.63 hectares per household, respectively. A relatively small size of land holding per household is observed in *shumsheha,* which is 1.48 hectares. It is also in *Yetmen* that a relatively high amount of chemical fertilizer per hectare is applied. In this PA, farmers on the average applied about 100 kilograms per hectare (kgs/ha).

The lowest application is observed in *Dinki,* where farmers on the average used about 40 kgs/ha.

A higher labor force in mandays involved in major agricultural activities such as weeding, ploughing and harvesting is recorded in *Yetmen.* This may indicate a relatively labor abundance in the PA. Households owned oxen/bulls as large as 5 in some of the PAs. In most of the PAs, households owned, on the average, 1 ox/bull. This implies that most farmers in the areas considered suffer from lack of a pair of oxen. The highest size of livestock holding (excluding oxen/bulls) is in *Bokafya,* where households owned as large as 19 and the lowest holding is in *Shumsheha* which is only as large as 7.

When we see the age of household heads in the PAs, the average age is found to be between 47 and 54. This age level may enable farmers to be richer in agricultural knowledge, i.e., in timing and management. Family sizes are recorded as high as 13 in *Koremargefia* and *Bokafya.* But the mean family size of the sample farmers in all PAs is about 6.

Table 5.2 below indicates that in *Milki,* only 14 per cent of the household heads are literate. It is in *Bokafya* that a relatively more literate household heads are found (59%). In *Dinki, Koremargefia, Karafino, Yetmen* and *shumsheha,* literate household heads are about 41, 38, 29, 47 and 38 per cent, respectively. In all PAs, the majority of household heads are found to be engaged in agricultural activities indicating that the major occupation for the majority of household heads is farming. In particular, in *Dinki* and *Yetmen*, only 8.82 pre cent and 12.50 per cent of the household heads, respectively were found to be engaged in other activities as their main occupations.

From the table, it is apparent that in all PAs, farmers who had credit accessibility were small in number. Only 21, 13, 17, 16, 13, 31 and 18 per cent of the farmers in *Dinki, Milki, Koremargefia, Karafino, Yetmen and Shumsheha,* respectively had credit availabilities. This may indicate that either farmers are constrained with some form of barrier to take credit or credit institutions are absent in the areas considered. Although it is not as such significant, the table reveals that one or more household members were involved in off-farm activities. From Table 5.2, we can see that 31, 45, 46, 38, 39, 13 and 11 per cent of the farmers in *Dinki, Milki, Koremargefia, Karafino, Yetmen and Shumsheha,* respectively reported that they were engaged in income generating off-farm activities. It is also important to note that, in *Dinki* and *Yetmen*, a small number of households were found to be female-led and a relatively larger female-headed households have been found in *Koremargefia* and *Karafino.*

Table: 5.2 Frequencies of Categorical Variables Included in the Study

Variable Name	Unit of Measurement	Number					
		Male	Female	Farm	Other	Yes	No
Dinki							
Sex of HH* Head	Dummy	65	3	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	62	6	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	28	40
Did the HH receive Credit?	Dummy	–	–	–	–	14	54
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	21	47
Milki							
Sex of HH Head	Dummy	72	12	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	70	14	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	12	72
Did the HH receive Credit?	Dummy	–	–	–	–	11	73
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	38	46
KoreMargefia							
Sex of HH Head	Dummy	60	36	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	74	22	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	36	60
Did the HH receive Credit?	Dummy	–	–	–	–	16	80
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	44	52
Karafino							
Sex of HH Head	Dummy	36	20	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	42	14	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	16	40
Did the HH receive Credit?	Dummy	–	–	–	–	9	47
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	21	35
Bokafya							
Sex of HH Head	Dummy	40	16	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	47	9	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	32	24
Did the HH receive Credit?	Dummy	–	–	–	–	7	49
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	22	34
Yetmen							
Sex of HH Head	Dummy	30	2	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	28	4	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	15	17
Did the HH receive Credit?	Dummy	–	–	–	–	10	22
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	4	28
Shumsheha							
Sex of HH Head	Dummy	134	18	–	–	–	–
Main Occupation/Activity of HH Head	Dummy	–	–	125	27	–	–
Can HH Head Read/Write?	Dummy	–	–	–	–	57	95
Did the HH receive Credit?	Dummy	–	–	–	–	27	125
Did the HH Obtain Off-Farm Income?	Dummy	–	–	–	–	17	135

Soure: Author's Manipulation

*HH= household

"-" indicates the irrelevance of the label to the corresponding Variable

5.3.2 Empirical Results

5.3.2.1 Preliminary Tests

Before we delve into discussions of results, it is worthwhile mentioning some of the tests that were carried out. We first tested whether the technology is better represented by the Cobb-Douglas stochastic frontier or the translog stochastic frontier for each PA. The results of the log-likelihood ratio test is presented in Table 5.3.

Table 5.3 Hypothesis Testing on the Stochastic Frontier Functional form for Farmers in the PAs.

PAs	Log-likelihood for C-D (H_0)	Log-likelihood for Translog (H_1)	χ^2_{cal}	$\chi^2_{df,0.95}$ [a]
$H_0^{**}: \beta_{11} = \beta_{22} = ... = \beta_{34} = 0$				
Dinki	-112.42	-106.91	11.42	18.31
Milki	-106. 50	-92.24	28.52	18.31*
Koremrgefia	-131.70	-124.88	13.64	18.31
Karafino	-62.80	-40.93	43.74	18.31*
Bokafya	-61.75	-50.89	21.72	18.31*
Yetmen	-31.64	-23.14	17.00	18.31
Shumsheha	-237.50	-206.86	61.28	18.31*

Source: Author's Calculation.

[a] Degree of freedom (df) is equal to the number of restrictions (number of parameters equated to zero). Here the number of restrictions is 10.

* Significant at 5%

** See **Appendix I** for the corresponding variables of these parameters.

The table shows that Cobb-Douglas stochastic frontier production functional form is a better representation for the farmers in three of the PAs (*Dinki, Koremargefia* and *Yetmen*), whereas translog stochastic frontier production functional form is accepted for others.

Second, given such functional forms for each of the PAs, we considered whether the technical efficiency levels are better estimated using a half normal or a truncated normal distribution of U_{it}. The results indicate that we need different distributions of U_{it} for the PAs. As shown in Table 5.4, a half normal distribution of U_{it} seem to be appropriate for the PAs, except for *Milki* and *Shumsheha*.

Table 5.4 Hypothesis Testing on the Distribution of U_{it}.

PAs	Log-likelihood for		χ^2_{cal}	$\chi^2_{df,0.95}$ [b]
	$H_0 : \mu = 0$	$H_1 : \mu \neq 0$		
Dinki	-112.46	-112.42	0.08	3.84
Milki	-104.27	-92.24	24.06	3.84*
Koremargefia	-131.70	-131.63	0.14	3.84
Karafino	-40.94	-40.93	0.02	3.84
Bokafya	-51.41	-50.89	1.04	3.84
Yetmen	-31.64	-31.09	1.10	3.84
Shumsheha	-206.86	-204.78	4.16	3.84 *

Source: Author's calculation

[b] Degree of freedom (df) is equal to the number of restrictions (number of parameter equated to zero). Here the number of restriction is one.
* Significant at 5%

Third we tested the hypothesis whether technical inefficiency is absent and hence the conventional (average) production function is appropriate or not. The test is presented in Table 5.5.

Table 5.5 Hypothesis Testing for Parameters on Deciding whether Technical Inefficiency is absent from the model or not.

	Log-likelihood for			
PAs	OLS $(H_0 : \delta_0 = ... = \delta 12 = \gamma = 0)$**	MLE $(H_1 : \delta_0 \neq ... \neq \delta_{12} \neq \gamma \neq 0)$	χ^2_{cal}	$\chi^{2\ c}_{df,0.95}$
Dinki	-150.07	-112.46	75.22	22.36*
Milki	-116.02	-92.24	47.56	23.68*
Koremargefia	-148.35	-131.70	33.30	22.36*
Karafino	-54.74	-40.94	27.60	22.36*
Bokafya	-67.12	-51.41	31.42	22.36*
Yetmen	-45.99	-31.64	28.70	22.36*
Shumsheha	-344.37	-204.78	139.59	23.68*

Source: Author's calculation

[c] δ_0 is already excluded from the model for *Dinki, Koremargefia, Karafino, Bokafya* and *Yetmen*. (See Table 5.3). Therefore, δ_0 is not part of the restriction for these PAs. This means that the degree of freedom (df) which is equal to the number of restrictions is 13 for these PAs and 14 for others.
* Significant at 5%
** See **Appendix I** for the corresponding variables of these parameters

The null hypothesis, H_0, states that technical inefficiency is absent, given the specifications of Codd-Douglas or translog stochastic frontier production function. As illustrated in Table 5.5, this hypothesis was rejected for all PAs. This suggests the existence of technical inefficiency for the sample farmers in all PAs and thus the inappropriateness of the conventional (average) production function. Stated in other words, the average response function where all farmers are assumed to be fully technically efficient is not an adequate representation of the data, given the Cobb-Douglas or translog stochastic frontier model. Therefore, the analysis that follows and the estimates for technical efficiencies of individual farmers are based on the appropriate functional form that best represents and the distributional specification of the inefficiency term, U_{it}, for individual PAs.

5.3.2.2 Maximum Likelihood Estimates of Parameters of the Models

Maximum likelihood estimation procedure gives estimators which are asymptotically efficient. Even when maximum likelihood estimators are biased they are consistent in large samples (Thomas, 1983:103).

5.3.2.2.1 Production Function

Though estimated coefficients of the production function are not of immediate interest to this study, since the subject of efficiency studies as opposed to production models is the specification of the error term prediction of technical efficiency levels, and as such the estimation of the elasticity as characteristics of the production process is only of secondary interest, we tried to give some tentative explanations.

Considering the estimates of frontier function for those PAs whose production technology for the sample farmers is better represented by Cobb-Douglas stochastic production frontier, i.e., Tables 5.6.1, 5.6.3 and 5.6.6, we can see that, except for labor in *Yetmen*, others have expected relationships with output. The parameter estimates of these variables are also statistically significant both at the conventional 5 and 10 per cent significance levels. The negative sign of the natural logarithm of labor in y*etmen* can be explained as either because this input is relatively abundant in this PA, where a larger amount of labor is used on the relatively small amount of land available or it is extensively used during unfavorable cropping years (seasons) where output was low. Negative coefficient of labor is also found in other study about Ethiopian farmers (e.g., Abrar,1996:19).

In the remaining PAs as well, where the farmers production technology is represented by the translog stochastic production frontier, most of the parameter estimates are statistically significant at both 5 and 10 per cent significance levels but some of the coefficients turned out to have unexpected relationships with output. For instance, the coefficients of the natural logarithms of labor and oxen-bulls (together with their squares and interactions) in *Milki, Bokafya* and *Shumsheha* and that of chemical fertilizer in *Karafino* and *Shumsheha* appeared to have negative relationships with the natural logarithm of output. This is mainly the result of multicollinearity problems often associated with flexible functional forms, such as translog. In a production function analysis, correlation between some of the explanatory variables is expected. Collinearity among economic variables is an inherent and age-old problem leading to problems of multicollinearity. Some have, therefore, suggested that multicollinearity is not necessarily a problem unless it is very high (Gujarati, 1995:344). But in efficiency estimation, since the primary interest is to estimate the degree of technical efficiency, some degree of multicollinearity can be tolerated.

Caution should be exercised when interpreting the parameter estimates from translog functional forms since these parameters have little meaning in themselves (Squires and Tabor in Assefa and Franz, 1996:26). This is because, for the translog function, the elasticities of mean output with respect to the inputs are functions of subsets of the parameters and the levels of the explanatory variables. Hence, the individual coefficients in the translog stochastic frontier production function are not directly interpretable as elasticities, as for the C-D model.

Table 5.6.1 Maximum Likelihood Estimates (rounded to two significant digits) of Cobb-Douglas Stochastic Frontier Production Function for Farmers in **Dinki**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	5.34	1.06	5.05*
ln(AR)	0.45	0.20	2.23*
ln(CHFERTZ)	0.87	0.25	3.52*
ln(LBR)	0.20	0.25	7.94*
ln(OXB)	0.46	0.05	9.45*
Inefficiency model			
AGE	-0.11	0.04	-2.37*
AGESQR	0.001	0.003	4.24*
FS	-0.19	0.09	-2.04*
LVSK	-0.55	0.26	-2.14*
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	2.41	0.62	3.91*
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.40	0.17	2.29*
Log-likelihood	**-113.86**		
Mean TE	**0.69**		
Observations	**68**		

Source: Author's Calculation

* Significant at 5% and 10%

Table 5.6.2 Maximum Likelihood Estimates (rounded to two significant digits) of Translog Stochastic Frontier Production Function for Farmers in **Milki**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	22.96	4.77	4.81*
ln(AR)	4.79	1.26	3.79*
ln(CHFERTZ)	3.13	1.40	2.23*
ln(LBR)	-10.46	1.81	-5.77*
ln(OXB)	-2.77	1.87	-1.48
ln(AR)*ln(AR)	0.28	0.35	0.81
ln(CHFERTZ)*ln(CHFERTZ)	-0.32	0.21	-1.52
ln(LBR)*ln(LBR)	1.21	0.22	5.41*
ln(OXB)*ln(OXB)	0.82	0.84	0.97
ln(AR)*ln(CHFERTZ)	-0.94	0.35	-2.66*
ln(AR)*ln(LBR)	-0.19	0.31	-0.63
ln(AR)*ln(OXB)	-0.82	0.64	-1.27
ln(CHFERTZ)*ln(LBR)	-0.84	0.33	-0.26
ln(CHFERTZ)*ln(OXB)	-0.37	0.49	-0.75
ln(LBR)*ln(OXB)	0.70	0.49	1.44
Inefficiency model			
Constant	0.12	0.01	8.87*
AGE	-0.55	0.20	-2.70*
AGESQR	0.005	0.001	3.12*
OCC	-0.14	0.50	-2.82*
CRT	-0.49	0.14	-3.56*
OFF	-0.33	0.04	-8.57*

Table 5.6.2 (cont'd)

	Estimates	Std.error	t-ratio
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.55	0.10	5.71*
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.99	0.02	42.91*
Log-likelihood	**-92.76**		
Mean TE	**0.35**		
Observations	**84**		

Source: Author's Calculation

* Significant at 5% and 10%

Table 5.6.3 Maximum Likelihood Estimates (rounded to two significant digits) of Cobb-Douglas Stochastic Frontier Production Function for Farmers in **Koremargefia**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	5.50	0.82	6.71*
ln(AR)	0.91	0.20	4.52*
ln(CHFERTZ)	1.06	0.22	4.88*
ln(LBR)	0.19	0.18	2.52*
ln(OXB)	0.02	0.002	5.74*
Inefficiency model			
AGE	-0.75	0.37	-2.05*
AGESQR	0.008	0.001	5.42*
FS	-0.33	0.02	-2.59*
OCC	-0.55	0.17	-3.12*
EDUCA	-0.55	0.07	-8.43*
CRT	-0.19	0.03	-5.85*
OFF	-0.21	0.07	-3.08*

Table 5.6.3 (cont'd)

	Estimate	std.error	t-ratio
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	1.34	0.55	2.45*
$\gamma = \sigma_u^2 /(\sigma_u^2 + \sigma_v^2)$	0.34	0.05	6.21*
Log-likelihood	**-134.84**		
Mean TE	**0.75**		
Observations	**96**		

Source: Author's Calculation

* Significant at 5% and 10%

Table 5.6.4 Maximum Likelihood Estimates (rounded to two significant digits) of Translog Stochastic Frontier Production Function for Farmers in **Karafino**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	10.50	0.95	11.09*
ln(AR)	2.12	1.04	2.04*
ln(CHFERTZ)	-5.70	0.72	-7.87*
ln(LBR)	-3.20	0.78	-4.10*
ln(OXB)	1.92	1.00	1.93*
ln(AR)*ln(AR)	0.60	0.33	1.82*
ln(CHFERTZ)*ln(CHFERTZ)	1.04	0.17	6.25*
ln(LBR)*ln(LBR)	-0.01	0.16	- 0.04
ln(OXB)*ln(OXB)	0.73	0.75	0.98
ln(AR)*ln(CHFERTZ)	-0.71	0.40	-1.76*
ln(AR)*ln(LBR)	0.02	0.36	0.04
ln(AR)*ln(OXB)	2.00	0.85	-2.37*
ln(CHFERTZ)*ln(LBR)	-0.66	0.28	-2.39*
ln(CHFERTZ)*ln(OXB)	-0.13	0.40	-3.35*
ln(LBR)*ln(OXB)	0.50	0.39	1.30

Table 5.6.4 (cont'd)

	Estimate	std.error	t-ratio
Inefficiency model			
SEX	-0.15	0.04	-3.33*
FS	0.09	0.04	2.53*
EDUCA	-0.06	0.02	-3.02*
CRT	0.11	0.05	2.27*
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.38	0.18	2.06*
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.12	0.05	2.57*
Log-likelihood	**-48.09**		
Mean TE	**0.82**		
Observations	**56**		

Source: Author's Calculation

* Significant at 5% and 10%

Table 5.6.5 Maximum Likelihood Estimates (rounded to two significant digits) of Translog Stochastic Frontier Production Function for Farmers in **Bokafya**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	28.22	7.47	3.78*
ln(AR)	0.15	0.03	4.93*
ln(CHFERTZ)	0.14	0.02	7.43*
ln(LBR)	-10.33	2.82	-3.67*
ln(OXB)	-4.53	1.69	-2.68*
ln(AR)*ln(AR)	- 0.31	0.24	-1.26
ln(CHFERTZ)*ln(CHFERTZ)	0.15	0.23	0.64
ln(LBR)*ln(LBR)	1.38	0.34	4.06*
ln(OXB)*ln(OXB)	-0.32	0.32	-0.98
ln(AR)*ln(CHFERTZ)	0.43	0.39	1.11
ln(AR)*ln(LBR)	0.19	0.46	0.41
ln(AR)*ln(OXB)	-0.47	0.30	-1.55
ln(CHFERTZ)*ln(LBR)	-0.64	0.26	-2.50*
ln(CHFERTZ)*ln(OXB)	-0.03	0.33	-9.10*
ln(LBR)*ln(OXB)	1.17	0.40	2.90*
Inefficiency model			
SEX	-0.11	0.02	-6.59*
AGE	-0.33	0.07	-4.65*
AGESQR	0.003	0.001	3.02*
OCC	-0.10	0.17	-3.15*
EDUCA	-0.40	0.18	-9.51*

Table 5.6.5 (cont'd)

	Estimate	std.error	t-ratio
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	1.85	0.92	2.03*
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.90	1.12	8.04*
Log-likelihood	**-54.41**		
Mean TE	**0.64**		
Observations	**56**		

Source: Author's Calculation

* Significant at 5% and 10%

Table 5.6.6 Maximum Likelihood Estimates (rounded to two significant digits) of Cobb-Douglas Stochastic Frontier Production Function for Farmers in **Yetmen**

Variable	Estimates	Std. error	t-ratio
Frontier function			
Constant	12.72	1.83	6.96*
ln(AR)	1.12	0.43	2.59*
ln(CHFERTZ)	1.31	0.28	4.69*
ln(LBR)	-8.14	0.33	-2.50*
ln(OXB)	1.53	0.39	3.90*
Inefficiency model			
AGE	-0.16	0.06	-2.52*
AGESQR	0.001	0.0004	3.20*
FS	0.11	0.03	3.19*
EDUCA	-0.47	0.19	-2.54*
CRT	-0.57	0.19	-1.94*

Table 5.6.7 (cont'd)

	Estimate	std.error	t-ratio
Inefficiency model			
Constant	0.82	0.09	9.08*
SEX	-0.16	0.06	-2.69*
FS	-0.55	0.16	-3.53*
OCC	-0.67	0.09	-7.87*
EDUCA	-0.19	0.06	-3.08*
LVSK	-0.82	0.15	-5.51*
CRT	-0.41	0.05	-7.80*
Variance parameters			
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	7.89	0.31	25.32*
$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.99	0.36	2.80*
Log-likelihood	**-207.40**		
Mean TE	**0.42**		
Observations	**152**		

Source: Author's Calculation

* Significant at 5% and 10%

5.3.2.2.2 Farm Level Technical Efficiency Predictions

The results of the ML estimates (Tables 5.6.1-5.6.7) also indicate that, in all cases, there are significant inefficiency effects associated with production, which is in line with the test presented in Table 5.3. This is evident from the estimates of the discrepancy parameter γ which are 0.40, 0.99, 0.34, 0.12, 0.90, 0.43 and 0.99 for *Dinki, Milki, Koremargefia, Karafino, Bokafya, Yetmen and Shumsheha*, respectively. This means that around 40, 99, 34, 12, 90, 43 and 99 per cent of the discrepancies between the observed output and the frontier output are due to technical among farmers. This in turn has important implications for agricultural policy formulation.

Table 5.7.1 Technical efficiency (TE) frequencies for farmers in **Dinki**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.30	0	17.65	5.88	0
0.31-0.40	0	11.76	0	0
0.41-0.50	11.76	5.88	0	0
0.51-0.60	17.65	0	5.88	5.88
0.61-0.70	23.53	17.65	17.65	17.65
0.71-0.80	41.18	35.29	47.06	17.65
0.81-0.90	5.88	11.76	23.53	58.52
≥0.91	0	0	0	0
Mean	0.67	0.56	0.73	0.79
Maximum	0.84	0.85	0.88	0.90
Minimum	0.48	0.05	0.23	0.53
Standard deviation	0.10	0.28	0.15	0.10
Coefficient of variation	0.15	0.50	0.20	0.13

Source: Author's Calculation

The sample average levels of technical efficiencies for farmers in *Dinki* relative to the frontier level are found to be 67, 56, 73 and 79 in 1994, 1995, 1997 and 1999, respectively and the panel mean technical efficiency has been found to be 69 per cent. This means that, on the average, about 31 per cent difference exists between the observed level of output and the frontier that could have been obtained using the existing inputs and technology due to technical inefficiencies. This implies that under a perfect technical efficiency plan, the sample farmers in the PA could have (on the average) increased their output by about 31 per cent over the years under the existing technology environment.

Technical efficiency ranged from 48 to 84 per cent in 1994 and 5 to 85, 23 to 88 and 53 to 90 per cent in 1995, 1997 and 1999, respectively. Most of the farmers in *Dinki* operated in the range of 41 to 70, 5 to 70, 71 to 90 and 81 to 90 per cent technical efficiency levels in 1994, 1995, 1997 and 1999 cropping years, respectively. The result also shows that it was in the cropping year 1995 that farmers deviated more from the frontier. As the coefficient of variation (CV) indicates, it was also in same year that a high variation in technical efficiency among farmers is observed. A relatively high performance of farmers in general and low variation among farmers considered in this PA has been observed in 1999. This indicates that, at the end of the panel period, most farmers in *Dinki* improved their levels of technical efficiencies.

Table 5.7.2 Technical efficiency (TE) frequencies for farmers in **Milki**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.10	14.29	0	4.76	14.29
0.11-0.21	19.29	19.05	33.33	28.57
0.22-0.32	14.29	19.05	19.05	28.57
0.33-0.43	4.76	14.29	14.29	23.81
0.44-0.54	9.52	9.52	9.52	0
0.55-0.65	14.29	28.57	9.52	4.76
0.66-0.76	4.76	4.76	0	0
0.77-0.87	9.52	4.76	4.76	0
0.88-0.97	9.52	0	4.76	0
≥0.98	0	0	0	0
Mean	0.43	0.39	0.34	0.25
Maximum	0.99	0.77	0.91	0.61
Minimum	0.05	0.12	0.10	0.10
Standard deviation	0.31	0.19	0.23	0.14
Coefficient of variation	0.72	0.47	0.66	0.57

Source: Author's Calculation

Table 5.7.2 shows that the sample average levels of technical efficiencies for farmers in *Milki* relative to the frontier level are found to be 43, 39, 34 and 25 in 1994, 1995, 1997 and 1999, respectively. This implies that about 57, 61, 66 and 75 per cent of the total variability of output in the 1994, 1995, 1997 and 1999 cropping seasons, respectively was resulted due to technical inefficiency effect. Therefore, in this PA as well, under a perfect technical efficiency plan, the sample farmers could have been able to increase their output by about 43, 39, 34 and 25 per cent during the years in that order under the existing technology environment.

Technical efficiency ranged from 5 to 99 per cent in 1994 and 12 to 77, 10 to 91 and 10 to 61 per cent in 1995, 1997 and 1999, respectively. The technical efficiency scores of most farmers during the production years in this PA went only up to 43 per cent. It was at the beginning and at the end of the panel period that the highest number of farmers with technical efficiency scores of less than 11 per cent was observed in this PA. The table also shows that technical efficiency scores between 88 to 97 per cent were achieved by a relatively high number of farmers during the 1994 cropping year. No technical efficiency score over 65 per cent is observed at the end of the panel period, while about 24 per cent of the farmers in 1994 and 10 per cent of them in 1995 and 1997 scored technical efficiency levels over the technical efficiency level of 65 per cent.

A consistent decline in mean technical efficiency is observed in *Milki.* Although farmers' technical efficiency scores in 1994 were relatively high compared to the rest of production years, a high variation in technical efficiency among farmers have been observed. In this PA, the overall (or the panel) mean technical efficiency is only 35 per cent. This implies that farmers could have increased output levels by 65 per cent without additional costs.

Table 5.7.3 also shows that the highest number of farmers with technical efficiency scores of less than 30 per cent was found in the cropping year of 1995 (about 8%). On the other hand, it was in 1997 that the highest number of farmers with technical efficiency scores of over 90 per cent are observed (about 8%). More than 50 per cent of the farmers in 1994 and 1997 had technical efficiency scores of over 80 per cent, whereas a significant number of farmers in the remaining years had efficiency scores of less than 80 per cent.

Table 5.7.3 Technical efficiency (TE) frequencies for farmers in **Koremargefia**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.30	0	8.33	4.17	0
0.31-0.40	4.17	4.17	0	0
0.41-0.50	4.17	4.17	0	0
0.51-0.60	12.50	16.67	4.17	4.17
0.61-0.70	12.50	4.17	4.17	25.00
0.71-0.80	12.50	25.00	20.83	41.67
0.81-0.90	50.00	37.50	58.33	29.17
≥0.91	4.17	0	8.33	0
Mean	0.75	0.69	0.79	0.75
Maximum	0.92	0.89	0.92	0.88
Minimum	0.39	0.25	0.12	0.60
Standard deviation	0.16	0.18	0.17	0.08
Coefficient of variation	0.21	0.27	0.21	0.11

Source: Author's Calculation

For farmers in *Koremargefia,* the mean technical efficiency levels relative to the frontier level are found to be 75 per cent, 69 per cent, 79 per cent and 75 per cent in 1994, 1995, 1997 and 1999, respectively. This means that about 25, 31, 21, and 25 per cent differences between the observed and the "best" practice levels of output in the years of that order resulted due to technical inefficiency.

In this PA, the level of technical efficiency ranged from 39 to 92, 25 to 89, 12 to 92 and 60 to 88 per cent during the cropping seasons of 1994, 1995, 1997 and 1999, respectively. Only about 4, 17, 4 per cent of the farmers operated at a technical efficiency of less than 50 per cent in 1994, 1995 and 1997, respectively, whereas about 54, 38, 65 and 29 per cent of farmers operated at a technical efficiency level greater than 80 per cent during the cropping years considered, respectively. In the 1999 cropping season, most farmers operated with technical efficiency scores of 71 to 80 per cent and the mean technical efficiency level of the panel has been found to be 75 per cent..

The result in Table in 5.7.3 also shows that, compared to other cropping years, farmers performed less in 1995. More variations among farmers were also observed during this year where the variability of technical efficiency scores among them was 27 per cent.

The mean levels of technical efficiencies for farmers in *Karafino* relative to the frontier level are found to be 90, 79, 77 and 83 per cent in 1994, 1995, 1997 and 1999, respectively while the panel mean technical efficiency is found to be 82 per cent. What this shows is that about 10, 21, 23, and 17 per cent differences between the actual level of output and the level of output obtained from the "best" practice resulted due to lack of techniques of production. Farmers in this PA seem to be less deviated from the frontier in the sense that no greater hope is entertained to increase production gains without major investment.

Table 5.7.4 Technical efficiency (TE) frequencies for farmers in **Karafino**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.40	7.14	7.14	0	7.14
0.41-0.60	0	7.14	35.71	14.29
0.61-0.80	0	35.71	14.29	0
0.81-0.90	14.29	7.14	0	14.29
≥0.91	78.57	42.86	50.00	64.29
Mean	0.90	0.79	0.77	0.83
Maximum	0.97	0.98	0.97	0.97
Minimum	0.35	0.27	0.45	0.22
Standard deviation	0.16	0.20	0.22	0.23
Coefficient of variation	0.18	0.26	0.28	0.27

Source: Author's Calculation

Technical efficiency ranged from 35 to 94 in 1994 and 25 to 98, 45 to 97, and 22 to 97 per cent in 1995, 1997 and 1999, respectively. Technical efficiency scores of most farmers are found to be over 80 per cent in the years, except 1997 where the number of farmers with technical efficiency scores below 80 per cent and over 80 per cent were equal. A relatively high variation in technical efficiency among farmers has been observed in 1997 where the CV is 28 per cent.

The estimate of mean technical efficiency for farmers in *Bokafya* were 60, 59, 61 and 76 per cent in 1994, 1995 1997 and 1999, respectively. This implies that the actual output on average is 40, 41, 39, and 24 per cent less than the frontier output during the production years in that order, whereas the panel mean technical efficiency is obtained to be 64 per cent.

Table 5.7.5 Technical efficiency (TE) frequencies for farmers in **Bokafya**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.10	7.14	0	0	0
0.11-0.25	7.14	7.14	21.43	0
0.26-0.40	0	14.29	7.14	0
0.41-0.55	14.29	14.29	0	0
0.56-0.70	28.57	28.57	7.14	28.57
0.71-0.85	42.86	28.57	64.29	71.43
≥0.86	0	7.14	0	0
Mean	0.60	0.59	0.61	0.76
Maximum	0.85	0.89	0.85	0.89
Minimum	0.02	0.24	0.11	0.63
Standard deviation	0.24	0.19	0.28	0.08
Coefficient of variation	0.40	0.33	0.46	0.10

Source: Author's Calculation

Technical efficiency scores ranged from 2 per cent to 85 per cent in 1994, and 24 per cent to 89 per cent, 11 per cent to 85 per cent and 63 per cent to 85 per cent in 1995, 1997 and 1999, respectively. In this PA, a relatively high variation in technical efficiency scores is observed in 1997 where the CV is about 46 per cent. The variation in technical efficiency among farmers is minimized at the end of the panel period since the CV is found to be only 10 per cent. During this period, all technical efficiency scores were over 55 per cent. It is also evident from the table that over 70 per cent, 60 per cent and 70 per cent of the farmers in 1994, 1995 and 1997, respectively produced at the technical efficiency levels of more than 55 per cent.

Technical efficiency predictions in *Yetmen* reveal that the mean technical efficiency levels were 62, 53, 55, and 57 per cent in the cropping seasons of 1994, 1995, 1997 and 1999, respectively. As the table above indicates, the scores in technical efficiency ranged from 26 to 100 per cent in 1994 and 26 to 79, 32 to 100 and 29 to 100 per cent in 1995, 1997 and 1999, respectively.

Table 5.7.6 Technical efficiency (TE) frequencies for farmers in **Yetmen**

	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.39	12.50	25.00	50.00	25.00
0.40-0.69	62.50	50.00	25.00	50.00
0.70-0.99	12.50	25.00	12.50	12.50
1.00	12.50	0	12.50	12.50
Mean	0.62	0.53	0.55	0.57
Maximum	1.00	0.79	1.00	1.00
Minimum	0.26	0.26	0.32	0.29
Standard deviation	0.25	0.18	0.23	0.22
Coefficient of variation	0.40	0.34	0.42	0.38

Source: Author's Calculation

During all cropping years considered in the study, most of the farmers in this PA have been operating at the technical efficiency levels of less than 70 per cent. Looking into the mean technical efficiency scores of the farmers during each production year, there would have been a production gain almost by more than 40 per cent using the existing inputs and technology, i.e., if technical inefficiencies had not appeared. A high variation in technical efficiency among farmers in *Yetmen* existed during the 1997 cropping season where the CV was about 42 per cent and the overall (through the four years) mean technical efficiency score has been found to be 57 per cent.

The mean levels of technical efficiencies for farmers in *Shumsheha* relative to the frontier level have been found to be 34, 53, 36 and 44 in 1994, 1995, 1997 and 1999, respectively while the panel mean technical efficiency has been found to be 42 per cent. This implies that about 66, 48, 64, and 56 per cent differences between the actual level of output and the frontier output level obtained from the "best" practice resulted due to inefficiencies. This result indicates that there is a greater hope in this PA for farmers to increase the level of output using available resources.

Table 5.7.7 Technical efficiency (TE) frequencies for farmers in **Shumsheha**

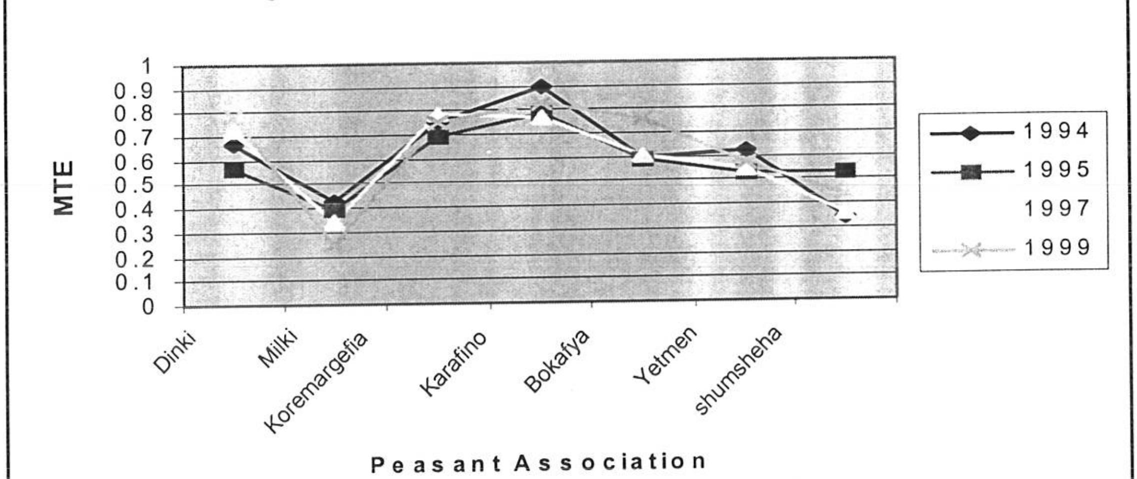
	Number of farmers (%)			
TE Interval	1994	1995	1997	1999
≤0.05	34.21	5.26	10.53	10.53
0.06-0.20	13.16	2.63	44.74	23.68
0.21-0.35	10.53	15.79	0	5.86
0.36-0.50	15.79	18.42	5.26	15.79
0.51-0.65	5.26	18.42	10.53	10.53
0.66-0.80	7.89	31.58	15.79	23.68
0.81-0.95	2.63	2.63	5.26	10.53
≥0.96	10.53	5.26	7.89	0
Mean	0.34	0.53	0.36	0.44
Maximum	0.99	0.99	0.99	0.92
Minimum	0.00	0.00	0.00	0.03
Standard deviation	0.33	0.25	0.34	0.31
Coefficient of variation	0.98	0.48	0.94	0.71

Source: Author's Calculation

Farmers in this PA operated at technical efficiency levels that ranged from virtually 0 to 99 per cent. During the 1994 cropping season, more than 50 per cent of the farmers in *Shumsheha* operated at a technical efficiency score of less than 36 per cent whereas a high number of farmers' technical efficiency scores of over 50 per cent is observed in 1995 and 1999. It is also evident from the table that only less than 50 per cent of the farmers operated at technical efficient scores of 36 per cent and over. The result further indicates that a relatively high variation in technical efficiency among farmers has been resulted in the 1994 cropping season where the CV was about 98 per cent while less variation is observed in 1995.

Below is a graph showing the average technical efficiencies for each PA in each year considered in the study. The plot shows that, except for *Milki* where a deterioration in mean technical efficiency of farmers is observed, the trend for the mean technical efficiency of sample farmers in other PAs is mixed. In fact, farmers in *Dinki, Bokafya* and *Yetmen* have shown improvement trends during the last two periods.

Figure 2 Mean technical Efficiency(MTE)



The results in general show that in most of the PAs, there is technical inefficiency indicating that there exists considerable scope (for a short run) for expanding production by improving farmers' technical management abilities at least in the short run.

5.3.2.2.3 Determinants of Technical Inefficiency

In addition to estimating farm level technical efficiencies, investigating sources of technical inefficiency is also the main concern of this study. Variations in technical efficiency arise from different practices or techniques, but it is difficult to obtain satisfactory measures of all these factors. In this study, a total of 12 variables (sex of household head, age of household head and its square, educational level of household head, main occupation of household head, household family size, number of livestock at the disposal of the household, credit availability, quality of soil and topography of the land under cultivation, off-farm income and the year of observations involved), which are assumed to influence the technical efficiency level of individual farmers, were included in each equation for the PAs.

From the result, we can observe that all variables in all PAs, except for the positive sign of family size in *Yetmen,* have turned to have expected signs. Despite this, some of them have been found to be statistically insignificant in explaining the variation in technical efficiency among farmers. In fact, any reduction in the number of explanatory variables in the model should be based on tests of hypotheses involving sets of parameters. Taking this into consideration, the joint effects of individually insignificant explanatory variables in a PA in question was tested using the log-likelihood ratio test and the result also suggested the insignificance of their joint effects. (See **Appendix III** for the test).

For instance, in four of the PAs (*Dinki, Milki, Koremargefia* and *Yetmen*) although male-headed households seem to be technically more efficient relative to female-headed households, the difference is not as such statistically significant. The variation in technical efficiency levels among farmers in *Dinki* and *Milki* have not also been explained by educational level of the household heads. A simple consideration of educational level as simply literate or illiterate may obscure the strong effect of education on the variation of technical efficiency among farmers. In fact, even studies based on better classification of educational levels of farmers also found a weak association of technical efficiency and education. For instance, Antiporta (1978) for The Philippines, and by Cotlear (1986) for Peru (in Bravo *et al,* 1994:35) have reported a weak association between technical efficiency and education. In a recent paper, using data from Pakistan, Azhar (1991) also lends further support to the notion "... that elementary education (4-5 years of schooling) does not have much effect on agricultural productivity" in traditional farm settings (Azhar, 1991:658). Azhar (1991: 658) emphasized that education has a more pronounced effect on technical efficiency in the face of new crop varieties.

In *Dinki, Karafino* and *Yetmen,* household heads main occupation has not been found to have a pronounced effect on technical efficiency. This may be due to the fact that other household members, in households where household heads are not engaged in farming as their main activity, take care of all agricultural activities equally as what the household head does. Or devotion, endurance or motivation may be more important to reflect technical efficiency variations among farmers than occupation.

The effect of livestock number on the variation of technical efficiency among farmers in *Milki, Koremargefia, Karafino, Bokafya* and *Yetmen,* is insignificant, perhaps because the variation in the size of livestock holding among farmers in these areas, as indicated in the descriptive statistics, is small compared to others. For farmers in *Dinki* and *Bokafya,* credit has not also been found to have a strong effect in explaining the variation in technical efficiency among farmers. Whether the loan taken is properly used for agricultural production or not matters in explaining the variation in technical efficiency. A weak association between credit and technical efficiency for Ethiopian farmers has also been reported by Croppensted and Mulat (1997:1224).

In *Milki* and *Bokafya,* although households with bigger family size tend to improve the level of their technical efficiency, the variable has not been found to be statistically significant to explain the argument why some farmers are technically more efficient while others are technically less efficient. The result also indicates that in *Karafino* and *Shumsheha,* experience of farmers, proxied by age and age square, has not been found to be an important variable in explaining the variation in technical efficiency among farmers considered.

Soil fertility and topography of the land under cultivation have not been found to be statistically significant in all PAs. The way the data was collected on these variables created difficulties in representing these variables to reflect the fertility and topography of the total cultivated land under a household. The representations were rough proxies. In addition to this, the farmers' evaluation itself might be another problem. Therefore, these problems may overwhelm the significant effect of these variables on technical efficiency variations.

Although households who obtained incomes from off-farm activities seem to be technically more efficient relative to those who did not, the difference has not been found to be statistically significant (both at the conventional 5 and 10 per cent significant levels). This result is true for all pAs, except for *Milki* and *Koremargefia.* This may be due to the fact that incomes generated from off-farm activities in these areas are low to bring a statistically significance variation in technical efficiency among farmers. Or there may be little variation in off-farm incomes among farmers. The result also signifies that the year of observations involved is not strong enough to show up technical efficiency improvements or deterioration among farmers in all PAs. This implies that the impact of time on the improvement or deterioration of farmers' technical efficiency in the PAs is not significant. This may be due to the fact that the period we considered is short for agricultural activities to show significant changes. (See **Appendix II** for the appearance of these variables before they were removed from the final estimation).

At this juncture, it is very important to note that although some of the variables mentioned above are found to be statistically insignificant, there are important variables that should not be given up by policy-makers who are striving to encourage farmers to increase their levels of technical efficiencies. For instance, in what so ever credit appears (in a statistical sense), it is important in improving the performance of farmers with respect to increasing agricultural output.

After we removed the variables which are both individually and jointly insignificant in a PA in question, the maximum likelihood (ML) estimates for the selected models are presented in Tables 5.6.1 - 5.6.7.

In *Karafino*, *Bokafya* and *Shumsheha*, it is evident from the result (Tables 5.6.1-5.6.7) that male-headed households, at least in a statistical sense, performance (in technical efficiency) was significant relative to female-headed households. It is also observed that, in five of the PAs (*Dinki, Milki, Koremargefia, Bokafya and Yetmen),* the coefficients of age of household head and its square indicate that households with older household heads (up to a certain age threshold) appeared to be technically more efficient. This implies that households with older household heads are more experienced with timing and management until they reach to a certain age threshold and after that experiences may saturate and the marginal effect to improvements in technical efficiency will decrease.

In *Dinki, Koremargefia, Karafino* and *shumsheha,* family size is negatively related to technical inefficiency and is also statistically significant. This implies that larger variables that should not be given up by policy-makers who are striving to encourage farmers to increase their levels of technical efficiencies. For instance, in what so ever credit appears (in a statistical sense), it is important in improving the performance of farmers with respect to increasing agricultural output.

After we removed the variables which are both individually and jointly insignificant in a PA in question, the maximum likelihood (ML) estimates for the selected models are presented in Tables 5.6.1 - 5.6.7.

In *Karafino*, *Bokafya* and *Shumsheha*, it is evident from the result (Tables 5.6.1-5.6.7) that male-headed households, at least in a statistical sense, performance (in technical efficiency) was significant relative to female-headed households. It is also observed that, in five of the PAs (*Dinki, Milki, Koremargefia, Bokafya and Yetmen),* the coefficients of age of household head and its square indicate that households with older household heads (up to a certain age threshold) appeared to be technically more efficient. This implies that households with older household heads are more experienced with timing and management until they reach to a certain age threshold and after that experiences may saturate and the marginal effect to improvements in technical efficiency will decrease.

In *Dinki, Koremargefia, Karafino* and *shumsheha,* family size is negatively related to technical inefficiency and is also statistically significant. This implies that larger family size is an important factor to improvements in technical efficiency, perhaps because households with bigger family strive more to secure the family in food and clothing or labor may be relatively scarce in these areas. What surprises is the positive association between family size and technical inefficiency in *Yetmen* and its significance. This could be because of under utilized labor which is available in the household. This is consistent with the negative sign of labor in the frontier model or in the production function.

In *Dinki* and S*humsheha,* agricultural households with bigger livestock size tend to be technically less inefficient. This may be due to the fact that a bigger size of livestock may improve the farmers' asset and facilitates to access the required inputs easily or on time so that the farmers able to improve their technical efficiency.

Households whose heads major occupation is farming are found to be technically less inefficient. This is evident from the PAs, *Milki, Koremargefia, Bokafya* and *Shumsheha.* This may be due to the fact that household heads who are mainly involved in farming can have a greater chance to be richer in managerial skill and timing concerning agricultural activities. This in tern may enable the household heads more rational to assign the right job to the right person at the right time.

In *Koremargefia, Karafino, Bokafya, Yetmen* and *shumsheha,* the educational level of the household head, that is, being literate or illiterate is statistically significant in explaining the variation in technical efficiency among farmers. The result indicates that literate farmers are technically more efficient than illiterates, perhaps because the farmers are likely to have readier access to information and are probably able to assimilate information more easily so that it helps them improving their technical efficiency levels. Stating in other words, literate farmers may have a relatively adequate knowledge to apply scientific methods to agricultural activities and thus the farmers may able to move away from being technically inefficient.

Credit has also been found to be an important variable in *Milki, Koremargefia, Karafino, Yetmen* and *shumsheha* in explaining the variation of technical efficiency among farmers. This implies that credit availability shifts the cash constraint outwards and thus enables farmers to make timely purchases of inputs that they cannot provide otherwise from their own resources. Farmers obtained off-farm incomes have also been found to be significantly more efficient relative to those who did not involve and derived incomes from this activity, perhaps because incomes generated from off-farm activities may improve the farmers' liquidity and facilitates the purchase of inputs. This is evident from farmers considered in *Milki* and *Koremargefia.* These results give some kind of clue to take actions and improve technical efficiencies of small-scale farmers.

CHAPTER VI: CONCLUSION, POLICY RECOMMENDATIONS AND POSSIBLE INDICATION FOR FUTURE RESEARCH

6.1 Conclusion

This study was undertaken with the intention of addressing three main objectives: testing whether farmers in the PAs are fully technically efficient so that the conventional (average) production function is adequate or not; examining farm level technical efficiencies over time; and assessing some factors that might affect the technical efficiency of small-scale farmers. Detail results in each PA based on the Ethiopian Rural Household Survey panel data are examined in Chapter 5. Following the details are conclusions and policy recommendations.

For the data we had, the Cobb-Douglas stochastic frontier production functional form has been found to be an appropriate production technology for three of the PAs (*Dinki*, *Koremargefia* and *Yetmen*), whereas translog stochastic frontier production functional form better represented the production technology of farmers in other PAs.

We have stated in previous chapters that the distributional form of the inefficiency term U_{it} matters in estimating the technical efficiency levels. Taking this into consideration, we have tested its distributional form and the result suggested that, except for *Milki* and *Shumsheha*, a half normal distribution of U_{it}, i.e., the mean of U_{it} is zero, could not be rejected in predicting the technical efficiency levels. This implies that a truncated normal distribution of the inefficiency term, i.e., the mean of U_{it} is different from zero, enables us to have better predictions of technical efficiencies for the two PAs mentioned above but a half normal distribution of U_{it} for others.

Moreover, the hypothesis that technical inefficiency effects are absent, given the specification of Cobb-Douglas or translog stochastic frontier production function, has been strongly rejected for all PAs. This indicates that technical inefficiency exists in the PAs considered and hence the average response function in which all farmers are fully technically efficient is not an adequate representation of the data.

Further findings of the analysis of technical efficiency at farm level have also indicated the existence of some degree of technical inefficiencies. The stochastic frontier production function in each PA has shown that there are discrepancies between the observed and the frontier output levels. In most of the PAs, the discrepancy has arisen not so much from chance factors but rather from differences in the farmers' ability to use the best practices which are possible under the state of the current economic environment. With the breakdown of the error term, i.e., the inefficiency component and the conventional random term, the former has outweighed the variations between the observed and the "best" practice output levels. It was only in *Koremargefia* that 98 per cent of the variation between the frontier and the actual output levels occurred due to factors which were beyond the control of farmers. But in other PAs (*Dinki, Milki, Karafino, Bokafya, Yetmen* and *Shumsheha*), 40, 99, 34, 90, 43 and 99 per cent of the discrepancies, respectively occurred due to technical inefficiency.

The power of some variables in explaining the variation in technical efficiency among farmers in different PAs appeared different, i.e., some of them are statistically significant in some PAs while they are not significant in other PAs. For instance, in *Dinki, Milki, Koremargefia* and *Yetmen,* though male-headed households seem to be technically more efficient relative to female-led households, the variation is not statistically significant. Furthermore, being literate headed household did not show a significant variation in technical efficiency among farmers in *Dinki* and *Milki.* A weak association between education and technical efficiency has also been reported by other studies (e.g., Antiporta (1978) for The Philippines and by Cotlear (1986) for Peru (in Bravo *et al*, 1994:35).

For many possible reasons, as stated in Chapter 5, in some of the PAs (in *Dinki, Karafino* and *Yetmen),* whether the household heads' main occupation is farming or not does not show significant variation in technical efficiency among farmers. Further, credit appears to have a weak relation with technical efficiency for farmers in *Dinki* and *Bokafya,* perhaps because it is used for non-agricultural purposes. Croppensted and Mulat (1997:1224) have also found a weak association between credit and technical efficiency for Ethiopian farmers.

In *Milki* and *Bokafya,* although households with bigger family size tend to improve the level of their technical efficiency, the effect has not been found to be strong enough to explain the variation in technical efficiency among farmers. The result also indicates that, in *Karafino* and *Shumsheha*, experience of farmers, proxied by age and its square, has not been found to be an important variable in explaining the variation in technical efficiency among the sample farmers.

What is common for all PAs is that soil fertility and topography of land under cultivation and the year of observations involved are statistically insignificant in answering the question why some farmers are technically more efficient and whether technical efficiency changes are observed or not, respectively.

Except for *Milki* and *Koremargefia*, incomes from off-farm activities have also insignificant effects on the variation in technical efficiency among farmers, perhaps because incomes generated from off-farm activities in these areas are too low to bring a statistically significant variation in technical efficiency, or they are used for other purposes.

However, it is important to note that, the variables which are found to be statistically insignificant, should not be given up by policy-makers who are striving to encourage farmers to increase their levels of technical efficiencies.

In this study, technical efficiency variation among farmers in *Dinki* is more explained by household heads' experience, family size and the size of livestock at the disposal of households. Experience has also been found to be a statistically significant variable in explaining the variation in technical efficiencies among farmers in *Milki*, *Koremargefia*, *Bokafya*, *Yetmen* and *Shumsheha*. Credit availability has also determined the technical efficiency levels. This is evident in most PAs except for *Dinki* and *Bokafya*. Whether the main occupation or activity of the household head is farming or not, strongly matters in *Milki*, *Koremargefia*, *Karafino* and *Shumsheha* in the variation of technical efficiency scores among farmers. Education in *Koremargefia*, *Karafino*, *Bokafya*, *Yetmen* and *Shumsheha*, incomes from off-farm activities in *Milki* and *Koremargefia* and family size in all PAs except for *Milki* have been found to be important variables in stating why some farmers are technically more efficient and others are technically less efficient. What is exceptional is that bigger family size in *Yetmen* is negatively related to technical efficiency.

It is also important to note that a pronounced variation in technical efficiency between male-headed and female-headed households has been observed in *Karafino*, *Bokafya* and *Shumsheha*. The result shows that, in a relative sense, male-headed households are technically more efficient than female-headed households. Similar to farmers in *Dinki*, the variation in technical efficiency among farmers in *Shumsheha* is also well explained by the size of livestock holding.

Due to the influence of such factors on the technical efficiency levels of farmers, the result of the study signifies that technical inefficiency does make a contribution in the analysis of agricultural production in the sample farmers involved in the PAs. This is apparent from the results of the farm level technical efficiency predictions. For instance, the sample average levels of technical efficiency for farmers in *Dinki* relative to the frontier level is ranged from 56 to 79 per cent during the four cropping years considered in this study where the lowest is observed in 1995 and the highest is in 1999. In this PA, the panel mean technical efficiency has been found to be 69 per cent implying that farmers on the average could have improved their efficiency by 31 per cent without major additional costs in each year. Farm level technical efficiency scores in *Dinki* have been found to be as low as 5 per cent and as high as 90 per cent during the cropping seasons of 1995 and 1999, respectively.

In *Milki,* the mean technical efficiency for farmers relative to the frontier level deteriorated from 43 per cent in 1994 to 25 per cent in 1999 which resulted in the mean technical efficiency level of the panel period being only 35 per cent. In this PA, there is a big scope to increase technical efficiency of farmers with the existing level of inputs. This means that without any additional cost, the technical efficiency can be increased substantially.

For farmers under study in *Koremargefia*, the mean technical efficiency levels relative to the frontier level are found to be 75, 69, 79 and 75 per cent in 1994, 1995, 1997 and 1999, respectively indicating that more than 21 per cent of the deviation from the frontier resulted in technical inefficiency. The lowest technical efficiency score in this PA, 0.12 (or 12%), was recorded in 1997. The overall or the panel mean technical efficiency level is 75 per cent implying that output levels in this PA could have been improved by 25 per cent without major investment.

In *Karafino* and *Bokafya,* the four year mean technical efficiencies have been found to be 82 per cent and 64 per cent, respectively. This result shows that it was possible to increase production gains under the existing technology and input levels by only 18 per cent in *Karafino* and 36 per cent in *Bokafya*. At individual level, technical efficiency scores found to be as low as 22 per cent in *Karafino* and 2 per cent in *Bokafya.*

The panel mean technical efficiency scores of farmers in *Yetmen* and *Shumsheha* have been found to be 57 per cent and 42 per cent, respectively. In *Yetmen,* relatively 100 per cent technically efficient farmers have been found while some others were operating only at a technical efficiency level of 26 per cent. In

Shumsheha on the other hand, farmers were operating almost at a technical efficiency level of 0 per cent relative to the "best" practice frontier indicating that a big scope exists for such farmers to improve technical efficiency without incurring major additional costs.

6.2 Policy Recommendations

Given the very nature of the data we used and its associated problems mentioned in previous chapters, it would not be worthwhile to provide conclusive policy recommendations. Nevertheless, based on the observations made from the study, the following general policy recommendations can be forwarded.

1. Although the areas considered in this study were not said to be representative of the region, much can be learned from the performance of sampled farmers from the PAs to be able to increase agricultural output, at least in the short-run. Given the limited resources in the region in general and in the study areas in particular, efforts to strengthen the technical efficiency of smallholder farmers who are the largest segment in agricultural production are indispensable. We have observed that, in most PAs, education is positively related to technical efficiency. This indicates that education is fundamental in improving the technical efficiency and thereby the performance of farmers. Therefore, we recommend that the regional government should have a prime responsibility for

its increased provision of education in these areas and others so that farmers can use the available inputs more efficiently under the existing technology.

2. Liquidity constraint makes small-scale farmers suffer much from lack of the necessary inputs. To overcome such problems, efforts towards establishing micro-enterprises to assist farmers in terms of financial support through credit are crucial. Besides the provision of credit, technical assistance for the positive return of the loan should also be augmented. This may include the formulation of mechanisms to follow up farmers whether the loan they are provided with is used for agricultural production or not.

3. Observations from our results also enable us to recommend the creation of off-farm job opportunities. This has two important advantages: for labor absorption and as a source of cash incomes. Off-farm job opportunities may reduce disguised unemployment that may exist in the areas and thus enable to increase the returns of others on agricultural production. On the other hand, off-farm job opportunities could replace credit as a source of funds for the farm and then improve the efficiency of farmers.

4. Special attention should also be given to female-led agricultural households as they seem technically less efficient relative to their counterparts. It is possible to improve their efficiency by making female-led households as "model farms".

But what is common and usually observed is the bias towards male-headed households in choosing model farmers. Therefore, to minimize the gap that exists between the technical efficiency levels of male-headed and female-headed households, the government in the region should involve the latter households in all areas that entertain male-headed households.

5. The result also indicates that the age of the household head, which is a proxy for experience, follows a U-shape to technical efficiency of farmers in the majority of PAs. This dictates that agricultural households with a relatively younger and older household heads in the PAs lack technical knowledge and therefore they are technically less efficient. Therefore, the regional government should give priorities in providing credits, access to education and other technical assistance such as extension services to agricultural households with younger and older households in the PAs.

6. In *Dinki* and *Shumsheha,* the size livestock holding is found to be one of the factors in explaining the variation of technical efficiency among farmers. Agricultural households with bigger livestock size are technically more efficient. A concern of the regional government in regard to livestock holding in addition to other policy formulations (e.g., land redistribution) in these PAs is, therefore, important to move technically less efficient farmers to a higher efficiency level.

7. In fact, the magnitude of technical inefficiency prevailing in most of the areas does not indicate a big scope (for a long run) for a substantial growth in agricultural production merely by improving technical efficiency. Therefore, as a more general recommendation, the long-term plan should involve introducing new technologies, improving institutional structures and build infrastructure. To name only a few, provision of modern yield-increasing inputs that are adaptable to the environments, accessible of markets and roads, and building a mechanism to insure farmers-to back up them during any distortion-are crucial elements to push the production function outward and create new production horizon.

6.3 Possible Indication for Future Research

Given the differences in agricultural environments in the PAs considered, different conclusions have been drawn based on the preferred stochastic frontier production functions and the effects of the socio-economic variables included in the inefficiency effects model. Therefore, the motivation to explain the basis for the different conclusions we made can be considered as one possible research problem for future researchers.

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Appendix I. Variables and the Corresponding Coefficients (Parameters)

Variable	Parameter
Frontier function	
$Constant$	β_0
$\ln(AR)$	β_1
$\ln(CHFERTZ)$	β_2
$\ln(LBR)$	β_3
$\ln(OXB)$	β_4
$\ln(AR)^2$	β_{11}
$\ln(CHFERTZ)^2$	β_{22}
$\ln(LBR)^2$	β_{33}
$\ln(OXB)^2$	β_{44}
$\ln(AR)\times\ln(CHFERTZ)$	β_{12}
$\ln(AR)\times\ln(LBR)$	β_{13}
$\ln(AR)\times\ln(OXB)$	β_{14}
$\ln(CHFERTZ)\times\ln(LBR)$	β_{23}
$\ln(CHFERTZ)\times\ln(OXB)$	β_{24}
$\ln(LBR)\times\ln(OXB)$	β_{34}
Technical Inefficiency Model	
$Constant$	δ_0
SEX	δ_1
AGE	δ_2
$AGESQR$	δ_3
FS	δ_4
OCC	δ_5
$EDUCA$	δ_6
$LVSK$	δ_7
CRT	δ_8
FER	δ_9
SLP	δ_{10}
OFF	δ_{11}
TIM	δ_{12}

Appendix II. Results of the ML estimates before and after individually insignificant variables have been removed from the technical inefficiency effects model

Result in Dinki before the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = cd3.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.45720537E+01	0.13642579E+01	0.33513118E+01*
ln(Ar)	0.50245493E+00	0.38763757E+00	0.32961977E+01*
ln(Chfertz)	0.13463829E+00	0.24787979E+00	0.54315959E+00
ln(Lbr)	0.33756765E+00	0.26953595E+00	0.22524031E+01*
ln(Oxb)	0.42400452E-01	0.48698672E+00	0.87066956E-01*

Technical Inefficiency Model

Sex	-0.52660803E+00	0.10939299E+01	-0.48139100E+00
Age	-0.59998381E-01	0.20515680E-01	-0.29245133E+01*
Agesqr	0.10209406E-02	0.19662387E-03	0.51923532E+01*
Fs	-0.34925816E-01	0.15001236E-01	-0.23281960E+01*
Occ	-0.52660803E+00	0.10939299E+01	-0.48139100E+00
Educa	-0.13111828E+00	0.12462799E+00	-0.10520773E+01
Lvsk	-0.15481979E+00	0.32683401E+00	-0.47369548E+01*
Cdt	-0.92552171E+00	0.76931450E+00	-0.12030473E+01
Fer	-0.29930449E+00	0.26204418E+01	-0.11182906E+01
Slp	-0.12579247E+00	0.11721185E+00	-0.10732061E+01
Off	-0.10189442E+00	0.95488635E-01	-0.10670843E+01
Tim	-0.34430384E+00	0.53531758E+00	-0.64317679E+00
σ^2	0.20941391E+01	0.58042906E+00	0.36079157E+01*
γ	0.32275100E+00	0.20668485E+00	0.15615610E+01*

log likelihood function = -0.11245813E+03

*significant at 5% and 10%

Appendix II (cont'd)

Results for *Dinki* after the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = test1.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.53360682E+01	0.10560563E+01	0.50528254E+01*
ln(Ar)	0.45288621E+00	0.20310384E+00	0.22298259E+01*
ln(Chfertz)	0.86585441E+00	0.24610160E+00	0.35182803E+01*
ln(Lbr)	0.20190493E+00	0.25437442E+00	0.79373128E+01*
ln(Oxb)	0.46065642E+00	0.48751778E-01	0.94490177E+01*
Technical Inefficiency Model			
Age	-0.10552433E+00	0.44605005E-01	-0.23657509E+01*
Agesqr	0.10484313E-02	0.27734338E-03	0.42387619E+01*
Fs	-0.18944019E+00	0.92946732E-01	-0.20381587E+01*
Lvsk	-0.55257436E+00	0.25872015E+00	-0.21357995E+01*
σ^2	0.24133361E+01	0.61758677E+00	0.39076875E+01*
γ	0.39530825E+00	0.17225632E+00	0.22948838E+01*

log likelihood function = -0.11386477E+03

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Milki* before the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =        tr17.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates
```

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.19068189E+02	0.58659108E+01	0.32506783E+01*
ln(Ar)	0.22810730E+01	0.10196354E+01	0.22371458E+01*
ln(Chfertz)	0.36510672E+01	0.15694423E+01	0.23263469E+01*
ln(Lbr)	-0.83325901E+01	0.23255093E+01	-0.35831248E+01*
ln(oxb)	-0.62934597E+01	0.23168955E+01	-0.27163330E+01*
ln(Ar)*ln(Ar)	0.11693488E-01	0.31636596E+00	0.36961902E-01
ln(Chfertz)*ln(Chfertz)	-0.39355912E+00	0.18081891E+00	-0.21765374E+01*
ln(Lbr)*ln(Lbr)	0.95627309E+00	0.25846755E+00	0.36997801E+01*
ln(Oxb)*ln(Oxb)	0.36415259E+00	0.68269232E+00	0.53340660E+00
ln(Ar)* ln(Chfertz)	-0.34610123E+00	0.43162850E+00	-0.80184981E+00
ln(Ar)* ln(Lbr)	-0.67515657E-01	0.30767913E+00	-0.21943529E+00
ln(Ar)* ln(oxb)	0.37263180E+00	0.50066645E+00	0.74427157E+00
ln(Chfertz)* ln(Lbr)	-0.14853245E-01	0.29490505E+00	-0.50366194E-01
ln(Chfertz)* ln(oxb)	-0.59603847E-01	0.46328240E+00	-0.12865554E+00
ln(Lbr)* ln(oxb)	0.12563744E+01	0.40302837E+00	0.31173349E+01*

Technical Inefficiency Model

Constant	0.15267379E+00	0.64927895E-01	0.23514360E+01*
Sex	-0.65821408E+00	0.33484373E-01	-0.19657351E+00
Age	-0.42038994E+00	0.42111852E+00	-0.59982699E+01*
Agesqr	0.71033799E-02	0.25529817E-02	0.27823857E+01*
Fs	-0.17985150E-01	0.47946032E-01	-0.37511237E+00
Occ	-0.50279896E+00	0.18661563E+00	-0.26943025E+01*
Educa	-0.57964627E+00	0.53772436E+00	-0.10779617E+01
Lvsk	-0.28397716E-01	0.38423387E-01	-0.73907372E+00
Cdt	-0.34108554E+00	0.16234629E+00	-0.21009753E+01*
Fer	-0.66899159E-01	0.21779157E+00	-0.30717056E+00
Slp	-0.55657515E+00	0.45677468E+00	-0.12192903E+01
Off	-0.54703228E+00	0.22196278E+00	-0.24645225E+01*
Tim	0.77622805E+00	0.14224216E-01	0.54570885E+00
σ^2	0.56123745E+00	0.78264877E-01	0.71710002E+01*
γ	0.99999999E+00	0.11809032E-05	0.84680942E+06*

log likelihood function = -0.92235118E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Milki* after the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = tr17.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function	coefficient	standard-error	t-ratio
Constant	0.22959995E+02	0.47747153E+01	0.48086626E+01*
ln(Ar)	0.47859459E+01	0.12641935E+01	0.37857700E+01*
ln(Chfertz)	0.31320053E+01	0.14019852E+01	0.22339788E+01*
ln(Lbr)	-0.10463732E+02	0.18149152E+01	-0.57654110E+01*
ln(Oxb)	-0.27697097E+01	0.18678692E+01	-0.14828178E+01
ln(Ar)*ln(Ar)	0.28186570E+00	0.34832037E+00	0.80921393E+00
ln(Chfertz)*ln(Chfertz)	-0.32247959E+00	0.21227551E+00	-0.15191559E+01
ln(Lbr)*ln(Lbr)	0.12125029E+01	0.22427264E+00	0.54063794E+01*
ln(Oxb)*ln(Oxb)	0.81785622E+00	0.83947620E+00	0.97424588E+00
ln(Ar)* ln(Chfertz)	-0.94143919E+00	0.35425305E+00	-0.26575331E+01*
ln(Ar)* ln(Lbr)	-0.19485807E+00	0.30722386E+00	-0.63425434E+00
ln(Ar)* ln(Oxb)	0.81709746E+00	0.64241698E+00	0.12719114E+01
ln(Chfertz)* ln(Lbr)	0.84301439E-01	0.32938642E+00	0.25593478E+00
ln(Chfertz)* ln(Oxb)	-0.37107440E+00	0.49150224E+00	-0.75498007E+00
ln(Lbr)* ln(Oxb)	0.70114420E+00	0.48539452E+00	0.14444831E+01
Technical Inefficiency Model			
Constant	0.11648261E+00	0.13134710E-01	0.88683046E+01*
Age	-0.54667988E+00	0.20277657E+00	-0.26959718E+01*
Agesqr	0.45833333E-02	0.14668641E-02	0.31245789E+01*
Occ	-0.13979867E+00	0.49512248E+00	-0.28235169E+01*
Cdt	-0.48799539E+00	0.13703152E+00	-0.35611907E+01*
Off	-0.33224559E+00	0.38761324E-01	-0.85715747E+01*
σ^2	0.55211351E+00	0.96664751E-01	0.57116323E+01*
γ	0.99999999E+00	0.23306824E-01	0.42905889E+02*

Log likelihood function = -0.92760384E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Koremargefia* before the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = cd18.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function	coefficient	standard-error	t-ratio
Constant	0.58962319E+01	0.10465130E+01	0.56341697E+01*
ln(Ar)	0.10009321E+01	0.19790524E+00	0.50576335E+01*
ln(Chfertz)	0.19035994E+01	0.20194401E+00	0.94263725E+01*
ln(Lbr)	0.66690952E-01	0.18568738E-01	0.35915717E+01*
ln(Oxb)	-0.13308643E+00	0.28560846E+00	-0.46597512E+00
Technical Inefficiency Model			
Sex	-0.86185497E-01	0.63955825E+00	-0.13475785E+00
Age	-0.12351532E+00	0.15214333E-01	-0.81183523E+01*
Agesqr	0.36620292E-02	0.52074676E-03	0.70322651E+01*
Fs	-0.80088196E+00	0.10960998E-01	-0.73066518E+01*
Occ	-0.33741070E+00	0.72393310E+00	-0.46607995E+01*
Educa	-0.19010788E+00	0.59350985E-01	-0.32031124E+01*
Lvsk	-0.17309067E+00	0.15741912E+00	-0.10995530E+01
Cdt	-0.31649704E+00	0.10323419E-01	-0.30667071E+01*
Fer	-0.92740401E+00	0.83418252E+00	-0.11117519E+01
Slp	-0.99937372E+00	0.97859406E+00	-0.10212342E+01
Off	-0.82339686E-01	0.34949878E-01	-0.23525706E+01*
Tim	-0.76887545E-01	0.35533331E+00	-0.21638147E+00
σ^2	0.11072209E+01	0.29091285E+00	0.38060227E+01*
γ	0.30161620E+00	0.13428439E+00	0.22461003E+01*

log likelihood function = -0.13169778E+03

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Koremargefia* after the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =        cd18.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged
```

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.55045541E+01	0.82094628E+00	0.67051331E+01*
ln(Ar)	0.91280166E+00	0.20212595E+00	0.45160043E+01*
ln(Chfertz)	0.10570135E+01	0.21669052E+00	0.48779867E+01*
ln(Lbr)	0.18555692E+00	0.73634538E-01	0.25206559E+01*
ln(Oxb)	0.16278681E-01	0.28371356E-02	0.57377169E+01*
Technical Inefficiency Model			
Age	-0.75035695E+00	0.36614334E+00	-0.2049353E+01*
Agesqr	0.78125615E-02	0.14418323E-02	0.54184942E+01*
Fs	-0.33183942E+00	0.20915706E-01	-0.25865561E+01*
Occ	-0.54707376E+00	0.17096452E+00	-0.31199926E+01*
Educa	-0.55384165E+00	0.65730859E-01	-0.84259000E+01*
Cdt	-0.18786639E+00	0.32100903E-01	-0.58523709E+01*
Off	-0.21340084E+00	0.69317008E-01	-0.30786217E+01*
σ^2	0.13397090E+01	0.54776246E+00	0.24457846E+01*
γ	0.33823925E+00	0.54431889E-01	0.62139906E+01*

log likelihood function = -0.13483847E+03

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Karafino* before the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = tr19.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function	coefficient	standard-error	t-ratio
Constant	0.94298331E+01	0.48257740E+01	0.19540561E+01*
ln(Ar)	0.10143725E+00	0.20476998E-01	0.49537166E+01*
ln(Chfertz)	-0.44736594E+01	0.17833109E+01	-0.25086256E+01*
ln(Lbr)	0.34524330E+01	0.89737135E+00	0.38472735E+01*
ln(Oxb)	0.10124688E+01	0.30188649E+00	0.33538062E+01*
ln(Ar)*ln(Ar)	0.19799091E+00	0.27998699E+00	0.70714325E+00
ln(Chfertz)*ln(Chfertz)	0.64624380E+00	0.26054519E+00	0.24803521E+01*
ln(Lbr)*ln(Lbr)	-0.25640919E+00	0.22305775E+00	-0.11495193E+01
ln(Oxb)*ln(Oxb)	0.45983915E+00	0.59020973E+00	0.77911143E+00
ln(Ar)*ln(Chfertz)	0.13226977E-01	0.47405031E+00	0.27902052E-01
ln(Ar)*ln(Lbr)	-0.24294678E+00	0.31594853E+00	-0.76894415E+00
ln(Ar)*ln(Oxb)	0.23534960E+01	0.70787849E+00	0.33247175E+01*
ln(Chfertz)*ln(Lbr)	-0.21287840E+00	0.30170421E+00	-0.70558646E+00
ln(Chfertz)*ln(Oxb)	-0.83148751E+00	0.61834288E+00	-0.13447030E+01
ln(Lbr)*ln(Oxb)	0.67600692E+00	0.36303823E+00	0.18620819E+01
Technical Inefficiency Model			
Sex	-0.10701849E+00	0.33401970E-01	-0.32039575E+01*
Age	-0.26009250E-01	0.13947728E+00	-0.18647660E+00
Agesqr	0.33345146E-03	0.98991239E-03	0.33684977E+00
Fs	-0.52847760E+00	0.62202092E-01	-0.84961386E+01*
Occ	-0.31687068E+00	0.25216042E+00	-0.12566234E+01
Educa	-0.98298373E+00	0.32620336E+00	-0.30134077E+01*
Lvsk	-0.17692945E-01	0.36891644E-01	-0.47959222E+00
Cdt	-0.23035533E+00	0.31269800E-00	-0.73667030E+01*
Fer	-0.46625631E+00	0.16390561E-01	-0.28446635E+00
Slp	-0.48815557E+00	0.45059347E+00	-0.10833614E+01
Off	-0.31927629E+00	0.14631729E+01	-0.21820817E+00
Tim	-0.14661581E-01	0.16387910E+00	-0.89465839E-01
σ^2	0.25257573E+00	0.48459168E-01	0.52121351E+01
γ	0.99999999E+00	0.39921914E+00	0.25048899E+02

log likelihood function = -0.40942539E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Karafino* after the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =        tr19.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged
```

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.10496472E+02	0.94637837E+00	0.11091200E+02*
ln(Ar)	0.21200862E+01	0.10414848E+01	0.20356382E+01*
ln(Chfertz)	-0.57017033E+01	0.72429881E+00	-0.78720319E+01*
ln(Lbr)	-0.31956803E+01	0.78029245E+00	-0.40954905E+01*
ln(Oxb)	0.19186934E+01	0.99547896E+00	0.19274072E+01*
ln(Ar)*ln(Ar)	0.60239566E+00	0.33122626E+00	0.18186833E+01*
ln(Chfertz)*ln(Chfertz)	0.10410901E+01	0.16665746E+00	0.62468859E+01*
ln(Lbr)*ln(lbr)	-0.61543257E-02	0.15797336E+00	-0.38957998E-01
ln(Oxb)*ln(Oxb)	0.73181400E+00	0.74623929E+00	0.98066935E+00
ln(Ar)* ln(Chfertz)	-0.70782398E+00	0.40261343E+00	-0.17580734E+01
ln(Ar)* ln(lbr)	0.15315338E-01	0.35942249E+00	0.42610963E-01
ln(Ar)* ln(Oxb)	0.20024017E+01	0.84581562E+00	0.23674211E+01*
ln(Chfertz)*ln(Lbr)	-0.65792609E+00	0.27527746E+00	-0.23900471E+01*
ln(Chfertz)*ln(Oxb)	-0.13251964E+01	0.39614923E+00	-0.33451948E+01*
ln(Lbr)*ln(Oxb)	0.50392600E+00	0.38896127E+00	0.12955686E+01
Technical Inefficiency Model			
Sex	-0.15321985E+00	0.44510749E-01	-0.34423111E+01*
Fs	-0.93868841E-01	0.37169473E-01	-0.25254283E+01*
Educa	-0.64058100E-01	0.21231751E-01	-0.30170898E+01*
Cdt	-0.10542089E+00	0.46454274E-01	-0.22693475E+01*
σ^2	0.37801402E+00	0.18347644E+00	0.20602864E+01*
γ	0.12448275E+00	0.48499962E-01	0.25666566E+01*

log likelihood function = -0.48088731E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Bokafya* before the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =         tr20.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged
```

Maximum-Likelihood estimates:

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.30723914E+02	0.39946760E+01	0.76912155E+01*
ln(Ar)	0.39168802E+01	0.14643356E+01	0.26748515E+01*
ln(Chfertz)	0.93058435E+00	0.10497532E-01	0.88647921E+01*
ln(Lbr)	-0.10840694E+02	0.16113617E+01	-0.67276606E+01*
ln(Oxb)	0.39464618E+01	0.12417868E+01	0.31780511E+01*
ln(Ar)*ln(Ar)	0.52272436E+00	0.22582544E+00	0.23147275E+01*
ln(Chfertz)*ln(Chfertz)	0.16481684E+00	0.17386184E-01	0.94797591E+01*
ln(Lbr)*ln(Lbr)	0.13724662E+01	0.23956917E+00	0.57288932E+01*
ln(Oxb)*ln(Oxb)	-0.26847836E+00	0.32543397E-01	-0.82498568E+01*
ln(Ar)* ln(Chfertz)	0.71050188E+00	0.37725093E+00	0.18833668E+01
ln(Ar)* ln(Lbr)	0.42242633E+00	0.33660700E+00	0.12549541E+01
ln(Ar)*ln(Oxb)	-0.40770339E+00	0.32360831E+00	-0.12598669E+01
ln(Chfertz)*ln(Lbr)	-0.54609873E+00	0.21958187E+00	-0.24869937E+01*
ln(Chfertz)*ln(Oxb)	-0.32374644E+00	0.31982037E+00	-0.10122759E+01
ln(Lbr)*ln(Oxb)	0.13037747E+01	0.30510357E+00	0.42732201E+01*
Technical Inefficiency Model			
Sex	-0.13578056E+00	0.42314374E-01	-0.32088519E+01*
Age	-0.30561756E+00	0.69176220E-01	-0.44179569E+01*
Agesqr	0.38270349E-02	0.13158316E-02	0.29084533E+01*
Fs	-0.45597133E+00	0.39602624E+00	-0.11513664E+01
Occ	-0.10372235E+00	0.16735768E-01	-0.61976447E+01*
Educa	-0.39837162E+00	0.17673797E+00	-0.22540240E+01*
Lvsk	-0.81680295E-01	0.92326960E-01	-0.88468520E+00
Cdt	-0.35528943E+00	0.29020015E+00	-0.10242910E+01
Fer	-0.36865636E-01	0.10102524E+01	-0.36491509E-01
Slp	-0.25801740E+00	0.10532091E+01	-0.24498211E+00
Off	-0.26903718E+00	0.16891494E+01	-0.15927377E+00
Tim	-0.10758621E+00	0.42977885E+00	-0.25034671E+00
σ^2	0.11658186E+01	0.32026990E+00	0.36401130E+01*
γ	0.78704324E+00	0.11956042E+00	0.65828075E+01*

log likelihood function = -0.51405524E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Bokafya* after the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = tr20.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function

	Coefficient	standard-error	t-ratio
Constant	0.28221120E+02	0.74744838E+01	0.37756614E+01*
ln(AR)	0.14966971E+00	0.30328563E-01	0.49349424E+01*
ln(CHFERTZ)	0.14285064E+00	0.19227370E-01	0.74295468E+01*
ln(LBR)	-0.10328330E+02	0.28175056E+01	-0.36657707E+01*
ln(OXB)	-0.45254857E+01	0.16909925E+01	-0.26762304E+01*
ln(AR)*ln(AR)	-0.30578734E+00	0.24318413E+00	-0.12574313E+01
ln(CHFERTZ)*ln(CHFETZ)	0.14776578E+00	0.23253753E+00	0.63544915E+00
ln(LBR)*ln(LBR)	0.13819980E+01	0.34059558E+00	0.40575925E+01*
ln(OXB)*ln(OXB)	-0.31781705E+00	0.32343870E+00	-0.98261911E+00
ln(Ar)*ln(CHFERTZ)	0.43442386E+00	0.39036563E+00	0.11128640E+01
ln(Ar)*ln(LBR)	0.18863051E+00	0.45697564E+00	0.41278024E+00
ln(AR)*ln(OXB)	-0.47284052E+00	0.30490786E+00	-0.15507653E+01
ln(CHFERTZ)*ln(LBR)	-0.63927283E+00	0.25532051E+00	-0.25038052E+01*
ln(CHFERTZ)*ln(OXB)	-0.30288660E-01	0.33297412E+00	-0.90964006E-01
ln(LBR)*ln(OXB)	0.11651430E+01	0.40164185E+00	0.29009502E+01*

Technical Inefficiency Model

SEX	-0.11063031E+00	0.16784815E-01	-0.65910949E+01*
AGE	-0.33097415E+00	0.71170872E-01	-0.46504158E+01*
AGESQR	0.33673463E-02	0.11131850E+00	0.30249628E+01*
OCC	-0.39603174E+00	0.12548538E+00	-0.31545999E+01*
EDUCA	-0.34282283E+00	0.36065434E-01	-0.95055789E+01*
σ^2	0.18534163E+01	0.91520711E+00	0.20251332E+01*
γ	0.90078245E+00	0.11205450E+00	0.80387885E+01*

log likelihood function = -0.54405462E+02

* significant at 5% and 10%

Appendix II (cont'd)

Result for *Yetmen* before the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =        cd5.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates
```

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.14892435E+02	0.33206137E+01	0.44848440E+01*
ln(Ar)	0.19936431E+00	0.43198630E+00	0.46150610E+00
ln(Chfertz)	0.45082091E+00	0.37813023E+00	0.11922372E+01*
ln(Lbr)	-0.68784845E+00	0.34388478E+00	-0.20002294E+01*
ln(Oxb)	0.68116440E+00	0.61851613E+00	0.11012880E+01

Technical Inefficiency Model

	coefficient	standard-error	t-ratio
Sex	-0.65264352E+00	0.92328814E+00	-0.70686874E+00
Age	-0.93905269E+00	0.10148533E-01	-0.92530878E+01*
Agesqr	0.25660443E-02	0.10340292E-02	0.24815977E+01*
Fs	0.75861541E+00	0.94532718E-01	0.80248979E+01*
Occ	-0.65264352E+00	0.92328814E+00	-0.70686874E+00
Educa	-0.48245750E+00	0.19182922E+00	-0.25150365E+01*
Lvsk	-0.16002982E+00	0.12883960E+00	-0.12420856E+01
Cdt	-0.76947726E+00	0.31958084E+00	-0.24077703E+01*
Fer	-0.10301894E+00	0.28040587E+00	-0.36739223E+00
Slp	-0.65264352E+00	0.92328814E+00	-0.70686874E+00
Off	-0.57620759E+00	0.72023697E+00	-0.80002501E+00
Tim	-0.60769731E-01	0.18451770E+00	-0.32934364E+00
σ^2	0.51908288E+00	0.12878389E+00	0.40306507E+01*
γ	0.99999999E+00	0.44791072E-04	0.22325878E+05*

log likelihood function = -0.31642507E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Result for *Yetmen* after the variables have been removed

```
Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =        cd5.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged
```

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.12721285E+02	0.18271290E+01	0.69624446E+01*
ln(Ar)	0.11234329E+01	0.43356387E+00	0.25911590E+01*
ln(Chfertz)	0.13146256E+01	0.28046240E+00	0.46873507E+01*
ln(Lbr)	-0.81366201E+01	0.32541449E+00	-0.25003865E+01*
ln(Oxb)	0.15269022E+01	0.39170844E+00	0.38980579E+01*
Technical Inefficiency Model			
Age	-0.15570394E+00	0.61633854E-01	-0.25262730E+01*
Agesqr	0.14545454E-02	0.45491405E-03	0.31974052E+01*
FS	0.10701072E+00	0.33557243E-01	0.31889008E+01*
Educa	-0.47328325E+00	0.18608219E+00	-0.25434097E+01*
Cdt	-0.56525583E+00	0.19230135E+00	-0.19394273E+01*
σ^2	0.44778438E+00	0.10843932E+00	0.41293543E+01*
γ	0.43139545E+00	0.10883509E+00	0.39637534E+01*

log likelihood function = -0.32550469E+02

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *shumsheha* before the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = tr6.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

Frontier Function

	coefficient	standard-error	t-ratio
Constant	0.22568865E+02	0.95553388E+00	0.23619116E+02*
ln(Ar)	0.45166321E+01	0.77273601E+00	0.58449872E+01*
ln(Chfertz)	0.77941065E+00	0.35358948E+00	0.22042812E+01*
ln(Lbr)	-0.78984289E+01	0.60071563E+00	-0.13148366E+02*
ln(Oxb)	-0.73088837E+01	0.97310041E+00	-0.75109245E+01*
ln(Ar)*ln(Ar)	-0.95046461E-01	0.54694320E-01	-0.17377757E+01*
ln(Chfertz)*ln(Chfertz)	-0.25138349E+00	0.12931540E+00	-0.19439563E+01*
ln(Lbr)*ln(Lbr)	0.85359471E+00	0.76687381E-01	0.11130837E+02*
ln(Oxb)*ln(Oxb)	0.28474094E+01	0.30795156E+00	0.92462900E+01*
ln(Ar)*ln(Chfertz)	-0.16695509E+00	0.23469100E+00	-0.71138258E+00
ln(Ar)*ln(Lbr)	-0.77784252E+00	0.17902087E+00	-0.43449824E+01*
ln(Ar)*ln(Oxb)	0.33883939E-01	0.27535971E+00	0.12305336E+00
ln(Chfertz)*ln(Lbr)	0.29518869E+00	0.12128149E+00	0.24339139E+01*
ln(Chfertz)*ln(Oxb)	-0.40675490E+00	0.20020506E+00	-0.20316914E+01*
ln(Lbr)*ln(oxb)	0.74267703E+00	0.12374845E+00	0.60015058E+01*

Technical Inefficiency Model

	coefficient	standard-error	t-ratio
Constant	-0.57139900E+00	0.96233184E-01	-0.59376503E+01*
Sex	-0.27410353E+00	0.92146902E-01	-0.29746365E+01*
Age	-0.27897814E-01	0.23926776E-01	-0.11659663E+01
Agesqr	0.31211667E-03	0.69596101E-03	0.47720677E+00
Fs	-0.25705997E+00	0.99919329E-01	-0.25726751E+01*
Occ	-0.10299030E+00	0.93488066E-01	-0.21016412E+01*
Educa	-0.17329435E+00	0.80595809E-01	-0.21501657E+01*
Lvsk	-0.98733373E+00	0.20593508E+00	-0.47943931E+01*
Cdt	-0.38911298E+00	0.97466527E-01	-0.39922730E+01*
Fer	-0.41571669E+00	0.91941015E+00	-0.45215587E+00
Slp	-0.86928941E+00	0.87342730E+00	-0.99526248E+00
Off	-0.16949697E+00	0.98803376E+00	-0.17154978E+00
Tim	-0.39008531E+00	0.31464941E+00	-0.12397459E+01
σ^2	0.79954601E+01	0.71194431E+00	0.11230457E+02*
γ	0.99999999E+00	0.36019689E-06	0.27762594E+07*

log likelihood function = -0.20686364E+03

* Significant at 5% and 10%

Appendix II (cont'd)

Results for *Shumsheha* after the variables have been removed

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file = tr6.txt
Tech. Eff. Effects Frontier (see B&C 1993)
The model is a production function
The dependent variable is logged

Maximum-Likelihood estimates

	coefficient	standard-error	t-ratio
Frontier Function			
Constant	0.23288836E+02	0.88542504E+00	0.26302437E+02*
ln(Ar)	0.53755199E+01	0.79446128E+00	0.67662453E+01*
ln(Chfertz)	0.19288833E+01	0.65672147E+00	0.29371406E+01*
ln(Lbr)	-0.93764318E+01	0.54325587E+00	-0.17259697E+02*
ln(Oxb)	-0.56458512E+01	0.40427013E+00	-0.13965541E+02*
ln(Ar)*ln(Ar)	-0.89529910E-01	0.22865590E-01	-0.39154866E+01*
ln(Chfertz)*ln(Chfertz)	-0.48853237E+00	0.13510802E+00	-0.36158651E+01*
ln(Lbr)*ln(Lbr)	0.95693040E+00	0.18904378E-01	0.50619512E+02*
ln(Oxb)*ln(Oxb)	0.24172113E+01	0.10334033E+00	0.23390782E+02*
ln(Ar)*ln(Chfertz)	-0.20760652E+00	0.40879524E-01	-0.50784967E+01*
ln(Ar)*ln(Lbr)	-0.93327892E+00	0.73234102E-01	-0.12743775E+02*
ln(Ar)*ln(Oxb)	-0.27667999E-01	0.20564409E+00	-0.13454312E+00
ln(Chfertz)*ln(Lbr)	0.46094558E+00	0.92362979E-01	0.49905881E+01*
ln(Chfertz)*ln(Oxb)	-0.59114530E+00	0.95086851E-01	-0.62168985E+01*
ln(Lbr)*ln(Oxb)	0.64540452E+00	0.11684033E+00	0.55238164E+01*
Technical Inefficiency Model			
Constant	0.81860168E+00	0.90203568E-01	0.90750476E+01*
Sex	-0.16067479E+00	0.59807628E-01	-0.26865266E+01*
Fs	-0.54854741E+00	0.15536970E+00	-0.35305945E+01*
Occ	-0.67470197E+00	0.85685975E-01	-0.78741237E+01*
Educa	-0.19321343E+00	0.62795507E-01	-0.30768671E+01*
Lvsk	-0.82299056E+00	0.14927428E+00	-0.55132778E+01*
Cdt	-0.40926345E+00	0.52487070E-00	-0.77974146E+01*
σ^2	0.78890609E+01	0.31159206E+00	0.25318556E+02*
γ	0.99999859E+00	0.35747888E+00	0.27973641E+01*

log likelihood function = -0.20740226E+03

* Significant at 5% and 10%

Appendix III. Likelihood-ratio Test of Null hypothesis for Individually Insignificant Variables in the Technical Inefficiency Model

PA	Hypothesis	Log-Likelihood	χ^2_{cal}	$\chi^2_{df,0.95}$*	Decision
Dinki	$H_0: \delta_1 = \delta_5 = \delta_6 = \delta_8 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$	-113.86	2.80	15.51	Do not reject H_0
	$H_1: \delta_1 \neq \delta_5 \neq \delta_6 \neq \delta_8 \neq \delta_9 \neq \delta_{10} \neq \delta_{11} \neq \delta_{12} \neq 0$	-112.46			
Milki	$H_0: \delta_1 = \delta_4 = \delta_6 = \delta_7 = \delta_9 = \delta_{10} = \delta_{12} = 0$	-92.76	1.04	14.07	Do not reject H_0
	$H_1: \delta_1 \neq \delta_4 \neq \delta_6 \neq \delta_7 \neq \delta_9 \neq \delta_{10} \neq \delta_{12} \neq 0$	-92.24			
Koremargefia	$H_0: \delta_1 = \delta_7 = \delta_9 = \delta_{10} = \delta_{12} = 0$	-134.84	6.28	11.07	Do not reject H_0
	$H_1: \delta_1 \neq \delta_7 \neq \delta_9 \neq \delta_{10} \neq \delta_{12} \neq 0$	-131.70			
Karafino	$H_0: \delta_2 = \delta_3 = \delta_5 = \delta_7 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$	-48.09	14.30	15.51	Do not reject H_0
	$H_1: \delta_2 \neq \delta_3 \neq \delta_5 \neq \delta_7 \neq \delta_9 \neq \delta_{10} \neq \delta_{11} \neq \delta_{12} \neq 0$	-40.94			
Bokafya	$H_0: \delta_4 = \delta_7 = \delta_8 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$	-54.41	6.00	14.07	Do not reject H_0
	$H_1: \delta_4 \neq \delta_7 \neq \delta_8 \neq \delta_9 \neq \delta_{10} \neq \delta_{11} \neq \delta_{12} \neq 0$	-51.41			
Yetmen	$H_0: \delta_1 = \delta_5 = \delta_7 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$	-32.55	1.82	14.07	Do not reject H_0
	$H_1: \delta_1 \neq \delta_5 \neq \delta_7 \neq \delta_9 \neq \delta_{10} \neq \delta_{11} \neq \delta_{12} \neq 0$	-31.64			
Shumsheha	$H_0: \delta_2 = \delta_3 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$	-207.40	5.24	12.59	Do not reject H_0
	$H_1: \delta_2 \neq \delta_3 \neq \delta_9 \neq \delta_{10} \neq \delta_{11} \neq \delta_{12} \neq 0$	-204.78			

* df = degree of freedom = the number of restrictions (number of parameters equated to zero)

Appendix IV. Farm Level Technical Efficiency Estimates

Farmers' technical efficiency estimtes in *Dinki*

Farm	Year 1994	1995	1997	1999
1	0.685	0.389	0.722	0.734
2	0.657	0.746	0.798	0.854
3	0.645	0.422	0.839	0.700
4	0.644	0.797	0.837	0.900
5	0.588	0.693	0.715	0.865
6	0.755	0.845	0.772	0.532
7	0.574	0.817	0.686	0.867
8	0.736	0.379	0.765	0.895
9	0.785	0.630	0.763	0.879
10	0.720	0.745	0.800	0.824
11	0.752	0.731	0.879	0.888
12	0.838	0.753	0.764	0.821
13	0.582	0.760	0.827	0.675
14	0.764	0.692	0.599	0.849
15	0.500	0.067	0.232	0.755
16	0.718	0.054	0.650	0.725
17	0.484	0.054	0.684	0.672

Farmers' technical efficiency estimates in *Koremargefia*

Farm	Year 1994	1995	1997	1999
1	0.875	0.748	0.899	0.838
2	0.480	0.601	0.839	0.766
3	0.849	0.822	0.813	0.818
4	0.888	0.867	0.884	0.869
5	0.799	0.819	0.900	0.731
6	0.840	0.706	0.825	0.658
7	0.889	0.894	0.889	0.799
8	0.858	0.815	0.881	0.866
9	0.877	0.828	0.717	0.668
10	0.663	0.648	0.793	0.845
11	0.920	0.887	0.921	0.710
12	0.814	0.768	0.897	0.713
13	0.858	0.783	0.799	0.752
14	0.699	0.393	0.716	0.636
15	0.859	0.773	0.862	0.790
16	0.393	0.248	0.524	0.675
17	0.862	0.820	0.908	0.884
18	0.523	0.475	0.823	0.719
19	0.653	0.600	0.893	0.735
20	0.795	0.278	0.115	0.647
21	0.884	0.812	0.828	0.855
22	0.509	0.593	0.793	0.668
23	0.750	0.723	0.701	0.600
24	0.528	0.542	0.830	0.756

Farmers' technical efficiency estimates in *Milki*

Farm	Year 1994	1995	1997	1999
1	0.111	0.250	0.448	0.105
2	0.052	0.312	0.155	0.106
3	0.130	0.303	0.570	0.155
4	0.436	0.123	0.325	0.248
5	0.999	0.641	0.179	0.113
6	0.282	0.146	0.181	0.192
7	0.118	0.696	0.361	0.327
8	0.566	0.115	0.120	0.134
9	0.751	0.311	0.095	0.222
10	0.074	0.446	0.804	0.266
11	0.205	0.127	0.909	0.095
12	0.413	0.410	0.409	0.399
13	0.849	0.339	0.282	0.246
14	0.294	0.456	0.599	0.095
15	0.977	0.358	0.215	0.096
16	0.571	0.544	0.323	0.430
17	0.444	0.567	0.293	0.389
18	0.826	0.484	0.115	0.607
19	0.607	0.772	0.117	0.303
20	0.307	0.448	0.205	0.425
21	0.076	0.436	0.468	0.283

Farmers' technial efficiency estimates in *Karafino*

Farm	Year 1994	19995	1997	1999
1	0.971	0.954	0.955	0.960
2	0.973	0.960	0.944	0.962
3	0.940	0.943	0.966	0.967
4	0.961	0.723	0.948	0.884
5	0.973	0.855	0.956	0.949
6	0.974	0.799	0.774	0.965
7	0.944	0.968	0.969	0.971
8	0.971	0.975	0.804	0.961
9	0.945	0.952	0.966	0.945
10	0.864	0.581	0.456	0.928
11	0.353	0.609	0.581	0.553
12	0.818	0.786	0.512	0.561
13	0.928	0.674	0.447	0.220
14	0.918	0.269	0.542	0.821

Appendix V Test for Selectivity Bias

```
+-------------------------------------------------------------------------+
| Dependent variable is binary, y=0 or y not equal 0                      |
| Ordinary    least squares regression Weighting variable = none          |
| Dep. var. = DUMMY    Mean=    .8033306899 , S.D.=    .3976378778        |
| Model size: Observations = 716, Parameters = 6,Deg.Fr.= 710             |
| Residuals:  Sum of squares= 196.4404559, Std.Dev.=  .39563              |
| Fit:        R-squared=  .013982, Adjusted R-squared = .01005            |
|                                                                         |
Model test: F[  5,    710] =    3.56,    Prob value =  .00336             |
|                                                                         |
Diagnostic: Log-L =-616.9922, Restricted(b=0) Log-L = -625.8700           |
|        LogAmemiyaPrCrt.=    -1.850, Akaike Info. Crt.= .988             |
+-------------------------------------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean ofX
Constant	.5347492610	.15082906	3.545	.0004	
AREA	.2608119118E-01	.18662537E-01	1.398	.1623	.24191294
LABOR	.2889216759E-01	.14722342E-01	1.962	.0497	4.4710288
AGE	.1731886646E-01	.34366641E-01	.504	.6143	3.8263744
SEX	.6306532191E-01	.31277458E-01	2.016	.0438	.84456780
EDUCATIO	.3654456002E-01	.24204921E-01	1.510	.1311	.37113402

Normal exit from iterations. Exit status=0.

```
+---------------------------------------------------+
| Binomial Probit Model                             |
| Maximum Likelihood Estimates                      |
| Dependent variable                  DUMMY         |
| Weighting variable                    ONE         |
| Number of observations                716         |
| Iterations completed                    4         |
| Log likelihood function         -616.6417         |
| Restricted log likelihood       -625.1411         |
| Chi-squared                      16.99891         |
| Degrees of freedom                      5         |
| Significance level            .4501867E-02        |
| Results retained for SELECTION model.             |
+---------------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	-.6975486963E-01	.54055012	-.129	.8973	
AREA	.9024034523E-01	.65766186E-01	1.372	.1700	.24191294
LABOR	.1032737279	.52989706E-01	1.949	.0513	4.4710288
AGE	.5908999057E-01	.12353501	.478	.6324	3.8263744
SEX	.2076563678	.10860229	1.912	.0559	.84456780
EDUCATIO	.1330833137	.89319923E-01	1.490	.1362	.37113402

APPendix V (cont'd)

```
Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.
              Predicted
------  ----------  +  -----
Actual      0    1  |  Total
------  ----------  +  -----
  0         0  172  |    172
  1         0  544  |    544
------  ----------  +  -----
Total       0  716  |    716
```

```
 --> select;lhs=OUTPUT;
     rhs=ONE,AREA,LABOR,FERT,AGE,SEX,EDUCATIO,OXB$
          +----------------------------------------------------+
          | Sample Selection Model                             |
          | Probit selection equation based on DUMMY           |
          | Selection rule is: Observations with DUMMY   =  1  |
          | Results of selection:                              |
          |                     Data points    Sum of weights  |
          | Data set                716            716.0       |
          | Selected sample         544            544.0       |
          +----------------------------------------------------+

+-----------------------------------------------------------------------+
| Sample Selection Model                                                |
| Two stage   least squares regression    Weighting variable = none     |
| Dep. var. = OUTPUT   Mean=    6.504899767    , S.D.=    .9147074752   |
| Model size: Observations =     1013, Parameters =   9, Deg.Fr.=   707 |
| Residuals:  Sum of squares= 690.1072663    , Std.Dev.=         .82907 |
| Fit:        R-squared=  .177668, Adjusted R-squared =          .17112 |
|             (Note:  Not using OLS.  R-squared is not bounded in [0,1] |
| Model test: F[  8,     707] =     27.11,     Prob value =      .00000 |
| Diagnostic: Log-L =  -1242.9777, Restricted(b=0) Log-L =   -1346.5746 |
|             LogAmemiyaPrCrt.=     -.366, Akaike Info. Crt.=     2.472 |
| Standard error corrected for selection.....     .88779                |
| Correlation of disturbance in regression                              |
| and Selection Criterion (Rho).............     -.56060                |
+-----------------------------------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	6.240886552	3.9176415	1.593	.1112	
AREA	.4327796564	.20954807	2.065	.0389	.26281321
LABOR	-.1637528986E-01	.23369913	-.070	.9441	4.5037523
FERT	.5861415865E-01	.13914696E-01	4.212	.0000	2.5659420
AGE	.1696600232E-02	.15017144	.011	.9910	3.8256434
SEX	.5697743057E-01	.49544795	.115	.9084	.85784798
EDUCATIO	.1682422901	.29272106	.575	.5655	.38302073
OXB	.2473418981	.52974375E-01	4.669	.0000	.49774425
LAMBDA	-.4976963206	5.3255275	-.093	.9255	.34016553

DECLARATION

The thesis is my own work, has not been presented for a degree in any other university and all sources of material used for the thesis have been duly acknowledged.

Declared by:

Awoke Tilahun

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July 11, 2001