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by

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Abstract

In an effort to boost agricultural productivity the Ethiopian government has embarked on implementing policy reforms since 1991. Assessing the performance of this sector after the introduction of these policies can help to evaluate the real impact of the reforms on agricultural productivity and to design future policy reforms or take corrective measures. In this paper we employ the stochastic frontier production function to examine technical, allocative and economic efficiency in crop production using farm level data from 1993/94 and 2000/01 production years in post-reform Ethiopia. In addition, we decompose the growth in agricultural production to examine the contributions of the changes in efficiency, technology and inputs to the total factor productivity (TFP) in agriculture. Results show that there are inefficiencies attributable to household and farm characteristics and the policy environment. There was a decline in TFP, allocative and economic efficiency during the period resulting in poor performance of the sub-sector and indicating an adverse impact of the reform. There was no significant change in technical efficiency.

Keywords: policy reforms; growth accounting; efficiency; frontier production function; Ethiopia
JEL Classification Numbers: C23; D13; D24; O13; Q12

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1. Introduction

The Ethiopian economy is dominated by agriculture, which accounts for over 50% of the GDP, 90% of export earnings, and 88% of the labour force (FAO, 1995). Peasant farming is by far the most dominant sub-sector, accounting for over 97% of the agricultural output. Nearly 80% of the peasant production is designed for home consumption and production of seed. Unlike the development in other countries, the smallholder's farm size has declined over time. The current national average farm size of the smallholders is about one hectare compared to about two hectares three decades ago (Afrint, 2003). Growing population, sectarian composition of the population and land ownership structure are factors causing the reverse development of the small farm sizes.

The performance of agriculture has been rather disappointing over the last three decades. Drought, inappropriate institutional and economic policy frameworks under the socialist system, low levels of public expenditure in agriculture, declining soil fertility, sub-economic holdings, limited use of modern inputs such as fertilizer and improved seeds, lack of education, and poor infrastructure are often blamed as causal factors for the poor performance of agriculture. On the other hand, the population grew at an annual rate of 3%. With fluctuating agricultural production levels leading to frequent annual negative growth rates, it has become difficult to feed the increasing number of people, leading to dependence on food aid (Afrint, 2003). If this problem of increasing food insecurity is to be resolved, production should keep pace with the population. The increase in agricultural production can be achieved either through expanding the cultivated area or through intensification, i.e., increasing productivity of cultivated land.

Although a combination of the two measures seems to be an appropriate solution to the food security problem, the choice set is limited for various reasons. For instance, there is small room for increasing the size of cultivated land. Thus, most of the production increase must come from increased productivity. There are two ways to increase productivity in agriculture. The first is through technological progress, which calls for investing in agricultural research and extension. The second is to increase technical efficiency in production. Moreover, increasing allocative efficiency can increase the net income that farmers can receive from the given level of input use (Bravo-Ureta and Pinheiro, 1997; Seyoum et al., 1998). However, a transformation of agriculture to a modern sector is a long-term solution to the problems of low productivity and population growth, while the improvement in production efficiency is only a short-term, partial solution and far from being optimal in the long run.

In an effort to raise production and productivity several economic policy reforms have been undertaken by the current Ethiopian government over the last decade. The economic reform program, which was initiated in 1991, took the form of a structural adjustment program under the auspices of the International Monetary Fund (IMF) and the World Bank. Some of the major policy reforms are the reorganization of wholesale trading corporations and other enterprises with a wide managerial autonomy; privatisation of all state-owned retail trade shops and stores; elimination of price controls of all products except prices of petroleum and petroleum products; and the abolition of administrative and bureaucratic bottlenecks associated with the registration and issuance of trade licenses, with a view to drastically simplify the provision of export and import trade licenses.

The major components of the policy reforms designed to assist agriculture include removal of price controls on agricultural commodities and allowance of private traders to work freely in the market; devaluation of the Ethiopian currency in 1993; introduction and then removal of fertilizer subsidies; abolition of forced delivery of grain to the government grain trading parastatal at predetermined low prices; and privatisation of large state-owned farms (MeDAC, 1993). There is also establishment of export promotion institutions designed to encourage foreign trade.

The reforms had different implications for farm households. For example, the devaluation of the Ethiopian currency encouraged production and export of coffee and raised income to exporters, while it raised fertilizer prices. The increased fertilizer prices resulted in a fall in consumption of fertilizer following the reform. Removal of fertilizer subsidies raised the fertilizer prices further. The overall effect was a major reduction in the consumption of fertilizer and a decline in productivity of land measured as the yield per hectare of land.

Reports on the actual performance of the Ethiopian economy in general and the agricultural sector in particular are mixed. Afrint (2003) and MEDaC (1999) report both negative and positive growth rates between 1992/93 and 2001/01. However, these studies report the percentage increase in national GDP or for a particular sector. These studies lack analyses of the causes of the increases or decreases in performance of a particular sector. The only known cause of the production decrease is drought. Yet, production fluctuates even during non-drought years and in areas where drought incidence is minimal. In order to evaluate the effects of current policy reforms for corrective measures, it is necessary to identify the factors causing changes in the performance of agriculture and the direction of their effects. Yet such empirical studies are lacking in Ethiopia. The few studies that are available were either done prior to some of the relevant policy reforms for agriculture (e.g. removal of fertilizer subsidies) or they were not appropriate to evaluate the effects of such policy reforms. This paper tries to bridge the gap using data covering both the period before and after the reforms. In particular, it analyses the effect of the removal of fertilizer subsidy on agricultural production and productivity.

The objective of this study is to analyse the technical and allocative efficiency of the farmers. In doing so, we identify factors explaining these efficiency differences and account for agricultural production growth between 1993/94 and 2000/01 using the growth accounting method. Technical efficiency (TE) is defined as the ability of a farm to achieve maximum possible output with available resources, given the current best practice technology, while allocative efficiency (AE) refers to the ability to contrive an optimal allocation of inputs given resources. In growth accounting the changes in output are broken down into its underlying components, namely changes in input use and changes in productivity growth. Analysis of growth accounting and knowledge about the sources of output growth can help policy makers to take appropriate measures in the design of a pro-growth economic policy.

The presence of inefficiency means that output can be increased without requiring additional conventional inputs and without the need for new technology other than applying the existing best practiced farming technology. Thus, empirical measures of efficiency are necessary to determine the magnitude of the gains that could be obtained by improving performance in agricultural production with a given technology. This paper is a first comprehensive evaluation of the impacts of economic reforms on the performance of agriculture in Ethiopia. It aims at identification of factors causing changes in performance of agriculture. We suggest changes in the design of new policy measures to enhance positive factors to prevent food insecurity in the country by promoting productivity of local production.

The rest of the paper is organized as follows: In section two we present an overview of economic policy reforms in Ethiopia. Section three describes the performance of the economy after the reforms. In section four we present a review of the existing literature. The methodological framework of the study is presented in section five. In section six we describe the study area and data collection. Section seven presents estimation methods and discussion of the results. The paper concludes with section eight.

2. Overview of Economic Policy Reforms

In line with the principles of a planned economy, the former Ethiopian government nationalized all private and commercial farms; limited private investment in the agricultural sector; forced the villagization of peasants; established involuntary producers' associations and service cooperatives, controlled agricultural markets; established a government parastatal which forced farmers to deliver a certain share of their outputs in the form of quota at very low prices; banned private traders from taking part in grain trading and also restricted the free movement of grain within the country both by producers and traders. For reviews of the planned economy in past see Aredo (1990).

After the overthrow of the socialist government (Derg) in 1991, the current government of Ethiopia, in collaboration with the international financial organizations, has taken steps to implement economic policy reforms to enhance economic development. Consistent with the principles of a free market economy, measures have been taken which reduce the role of the public sector in agriculture and other productive sectors through rationalization and divestiture of parastatals[1]. These measures include devaluation of exchange rate in 1993 from Birr 2.07 to Birr 5.00 against one US $, removal of fertilizer subsidies and pan-territorial pricing system in 1997; involvement of private traders in the supply of fertilizers to farmers; abolition of price controls on agricultural commodities (pan-territorial pricing); and privatisation of public companies. Cooperative farms dismantled completely with the fall of the Derg regime and the number of state owned and managed farms has been reduced. All taxes and subsidies on exports were eliminated and state exporting enterprises are required to participate competitively with private enterprises. This paved the way for greater competition including in coffee export which had been controlled by the state-owned monopoly, the Ethiopian Coffee Marketing Corporation (ECMC).

[1] See Aredo (1990) for the complete review of rural policy reforms in Ethiopia.

To facilitate external trade several domestic support institutions were also involved in the implementation of the reform policies. These support institutions, mainly the Ethiopian Export Promotion Agency, are engaged in the provision of information on international markets, training, and conducting studies of exportable products. There are also policy reform measures in the livestock sub-sector of agriculture.

Land, fertilizer and seed are the main components of agricultural policy in both the pre- and post-reform periods. Land in Ethiopia is owned by the state and farmers have only user right (usufruct) to land. Every form of transfer of land, including vertically between generations or horizontally among the farmers, is prohibited by law. Farmers have no right to sell their plots, but can enter into short-term leasing or sharecropping agreements.

With the removal of fertilizer subsidies in 1997 a new fertilizer distribution policy was introduced. Private traders were allowed to engage in fertilizer supply business alongside the cooperatives and the state. Improved seeds are provided together with fertilizer on credit basis, whereas consultation and advisory services (extension services) are provided by the Ministry of Agriculture through Participatory Agricultural Demonstration and Extension system (PADETES). While farmers can seek advice from agricultural office workers assigned by the Ministry of Agriculture, full consultation and advisory services are provided only if the household is selected to participate in the PADETES for demonstrating the extension package. Participant farmers are expected to allocate 0.25 to 0.50 hectares of land for the demonstration and pay a 25% to 50% down payment on the input package (mainly fertilizer and improved seeds) at the time of planting with the rest due after harvest. Unlike other farmers who get fertilizer and seeds on their own initiative at full cost, farmers selected to participate in PADETES are provided with package of inputs by government agricultural offices. These farmers have little influence in the way the PADETES is organized or the package is designed as far as the plots allocated for demonstration are concerned.

3. Performance of the Economy after the Introduction of Policy Reforms

Assessments on the performance of the economy after the implementation of the policy reforms in 1990s are mixed. Afrint (2003) reported that real GDP grew on average by nearly 6% percent between 1992/93 and 2000/2001. This is largely due to the growth in the industrial and service sectors that recovered after experiencing a decline in the previous years as a result of unfavourable economic policies. Owing mainly to the strong recovery from a very low base or negative growth rates (-3.7%) in the previous year, the growth rate was 12% in 1992/93. Growth rates were 10.6% and 9% for 1995/96 and 2000/01, respectively mainly because of the favourable weather conditions in these years. But the growth rate fell to –1.2% in 1997/98 because of the bad weather conditions which reduced agricultural production.

Performance of agriculture depends largely on rainfall which means that rainfall is a major factor influencing the performance of the Ethiopian economy even in the face of favourable economic policy. There is a lack of resources and irrigation technology to compensate for low rainfall in drought periods.

Although increased use of fertilizer and learning by doing has raised output in areas with potential for more productive growth, productivity has declined in less productive areas. The decline in productivity growth in the latter case is largely due to decreased and non-optimal size of holdings and environmental degradation of land.

As a result of currency devaluation, fertilizer prices increased dramatically in 1993 and this caused a decline in fertilizer consumption in the following years. The emerged situation forced the government to introduce fertilizer subsidies. The subsidies were later reduced and finally eliminated altogether in 1997. The subsidy amounted to 15%, 20%, 30%, 20% and 0% of the fertilizer prices in 1993, 1994, 1995, 1996 and 1997, respectively. The complete removal of the subsidy resulted in a persistent low level of fertilizer usage in farming and subsequent productivity decline.

In recent years rapid population growth, combined with lack of agricultural development has brought far-reaching changes in the living situation of the rural population in general and farmers in particular. Continuous cultivation of lands without measures to restore soil fertility and soil erosion has led to a high degree of land degradation which, coupled with frequent droughts, has resulted in increasing food insecurity and risk of hunger. Land fragmentation is another factor contributing to low levels of production. It is therefore clear that the reforms have not been successful in reducing the widespread poverty in the country.

Actual use of fertilizer remained low despite the efforts to increase its utilization. Fertilizer consumption reached a record level of 297,907 tons in 2000 and then declined thereafter (Appendix A). Distribution of fertilizer has not been optimal due to delays in distribution caused by late import, transportation problems, loan repayment difficulties, and lack of credit availability. Farmers who failed to repay their previous fertilizer credit faced fines including imprisonment. One should take into account the timeliness of the use of fertilizers, and not only the amount used while assessing its impact on productivity of farms. Even with the use of fertilizers, productivity might be low in some areas due to drought and the highly degraded soils of the highlands.

The majority of farmers in Ethiopia do not use improved seeds. Seed multiplication system is poor and is dominated by a single parastatal, the Ethiopian seed enterprise. There has not been a significant increasing trend in seed production in Ethiopia since 1991 (Appendix A)

Although the share of small holders from the total of farms using improved seeds has increased after the reform, the total sale of improved seeds has fallen since the reform. The quality of improved seed in Ethiopia is low due to low genetic quality, limited genetic potential and/or long period of repeated use, and inadequate storage facilities. There is room for increased knowledge in the optimal use of modern inputs of fertilizer, pesticide, improved seed and irrigation in Ethiopian farming to improve productivity growth of the agricultural sector.

At the national level, the yield levels of cereals, pulses and oil seed have stagnated or even tended to decline in some cases. Among the major food crops, only maize yields have shown some improvement (Afrint, 2003). This led to the increase in maize share (Appendix A). Farm income and labour productivity of agriculture is falling mainly because of land fragmentation, and also due to negative consequences of frequent changes in agricultural policy.

Poverty has remained widespread and farmers became more and more vulnerable to famine due to natural factors. A sizable proportion of farm community are dependent on food aid every year. Agriculture has a strategic importance in the fight against poverty and famine and ensuring food self-sufficiency. Because of its importance as a source of livelihood for the majority of population, policy makers have focused on agricultural development programmes. Therefore, improving agricultural productivity enables the country to address the problems of poverty and food insecurity, which are two of the most pressing issues in the country today.

4. A Review of the Literature

Literature on the study of various aspects of production, productivity, and growth accounting are enormous and unevenly distributed. However, there are very few such studies in Ethiopia. No attempt is made to exhaust all the available literature in this review. The focus is on a brief review of studies relevant to the current one.

The study of efficiency in production using the stochastic frontier dates back to Aigner et al. (1977) and Meeusen and van den Broeck (1977). Since then these models have gone through various modifications and developments and have been applied to both agriculture and other sectors mostly using cross-sectional data. Recently panel data have proven to be more useful in this regard. Thiam et al. (2001), Lovell (1995) and Battese (1992) provide review of technical efficiency studies applied to developing country agriculture.[2] Both panel and cross-sectional data have been used to assess components of economic efficiency (EE) including technical efficiency (TE), allocative efficiency (AE), elasticity of production, and factors explaining inefficiency. Panel data are used to study technical change, efficiency change and growth accounting. Some of the studies on technical efficiency and related subjects in agriculture using panel data include Abdulahi and Eberlin (2001), Heshmati (1998, 1994a, 1994b), Heshmati et al. (1995), Wu (1995), Kumbhakar and Heshmati (1995), Battese and Tessema (1993), Kumbhakar (1993), Battese and Coelli (1992), and Lin (1992).

Lin (1992) analysed the impacts of rural reforms on the growth of agricultural production. Using provincial level panel data from China he decomposes growth in agricultural production into increases in input, changes in efficiency, technical progress and unexplained residual components. He concluded that agricultural reforms in China have contributed to agricultural productivity growth. Wu ((1995) used panel

[2] For a recent survey on measurement of performance in manufacturing and services see Heshmati (2003).

data to examine total factor productivity growth, technological progress and technical efficiency in post reform China and made comparisons among regions as well as among different sub-sectors.

Bravo-Ureta and Pinheiro (1997) use farm level data to estimate TE, AE and EE in Dominican Republic. They found that age, education, contract agreement with agribusiness enterprises, participation in agrarian reform program, farm size and family size influence efficiency of farms. Liu and Zhuang (2000) use farm level data from China and conclude that there are significant efficiency differences among farms and provinces and these inefficiencies are determined by nutritional intake, education and age. Ali and Chaudhry (1990) examined TE, and AE of different regions in Pakistan using aggregate crop output and stochastic frontier approach. They found significant technical and allocative inefficiencies among farmers. These and many other studies suggest that farmers in developing country agriculture fail to exploit fully the potential of a technology and/or make allocative errors in input usage. These result in a wide variation in yields, usually reflecting a corresponding variation in the management capacity of the farmers.

There are very few studies on farm efficiency in Ethiopia. Studies by Gavian and Ehui (1999), Asfaw and Admassie (1996) and Seyoum et al. (1998) are the only efficiency studies according to literature search on agricultural efficiency studies in Ethiopia. Asfaw and Admassie (1996) studied efficiency and factors related to TE and AE for the Ethiopian smallholders. Seyoum et al. (1998) investigated the technical efficiency of two samples of maize producers in eastern Ethiopia, with one sample comprising farmers embraced in Sasakawa-global 2000 (SG 2000) extension project and the other sample comprising farmers outside this program[3]. They used stochastic frontier production function and related the estimated technical inefficiencies to age, education, and time spent with extension advisors in assisting farmers. They used cross-sectional data and a Cobb-Douglas functional form. They found that farmers outside the project are less efficient than those enrolled in the project.

Gavian and Ehui (1999) studied the production efficiency of alternative land tenure contracts in Ethiopia using cross-sectional production data from 477 plots in the Ethiopian highlands. They used interspatial measure of total factor productivity, based on Divisia Index as a measure of differences in TE among plots of different land contracts related to land held under formal contract with the Ethiopian

[3] SG 2000 program is an agricultural initiative of two-nongovernmental organizations-Sasakawa Africa Association (SSA) and Global 2000 program of the Carter Centre.

government[4]. Their finding is that although the informally contracted lands are farmed 10-16% less efficiently, the analysis indicates that such informally contracted lands receive more inputs than the formally contracted lands. Thus they attributed the gaps in total factor productivity to the inferior quality of inputs (or lack of inputs in applying them) rather than a lack of incentives to allocate inputs - thus finding no evidence to support the hypothesis that land tenure is a constraint to agricultural productivity in Ethiopia.

Apparently, the study by Asfaw and Admassie (1996) doesn't throw much light on the performance of the reform especially the removal of fertilizer subsidies which took place in 1997. Second this study doesn't employ growth decomposition methods like growth accounting. The study by Seyoum et al. (1998) is aimed at maize productivity and doesn't represent aggregate crop productivity. Moreover it targets those farmers participating in the extension project and is designed to evaluate the impact of a certain project, and this is not representative of the whole crop production. On the other hand the study by Gavian and Ehui (1999) is aimed at examining the impact of land tenure on productivity of agriculture. It is also a non-parametric approach in which it is difficult to test the results and attribute the inefficiencies to specific factors determining inefficiency.

A shortcoming common to all the three studies is that they used cross-sectional data. In a cross-sectional case it is difficult to characterize the temporal patterns of inefficiency in terms of its time-variance nature and to separate the persistent inefficiency from time-varying inefficiency. Panel data enable us to avoid these shortcomings and it has the advantages by allowing computation of growth and its decomposition into underlying components and their association with different contributing factors. Despite having only two yearly fully overlapping observations our study is an important addition to the literature evaluating effects of reforms in general and to the evaluation of agriculture in Ethiopia in particular.

[4] The different land tenure contracts other than the formal contract with the government are fixed rent contract, sharecropping and borrowed land.

5. Methodological Framework

5.1 Technical Efficiency

In this study we employ a stochastic frontier production function first proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977) and then applied by Battese and Coelli (1992, 1995), Heshmati et al. (1995), Heshmati (1998), Bravo-ureta and Pinheiro (1997), Abdulai and Eberlin (2001) and Bakhshoodeh and Thomson (2001) and many others. The concept of a frontier defines the existence of an unobservable function, the production frontier which corresponds to the set of maximum attainable output levels for a given combination of inputs. To fix the idea consider the stochastic frontier production function with panel data:

(1) $$Y_{it} = f(X_{it};\theta)\exp(\varepsilon_{it})$$

such that $\varepsilon_{it} = v_{it} - u_{it}$ and where Y_{it} denotes an aggregate output index ith farm (i=1, 2, …N) observed in period *t*; $f(.)$ represents the production function technology common to all farms; X_{it} is a vector of *J* inputs; and θ is a vector of unknown parameters to be estimated.

The error term, ε_{it}, is composed of two components, v_{it} and u_{it}. The component v_{it} is an idiosyncratic error term similar with that in traditional regression model, while u_{it} is a nonnegative random variable, to account for the existence of technical inefficiency in production. The subtraction of the non-negative random variable, u_{it}, from the random error, v_{it}, implies that the logarithm of production is smaller than it would otherwise be if technical inefficiency did not exist (Battese and Coelli, 1992; Battese and Tessema, 1993). The $v_{it}'s$ are assumed to be independently and identically distributed as a normal random variable with mean zero and variance, σ_v^2, independent of the u_{it}. In this study the $u_{it}'s$ are assumed to follow a half normal distribution (*u*~ $N[0,\sigma_u^2]$) as typically done in empirical applications (Bravo-Ureta and Pinheiro, 1997).

The inefficiency effect, u_{it}, is assumed to consist of both unobserved systematic effects which vary across farms but which are constant over time for each farm (captureing the effects of fixed capital, soil quality, etc.) and the component which represents factors under the control of the farm. u_{it}, then, contains inefficiency free of noise effects but not farm specific fixed effects. Thus, u_{it} can be defined as:

$$(2) \qquad u_{it} = \eta_{it} u_i = \{\exp[-\eta(t-T)]\} u_i$$

where *T* is the last period of the data. According to equation (2) u_{it} is a product of two parts: time varying (η_{it}) and time invariant (u_i) parts (Battese and Coelli, 1992). The relation above implies that if the parameter η is positive then the non-negative farm effects of the *i*th farm, u_{it}, decline exponentially to its minimum value, u_i, at the last period, *T*, of the panel. In this case, the farms would be increasing their technical efficiency of production over time. If, however, η was zero, then the firm effects associated with *TE* of production would be constant over time (i.e., farms never improve in their *TE*). The estimation of the parameter η and testing for its significance is obviously of basic interest in this study.

It should be noted that time isincluded in the production function as an explanatory variable so that ε_{it} does not include any time-specific component. The statistical noise, v_{it}, represents factors that can not be controlled by the farm including weather, diseases, pests, purchase of seeds with low viability for germination, measurement errors in the dependent variable, etc.

The production model can be estimated by maximum likelihood (MLE) method which yields consistent estimates for the unknown parameters of $\theta, \lambda, \sigma^2$, where θ is as defined above; $\lambda = \sigma_u / \sigma_V$; and $\sigma^2 = \sigma_u^2 + \sigma_V^2$. Given the distributional assumptions of v_{it} and u_{it} and the assumption that these two components are independent, inferences about the technical inefficiency of individual farmers can be made by considering the conditional distribution of *u* given the fitted values of ε and the respective parameters (Jondrow et al., 1982). Thus, the conditional mean of *u* given ε is defined by:

$$(3) \qquad E(u_{it} \mid \varepsilon_{it}) = \sigma_*^2 \left[f^*(\varepsilon_{it}\lambda/\sigma)/(1-F^*(\varepsilon_{it}\lambda/\sigma)) - \varepsilon_{it}\lambda/\sigma \right]$$

where $\sigma_*^2 = \sigma_u^2 \sigma_V^2 / \sigma^2$, f^* is the standard normal density function and F^* is the distribution function, both functions being evaluated at $\lambda\varepsilon / \sigma$. By replacing ε, σ^*, and λ by their respective estimates in equations (1) and (3), we derive the estimates for *v* and *u*. Subtracting *v* from both sides of equation (1) yields the stochastic production frontier. Finally the technical efficiency for the *i*th farm in period *t* is derived from:

(4) $$TE_{it} = \exp(-u_{it}).$$

5.2 Economic Efficiency

Give the production frontier in equation (1), minimizing the cost of producing a given level of output is equivalent to maximizing output given a budget constraint. Assuming that the frontier is self-dual (e.g., *C-D* production function) the cost minimization problem is given by:

(5) Min $C_{it} = \sum_{J=1}^{K} p_{jt} X_{jit}$, j = 1, 2, …, k inputs

subject to the constraint $F(X_{it};\theta) \geq Y_{it}$, where C_{it} is total cost of production incurred by farm *i* in period t; P_{it} is price of input X_j in period *t*; θ is a vector of parameters to be estimated; and Y_{it} is a given level of output. Solving the first order conditions of the Lagrangean of the above minimization problem gives us the following output-conditional input demand functions:

(6) $$X_{jit} \mid Y_{it} = X_{jit} \mid Y_{it}(P, y; \propto)$$

where *P* is a vector of input prices, and α is vector of parameters to be estimated. Substituting (6) into (5) gives us the indirect cost function or the cost frontier given by:

(7) $$C = c(P, y; \pi)$$

where π is a vector of parameters in the cost frontier.[5] Applying Shepherd's Lemma to equation (7), the system of minimum-cost input demand equations can be obtained by differentiating the cost frontier with respect to each of the input prices. Thus, the demand equation for the *j*th input (X_{jit}) is given by:

$$(8) \qquad \partial C / \partial P_{jt} = X_{jit} = f\left(P, Y_{it;} \alpha\right).$$

It is to be noted that (6) and (8) are basically the same. By substituting input prices and the given level of output quantity into (8), we get the economically efficient input quantities, X_{jite}.

To account for the fact that the total deviation from the frontier is composed of the inefficiency effect, (u_{it}), and the statistical noise, (v_{it}), Schmidt (1985-86) suggests to use the farm's observed output adjusted for the statistical noise contained in v_{it}. Bravo-Ureta and Rieger (1990) and Bravo-Ureta and Pinheiro (1997) used this adjustment before deriving different efficiency indices. The noise-adjusted output is obtained by subtracting v_{it} from both sides of equation (1), which yields the stochastic frontier:

$$(9) \qquad Y_{it}^{*} = Y_{it} - \hat{v}_{it} = \hat{Y}_{it} - \hat{u}_{it}$$

where $\hat{Y}_{it}$ is the predicted value of Y_{it} and $\hat{v}_{it}$ or $\hat{u}_{it}$ are the estimated values of v_{it} and u_{it}, respectively. Equation (9) is used to derive the cost frontier in (7). The overall estimation procedure of various efficiency component indices has the following steps:

(a) Estimate the technical inefficiency effect, u_{it}, and the idiosyncratic error term, v_{it} from equation (1) using MLE for each farm;

(b) Calculate TE_{it};

(c) Use $\hat{v}_{it}$ or $\hat{u}_{it}$ to derive the stochastic cost frontier in equation (7) and derive the economically efficient input quantities, X_{ijt}, from equation (8);

(d) Calculate economic efficiency for each observation as:

[5] π and α are functions of the parameters of the production function, θ.

(10) $$EE_{it} = \left(\sum_{j=1}^{k} p_{jt} X_{ijt} \right) \Bigg/ \left(\sum_{j=1}^{k} p_{jt} X_{ijt} \right)$$

where $\sum_{j=1}^{k} p_{jt} X_{ijt}$ is the cost of economically efficient input combination associated with the farm's observed output and $\sum_{j=1}^{k} p_{jt} X_{ijt}$ is the cost of actual or observed input bundle.

(e) Calculate allocative efficiency of farm *i* in period *t* as:

(11) $$AE_{it} = EE_{it} / TE_{it} \, .$$

Having calculated the different efficiency indices, the next step is to identify and to examine factors causing the inefficiency to happen since the main objective of identifying a problem is to find the cause of the problem and finally find a solution to the problem. Various factors have previously in applied efficiency analysis been identified to explain the inefficiencies in agriculture. Identifying the sources of inefficiencies is specific to the individual production environment and could be accomplished by investigating the relationship between farm/farmer characteristics and the computed *TE* and *AE* indices. Since *EE* is a combination of *TE* and *AE*, the association between these factors can be studied similarly. Following the approach known as "second-step" estimation (Bravo-Ureta and Pinheiro (1997); Hazarika and Alwang (2003); Parikh et al. (1995); Wang et al. (1996); Bakhshoodeh and Thomson (2001)) we estimate the model specified as:

(12) $$EFF_{it} = f(Z_{it}; \gamma)$$

where EFF_{it} is alternatively, *TE*, *AE*, *EE*; and *Z* is a vector of farm and farmer characteristics; and γ is a vector of parameters to be estimated.

Liu and Zhuang (2000) argue that the two-stage procedure proposed here and the single- step estimation used by Battese and Coelli (1995) are flawed because unless the efficiency variables are independent of the input variables, the production function estimates will be biased and inconsistent. They say this will further bias the estimates for coefficients associated with the efficiency variables and suggest a third alternative in which the efficiency variables themselves are to be built into the systematic part of the stochastic frontier production function as long as they are observable, with the one-sided error component containing only the latent efficiency variables. However, the third alternative is not without a drawback. For one thing, inclusion of many efficiency variables into the frontier production function along with conventional inputs means that we would have to estimate a large number of parameters and our estimates might suffer from the problem of multicollinearity. Parameters of the deterministic part of the production function and estimated farm-specific efficiency scores in the single step procedure are very sensitive to the inclusion or exclusion of individual inefficiency determinants variables. Second application of some conventional inputs might be endogenous to some of the efficiency variables built into the systematic part of the frontier production function. In this case, the impact of these efficiency variables on production might be over- or underestimated in equation (1).

5.3 Growth Accounting

Policy measures take more than estimating the efficiency indices and identifying the sources of inefficiencies. Since efficiency is only one source of productivity, identifying other sources of output change allows the targeting of the most important sources of output. Thus, having estimated the efficiency indices and identified their sources, growth accounting enables us to quantify their real impacts on productivity growth of the efficiency changes and other sources. This calls for accounting for the growth of agricultural production, which consists of the change in technical efficiency, as one component. The objective of this section is to examine total factor productivity growth, technological progress/regress and technical efficiency change in post reform agriculture of Ethiopia.

We employ a frontier production function approach, equation (1). In logarithmic form it is written as:

$$\ln Y_{it} = \beta_0 + \beta_t D_t + \sum_{j=1}^{k} \beta_j \ln X_{ijt} + v_{it} - u_{it} \qquad (13)$$

where β_j (j=1,2,…,k) are the elasticities of output with respect changes in input *j*; β_0 is the intercept; β_t is the rate of technological progress or neutral shift in the output over time; $\ln Y_{it}$ and $\ln X_{jit}$ are the levels of output and inputs of the *i*th farm in period *t*; and v_{it} and u_{it} are as described previously. As specified earlier, the degree of technical efficiency is given by:

$$(14) \qquad TE_{it} = Y_{it} / Y_{it}^{F} = e^{-u_{it}}$$

where Y_{it} is the observed or actual level of output for farm *i* in period *t* and Y_{it}^{F} is in the sample frontier (maximum) output. Manipulating (13) and (14) gives the growth accounting equation:

$$(15) \qquad \dot{Y}_{it} = \beta_t + \sum_{j=1}^{k} \beta_j \dot{X}_{ijt} + \dot{TE}_{it}$$

where the over-dots indicate percentage changes (with respect to time here). According to equation (15) growth of output during a certain period can be decomposed into three components: technological progress (β_t); growth rate of inputs $\left(\sum_{j=1}^{k} \beta_j \dot{X}_{ijt}\right)$; and a change in technical efficiency $\left(\dot{TE}_{it}\right)$. In this paper we employ a time-varying and firm-specific technical efficiency. From equation (15) the growth rate of total factor productivity (*TFP*) can be calculated as:

$$(16) \qquad T\dot{F}P = \beta_t + \dot{TE}_{it}$$

Cornwell et al. (1990) propose an approach which specifies the inefficiency effect (u_{it}) as a quadratic function of time only. This approach was applied by Wu (1995). In this paper we use the residual left over after accounting for technological progress and input growth as a measure of technical efficiency change for growth accounting purpose. This measure of technical efficiency change includes both the explained and unexplained part of the *TE* change. The overall growth accounting procedure has the following steps:

(a) Calculate the percentage growth in output $(\dot{Y}_{it})$ from observed data between two time periods;

(b) Calculate the weighted growth rate of inputs $\left(\sum_{j=1}^{k} \beta_j \dot{X}_{ijt}\right)$ using the $\beta's$ from equation (1), technological progress (β_t) as shown in equation (15) and the change in technical efficiency $\left(\dot{TE}_{it}\right)$ as a residual; and finally

(c) Calculate $T\dot{F}P$ as the sum of β_t and $\dot{TE}_{it}$ components.

6. The Data and the Study Area

The data set used in this study comes from a sample survey of small farms located in the two peasant associations (administrative units) of the Ada-Liben district of the central highlands of Ethiopia. The surveys were conducted in 1993/94 and 2000/01.

The specific location of the area is 20 km from Debre Zeit, the capital of the district. Debre Zeit is located near the main highway only 50 km from Addis Ababa (Fifinne). The area has good market access, high agricultural potential and it is a major teff[6] producing area. Teff is both the main food crop and cash crop in the area and (very much) preferred among the Ethiopian consumers. In addition to its good market access, the area enjoys one of the highest rainfalls in the country which makes it one of the least prone areas to drought. These make it an appropriate for this kind of study because of the relatively low probability of random shock resulting from drought. Unlike drought affected areas, the decline in productivity which can be attributed to random shock is minimal, making it possible to explain much of the yield variation in terms of other non-random variables related to environmental, farm and farmer characteristics. In addition, the two survey years are normal years in terms of rainfall.

The production system, like in many other parts of the country, is an integrated crop-livestock system where oxen as the only source provide traction power for land cultivation and threshing. Crop residues are used as main sources of animal fodder.

The land operated by the farmers is owned by the state with only use right granted to the farmers. Land holding is egalitarian, resulting from the land reform of 1975 and several land redistributions that followed. Land distribution was based on the size of family. Land redistribution has ceased, except in a few regions, since the current government took over power. Because of this, young-headed households are mostly landless, except the informally contracted lands such as fixed contracts, sharecropping and, in some cases, some patches of land are shared voluntarily with their parents. The informal contract pattern is shifting from sharecropping to fixed rent contract. Only a few households reported that they had cultivated land under sharecropping contract.

[6] Teff (Eragrostis tef.) is a staple cereal crop in Ethiopia

Oxen ownership is important for cultivation and a limiting factor to the capacity of a household to cultivate land. Thus households who rent out their land are likely to have no oxen or not enough oxen power, and households renting in lands are likely to have ox(en) power in excess or better means to rent in oxen. Table 1 presents oxen ownership status of the sample farmers. As we can see from the table oxen ownership has increased in 2000/01. Oxen are used in pairs. Households with only one ox exchange oxen with another household having an odd number of oxen. Labour is imported to the area especially during peak seasons. But skilled labour is exported to urban areas. The opportunities for off-farm work are limited for unskilled labour.

The main crops grown in the area are teff, wheat, maize, barley, chickpea, beans, and lentil (see Table 2). The use of modern inputs in the area is limited. Most of the households use fertilizer only for production of teff, wheat and barely and sometimes maize, with the rate of application usually falling far below the recommended rates. However, the use of fertilizer is concentrated in production of teff and wheat followed by barely. The use of improved seeds is also very limited. For example in 2000/01 survey only 11.3% of the surveyed households reported that they used improved seeds. However, there is increasing trend in input use between the two years.

Fertilizer is provided on credit basis to farmers at 12% interest rate. To be eligible for fertilizer credit, the farmer must have repaid the previous credit completely. Farmers fail to repay their loans when yield is low and this risks them to be denied the credit the following year, in addition to the fine for failing to do so. Fertilizer credit is the only formal credit available to farmers. The prevalence of failure to repay fertilizer loans and the fact that sometimes farmers can't afford to buy fertilizer for fear that they might not be able to pay has left fertilizer suppliers with huge stock of fertilizers. This is a real threat to functioning of the fertilizer markets in the area.

There have been frequent delays in fertilizer provision with farmers failing to meet the recommended date of application. There are two main reasons for fertilizer rates to be below optimal. First, credit is either rationed or there is problem of indivisibility in fertilizer supply. Suppliers have a certain package for a farmer which is appropriate for handling. For instance, 100 kg of DAP plus 50kg of UREA and only the integer multiples of this package is supplied to a farmer in the area. Thus, farmers who need less than this amount can't get fertilizer on credit. If the farmer can't afford this package, he/she has to find another means to finance it. Second, even if farmers need all offers, they may not afford to repay and have to buy less. While this could be rational from the standpoint of suppliers, this “take it or leave it” kind of provision doesn’t fit the needs of small farmers in the face of absence of cash credit.

Land degradation is one of the main agricultural problems in the area. A study by Shiferaw and Holden (1999) indicate that soil productivity in the area is decreasing at a higher rate than what farmers perceive.

Data was collected as part of two surveys conducted in 1993/1994 and 2000/2001. The data sets cover the same 80 households observed during both survey years, 40 households were randomly selected in 1993/94 from each of the two peasant associations. A standard survey questionnaire was used. The data set is comprehensive, including household characteristics, farm characteristics, production data, consumption data, wealth, marketing activities, market information, income data, attitudes towards and perception about risk, willingness to pay for soil conservation, and subjective discount rate.

The 2000/2001 data collection was conducted under the strict supervision of one of the authors and other research personnel ensuring the overall quality of the data and minimizing measured errors. The two peasant associations do not have basic differences in terms of weather, and soil fertility. The difference, though, is that one (Hidi) is closer to the market area than the other (Hora) and may have better proximity to input supply and off-farm income opportunities. These two associations are found to be good representative of farming conditions within the region in view of their locations. The data collection was limited to two associations due to limited resource. Out of the sample of 80 households during the two survey years, 19 households were dropped because of incomplete data and outlier observations probably due to measurement errors in the data.

Table 3 presents descriptive statistics for variables used to estimate production function and subsequent estimation steps. The dependent variable is aggregate crop values the variation in which is explained by six inputs. The inputs are labour, fertilizer, operated land, oxen days, cash expenditure and seeds. Definition of these variables and other variables characterising farms, farmers and their households are given in Appendix B.

7. Estimation and Results

7.1 Production model parameter estimates

The Cobb-Douglass (C-D) functional form is used to specify the stochastic frontier production function in (1). This is the basis for deriving the cost frontier in (7), and the related efficiency measures.[7] Although the C-D production function imposes restrictions on the structure of the technology, it is used because the methodology employed requires that the production function be self-dual. It should also be noted that this functional form has been widely used in farm efficiency analysis.[8] The C-D form is also easy to interpret and holds the promise of more statistically efficient parameter estimates (Liu and Zhuang, 2000). Furthermore, since there are a large number of inputs, by using a simple functional form, the risk of multicollinearity due to addition of interactions and square of the input variables is avoided. The empirical specification of (1) is given by:

$$\text{(17)} \qquad \ln Y_{it} = \beta_0 + \beta_t D_t + \sum_{j=1}^{k} \beta_j \ln X_{ijt} + \varepsilon_{it} \ ,$$

where $\ln Y_{it}$ is logarithm of aggregate value of crop output for farm i,(i=1,…,61) in period *t* (t=1,2); and $\ln X_{jit}$ is logarithm of *j* vector of inputs including fertilizer, cash expenditure, seed, labour, oxen days, all values in 2000/01 constant prices and operated land size measured in 'kert'. The choice of the conventional input categories is similar to previous studies of efficiency in developing countries. In addition to the six conventional inputs, a time dummy, D_t, is included as an additional regressor to capture shift due to technological progress or regress in the production over time. The parameter estimates are presented in Table 4.

[7] We tried the translog functional form but only two out of about 35 terms were significant at 10%. More over, the generalized Cobb-Douglass functional form suffered from multicollinearity. The use of single equation model is justified assuming that farmers maximize expected profit (Bravo-Ureta and Rieger,1990).

[8] This statement is supported by the reviews of the empirical literature written by Battese (1992). Recent works also suggest that the choice of functional form might not have a significant impact on measured efficiency levels (Ahmad and Bravo-Ureta, 1996).

The appropriate method for obtaining consistent estimates of (17) depends on the structure of the composed error term, ε_{it}. If ε_{it} is spherical disturbance, the covariance estimator of ordinary least squares (OLS) is the best linear unbiased estimator. If there exists inefficiency in production, then the disturbance is specified as the difference of the idiosyncratic error term and the one-sided inefficiency term, MLE given multiple of observations per farm will produce consistent estimates of parameters. The parameter estimates associated with pooled OLS (Model 1) and two MLE methods are shown in Table 4.[9] The models estimated with MLE differ by the exclusion of one of the insignificant inputs, seed, from Model 3. The pooled OLS method is equivalent of an average production function, while ML model yields estimates of the stochastic production frontier. The pooled OLS estimates differ little from estimates resulting from stochastic frontier production function. This is consistent with the findings of Lin (1992). In the MLE there is an improvement over pooled OLS estimates in terms of significance of coefficients. In the pooled OLS estimates, seed and labour are not significant, whereas in the MLE models only seed is insignificant.

7.2 The cost frontier

The cost frontier dual to the stochastic frontier production function given in Table 4 is:

$$\begin{aligned} \ln C_{it} &= -0.090 + 0.074 \ln p_{fertilizer} + 0.043 \ln p_{cash\,\mathrm{exp}} + 0.024 \ln p_{seed} \\ &\quad + 0.269 \ln p_{oxen\,days} + 0.124 \ln p_{labour} + 0.463 \ln p_{land} + 0.919 \ln Y_{it} \end{aligned} \tag{18}$$

where C is the total cost of crop production per farm measured in Ethiopian Birr; $p_{fertilizer}$ is the average price of fertilizer; $p_{cash\,\mathrm{exp}}$ is price of cash expenses normalized to be one for 2000/01 and is adjusted by price index for 1993/94; p_{seed} is the average price of seed per kg; $p_{oxendays}$ is the average price of oxen day; p_{labour} is the average daily wage; p_{land} is the average rent per ‘kert’ (1 kert=0.30 hectare) of

[9] The test for poolability of the panel data rejects the pooled regression in favour of fixed effects. The chow-test for the null hypothesis that the data can be pooled and estimated as if they were cross-sectional data has a $\chi^2_{(7)}$ value of 75.52 which is significant at less than 1% level.

operated land; and *Y* is the aggregate value of crop output adjusted for statistical noise as defined earlier. It should be noted that prices for the two periods are different and are given in 2000/01 constant prices.

7.3 Patterns of inefficiency

The estimate of gamma, $\hat{\gamma}$, which measures the effect of technical inefficiency on the variation of observed output $\left(\gamma = \sigma_u^2 /(\sigma_u^2 + \sigma_V^2)\right)$ is 0.4123 in the time-variant Model 2 and its standard error is 0.3074. The Wald test statistic given by $W(ml) = \hat{\gamma} / s_{\hat{\gamma}} = 0.4123 / 0.3074 = 1.3412$, tests the null hypothesis $\gamma = 0$ against the alternative hypothesis $\gamma > 0$ and is asymptotically distributed as a standard normal random variable (Coelli, 1995). This test rejects the null hypothesis for one-sided test at 10% significance level. The estimate of η, which defines the non-negative farm effects, is positive and insignificant. This suggests that the inefficiency term tends to decline exponentially to its minimum, u_i, in the last period, 2000/01. However, this relationship is not strong since η is not significantly different from zero. Thus according to the model, the technical inefficiency of production would not change significantly over time. The fact that η is insignificant suggests that despite the long distance between the two periods of observation the inefficiency term, u_{it}, is dominated by persistent inefficiency. The estimated value of μ is small and not significantly different from zero, rejecting truncated normal distribution and suggesting that the firm effects have half-normal distribution.

The estimate of intertemporal correlation of the disturbance is given by:

$$R_{it,it-1} = \left(\sum_{i=1}^{61} \sum_{t=1}^{2} e_{it}, e_{it-1} \right) \Bigg/ \left(\sum_{i=1}^{61} \sum_{t=1}^{2} e_{it}^2 \right)$$

where e_{it} represents the estimate for ε_{it}. $R_{it,it-1}$ is reported at the bottom of Table 4. The resulting $R_{it,it-1}$ is –0.0777. Under the null hypothesis of no intertemporal or spatial correlation, $R_{it,it-1}$ has a standard error equal to $N^{-1/2}$, where *N* is the number of observations (George G. Judge et al., 1985, p.319). For $N = 122$, the standard error under the null hypothesis is 0.0905. This evidence suggests that intertemporal correlation does not exist in the disturbance. It should be noted that farms are observed over only two periods.

7.4 Input elasticities

We base our discussion in this section on the estimates time-variant MLE (Model 2 of Table 4). All variables have the expected signs and with the exception of seed are statistically significant. The insignificant coefficient of seed could be because of the fact that there are not many improved seeds in use. Farmers are mostly using the same traditional seeds or, if they have ever used improved seeds, they use it repeatedly and the productivity of the seed deteriorates over time as a result. Therefore, an increase in seed costs is more likely to be the result of the application of seed in excess of required rate than as a result of using improved seeds which are costlier and more productive. Application of seeds above the required rate leads to the density of plants being too high which can reduce yield.

The elasticity of output with respect to land is the most elastic and highly significant. This indicates the small size of land holding in the Ethiopian highlands and the fact that land holding is sub-optimal in the highlands. The elasticity of output with respect to oxen days is the second biggest. The elasticity of output with respect to labour comes next to oxen days. A close look at Table 4 shows the difference, in parameter size, between the two groups of inputs (fertilizer, cash expenditure, seed) and (oxen days, labour, land). Generally, the first group has lower elasticities and are less significant than the second group suggesting the fact that the variation in this first group of inputs does not necessarily mean similar variation in outputs. Variations in output are more associated with improved productivity than mere increase in fertilizers, cash expenditure and seed. The effect depends on how these variables are used in production. For instance, the time of fertilizer application, the actual use of cash spent, and the seed type and rates matter, which are typical problems in Ethiopia. In the case of the second group, farmers have learned over the years how to use these inputs and every addition of the inputs contribute positively to increase in output.

The estimated coefficient of the time dummy is large and highly significant. The negative sign shows that there is technological regress or downward neutral shift in the production function over time between these two time periods. While this seems counter-intuitive at the first glance, looking at the increased use of fertilizer and increased existence of extension and research services, one can easily convince oneself by thinking about the actual impact of these services on the environment and agriculture. The damages to agricultural land in terms of soil degradation (erosion and nutrient depletion) overweigh what is supplied through extension and use of fertilizers. Although there is no data on the percentage of households using improved seeds in 1993/94 survey in the area, the proportion in 2000/01 survey is very small (11.3%). Existing seeds lose quality over time because they are used repeatedly. The use of fertilizer is in most cases sub-optimal. Farmers do not have access to a complete and more productive package of inputs, making the impact of new technology on yield to remain low. Overexploitation of the natural resource base over a long period has resulted in severe soil degradation as reflected in declining or unchanging yield levels despite the significant increases in the use of chemical fertilizers (Afrint, 2003).

Returns to size (RTS) which measures the change in output resulting from a proportional changes in all variable inputs, is obtained by summing the input coefficients since we used the double-log transformation. The estimated value of the function coefficient is 1.0870 indicating increasing returns to scale. However, the constant returns to scale hypothesis can't be rejected based on the estimated $\chi^2_{(1)}$ value of 0.2299.

7.5 Measures of efficiency and its decomposition

Based on the technical inefficiency effect derived from the stochastic production frontier (Model 2 of Table 4) and its dual cost frontier, we calculate *TE* (equation 4), *EE* (equation 10) and *AE* (equation 11). Table 5 presents the summary statistics of the mean technical, economic and allocative efficiencies by year and sizes of land, stock of oxen and family labour.

The results show that technical efficiency index range from 59.0% to 90.9% in 1993/94 and from 59.3% to 91.0% in 2000/2001. The mean technical efficiency for 1993/94 and 2000/01 are 77.8% and 78.0%

respectively. It tends to increase little over time but statistically insignificantly as we have seen earlier. This suggests that the technical inefficiency term, u_{it} , is dominated by the persistent technical inefficiency[10]. Surprisingly no farmer is fully technically efficient in the sample due to the stochastic nature of the frontier function. Average technical efficiency for the sample is 77.9% varying in the interval 59.0% to 91.0%. Accordingly, if the average farmer in the sample was to achieve the efficiency of its most in the sample efficient counterpart, then the average farmer could realize a 14.4% cost saving, i.e. [1-(77.9/91.0)]. A similar calculation for the most technically inefficient farmer reveals a cost saving of 35.2% [1-(59.0/91.0)].

On the other hand, average allocative and economic efficiencies have declined over time while minimum values have slightly increased over the same period. Maximum economic efficiency has declined over the period while maximum allocative efficiency increased slightly. This indicates that for most of the farmers, economic efficiency including the most efficient farmers in the first year, have declined. Similar argument for allocative efficiency is that while most inefficient and most efficient farmers have improved efficiency, allocative efficiency has deteriorated for most of the farmers in the sample.

Average economic efficiency, which is the product of the two components equals 51.1% and ranging in the interval of 33.6% and 63.7%. These numbers indicate that if the average farmer in the sample were to reach the economic efficiency level of its most efficient counterpart, then the average farmer could experience a cost saving of 19.8% i.e., [1-(51.1/63.7)]. Similarly, the most economically inefficient farmer could achieve a cost savings of 47.3 percent i.e., [1-(33.6/63.7)]. These cost savings can alternatively be interpreted as equivalent potential increases in output for given input use in production by using the best practice production technology.

[10] This is consistent with the estimation results obtained from corrected ordinary least squares (COLS) in which the third moment of the OLS residual was found to be zero suggesting that the time-varying inefficiency term is not significant. The estimation results of the COLS were omitted for sake of limited spaces.

7.6 Distribution and heterogeneity in efficiency

We report summary statistics of efficiency indices by sizes of land, stock of oxen, and labour force in Table 5. The results suggest a significant degree of heterogeneity by farm and household characteristics. The average of three efficiency indices are higher for households with higher number of oxen suggesting that better access to traction power could improve efficiency of farms. Although the relationship between average technical efficiency and operated land holding is not clearly visible, average values of allocative and economic efficiencies tend to increase with operated land holding. On the other hand average allocative efficiency tends to decrease with total work force while economic efficiency tends to increase with total workforce.

Frequency distributions of three efficiency indices among the sample households are shown in Appendix C1-C4 by year, oxen ownership status, operated farm holding and labour force size, respectively. According to the information in Appendix C1, the number of farmers operating at below 60% of technical and allocative efficiency, are few and constitute only 3.2% and 27.8%, respectively. For economic efficiency the figure is 95.1% which is interpreted as that almost all sample farmers operate at below 60% level of economic efficiency. The highest concentration for economic efficiency is in the interval 80.1%-85.0% (30.3%), while the highest concentration of farms for allocative efficiency is in the interval of 60.1%-65.0% (23%). The corresponding interval concerning economic efficiency is 50.1%-55.0% (37.7%). The numbers in parentheses indicate the share of farms in the respective intervals.

Appendix C1 shows frequency distribution of the efficiency indices over time. Accordingly there is an indication that both allocative and economic efficiencies have worsened over time. The number of farmers operating at higher efficiency levels decreased in 2000/01 probably suggesting that the reform has affected allocative and economic efficiency of farming adversely through. The frequency distribution of the efficiency indices also varies with the size characteristics (Appendix C2-C4). Generally, the above suggest that economic efficiency could be improved substantially and that farmers are more allocatively inefficient than they are technically inefficient and allocative efficiency should be a major source of concern.

Although it is difficult to separately calculate the impact of policy changes on various efficiency components, which worsened over time, the possibility of adverse impact of policy change on different efficiency components is evident. The negative technological progress cannot be attributed directly to the lack of significant increase of modern input use although they can be responsible for stagnating production. However the indirect (external) impact of policy changes on soil degradation is a legitimate concern for the observed technological regress. The impact of fertilizer subsidy abolition policy on soil fertility was studied recently by Holden et al. (2003), with results confirming the adverse impact of the policy change on soil degradation. It would be possible to quantify this impact if data covering immediate conjunction of the reform years were available.

To show the consistency of our estimated efficiency results with those of previous studies, we present average efficiency indices reported by other studies that employed similar estimation methods, i.e., stochastic frontier production function using farm level data from developing countries in Table 6. Despite differences in technology and farming conditions among developing countries, the numbers in this table show that the average efficiency component indices found in this study are all in line with those of the previous studies. For instance, the 66.5% average allocative efficiency found in this study is very close to the one found by Ali and Chaudhry (1990) which is 63.0%. The average for economic efficiency (51.1%) is also close to the one found by the same authors for crops in Pakistan. On the other hand, the average allocative and economic efficiencies found by Bravo-Ureta and Pinheiro (1997) in Dominican Republic for the aggregate crops are lower than the ones found here.

7.7 Determinants of efficiency

Potential efficiency gains might depend on various characteristics of farm, farmer and production environment which vary among the farms. For policy purposes, it is useful to identify these sources of production inefficiency. The identification can be done by investigating the relationship between farm and farmer characteristics and the computed efficiency indices separately. This is accomplished a method known in the literature as “second step” estimation (Hazarika and Alwang, 2003; Bravo-Ureta and

Pinheiro, 1997). Thus, the relation between these characteristics and different efficiency indices was examined by estimating the following models:

(19) $$Efficiency = f(age, cash, land, location, oxen, oxend, labour, rented, time)$$

where efficiency represent different components of efficiency (*EE*, *AE*, *EE*); age is a dummy variables indicating whether the head of household is older than 55 years; cash is logarithm of off-farm cash income; location is a dummy variable indicating the village of Hidi distinguished from village of Hora; land is logarithm of operated land holding; oxen is the logarithm of the number of oxen owned normalized by the size of operated holding reflecting oxen density; oxend is a dummy variable indicating that households owns two or more oxen; labour is logarithm of the total work force; rented is the ratio of rented in land to total operated holding, and time is a dummy variable referring to 2000/01.

The models for the three efficiency indices based on MLE Model 2 are estimated separately using Tobit procedure given that the efficiency indices are bounded between 0 and 100 (Wooldridge 2002; STATA 2003; Maddala 1987).[11] The estimation results are presented in Table 7. Depending on the hypothesized relationship between the different efficiency indices and the explanatory variables, the form and the number of explanatory variables differ in each regression equations[12].

For technical efficiency, it is hypothesized that provided that cash income is available, total workforce, does not affect technical efficiency. On the other hand, for instance given the small size of operated holding, technical efficiency is affected only by timely cultivation, not by application of more number of oxen days. Those households with only one ox or no ox can not accomplish timely planting and this may reduce their level of technical efficiency. It is also hypothesized that land contract type (tenure) does not affect technical but allocative efficiency in the case of sharecropping.

Allocative efficiency is more likely to be affected by the oxen density per unit of land than number of oxen because variations in the number of oxen among households can affect the number of oxen days used on a given farm. Finally, since economic efficiency is a product of allocative and technical

[11] These models were also estimated using the SUR estimation method. Generally the two-limit Tobit model results were better than those of SUR. We have omitted the SUR results to save space.

[12] Of course, despite these hypotheses, we included all the possible determinant variables in all models, but omitted them when a variable turned out to be insignificant.

components, selection of variables in economic efficiency regression depends on specifications employed in the two separate components. Thus, the oxen dummy was selected based on its significance in the model. The results in Table 7 indicate that the sign of all the variables included in the technical efficiency model are positive. A positive association between technical efficiency and its determinants was, with the exception of age variable, expected. Age is positively correlated with experience, but negatively correlated with physical strength and also younger are generally more educated. A possible explanation for the findings here is that older farmers are more experienced and this experience outweighs the advantage of the strength and education of younger farmers.

The effect of off-farm cash income on technical efficiency is positive and significant. This is an expected result because farmers with more cash income can afford early purchase of inputs important to their timely use in farming. But it is negative and insignificant in allocative and economic efficiency models. This is because farmers with more cash income allocate less of their time to farming and also are able to overspend on inputs above the required level and this outweighs the positive impact it has on technical efficiency. The proximity of the locations of farmers to market and town areas has positive and significant impact on technical efficiency. This result is consistent with our expectation because farmers close to input supply areas and extension offices can benefit more than those far away because of transportation problems and roadside bias of the extension service. However, it has a negative and significant impact on allocative efficiency but insignificant impact on economic efficiency. This supports the notion that farmers close to towns have more resources because of their proximity to spend over and above the required amounts of inputs.

The size of land has a positive effect on the level of technical efficiency and negative effects on the allocative and economic efficiencies. This is interpreted as farms above average size tend to be more technically efficient although the relationship is not strong enough. This result is consistent with few studies using frontier methodology in developing countries. Most of these studies have found no significant relationship between size and technical efficiency (Bravo-Ureta and Evensen, 1994; Bravo-Ureta and Pinheiro, 1997). By contrast, in a non-frontier analysis, large farms in Dominican Republic had high economic efficiency than small farms (Bravo-Ureta and Pinheiro, 1997). The variable oxen density has a negative sign and is insignificant in allocative model. This is not surprising given the sub-optimal landholding; farmers with larger number of oxen may use more than required oxen days. On the other hand, the coefficient on oxen number is positive and insignificant both in technical and economic efficiency models suggesting that farmers with two or more oxen tend to be more technically and economically efficient than those with one or no oxen although the relationship is not strong.

The work force has a positive effect on both allocative and economic efficiencies but significant only in allocative model. This result is in conformity with our expectation that given the scarcity of labour in the area, the high cost of hired labour, households with larger number of workforce may not overuse labour on their own farm. Another variable of interest is the ratio of informally rented in land to total operated holding. The result is consistent with the theory of sharecropping which suggests that sharecropped farms are less efficient than owner-operated and fixed rent contract (Ellis, 1989). However, the relationship is weak probably due to the fact that most informal contracts among our sample farms are fixed contracts.

In the stochastic production frontier, time incorporated in the deterministic part of the production frontier accounts for neutral shift in production due to technological change. If one assumes a time-variant efficiency model, time accounts for neutral shift in efficiency levels over time. When using efficiency effect models where in a one or two-step procedure, in addition to input variables, determinants of inefficiency are added, the time variable again captures neutral shift in efficiency levels over time. This can be associated with policy reforms which affects the level of inefficiency. The results in Table 7 confirms the previous results from efficiency distribution that technical efficiency tends to increase over time but this relationship is not statistically significant. On the other hand, both allocative and economic efficiencies decrease with time which means that the positive impact of time on technical efficiency is more than off-set by its negative impact on allocative efficiency. This might suggest that policy reforms alone may not bear fruits unless other counteracting factors are solved for.

In general credit supply to enhance timely input use and better extension service can be potential areas for improvements in efficiency of farms. Since we have only two observations and not in immediate conjunction of reforms, it has not been possible to better evaluate the impact of specific policy reforms on efficiency of farms. Nevertheless, this study highlights the general directions of the impacts of the most notable policy changes (fertilizer subsidy policy) between the two periods covered in this study.

7.8 Growth Accounting

In this section, we attempt to identify the sources of a change in agricultural production based on methodological approach outlined in section 5.3. To accomplish this we use the estimation results of our stochastic frontier production function reported in Model 3 of Table 4. This estimation omits seed, the coefficient of which is not significant in the stochastic frontier model reported in Model 2 of the same Table.

The sources of output change between the two periods as shown in equation (15) are divided into three categories: changes in conventional inputs; technological progress/regress; and a change in technical efficiency. The first category is divided into different conventional inputs. The percentage growth in output and inputs between the two periods is reported in Table 8. Table 9 reports growth accounting results. During 1993/94-2000/01, total output declined by 58.4%. Out of the total decline in output 39.65% is due to the decline in conventional inputs. All inputs declined during the period except fertilizer the use of which was record high in 2000/01 across the country. The important source of decline in output was the decrease in oxen-days (19%), followed by labour (17.3%), land (16.7%), and finally cash expenditure (2.8%). The numbers in parentheses indicate the contribution of each input to the decline in output.

Although the use of fertilizer increased by 105.9% during the period, its contribution to the total output growth was only 16.1%. This is due to the low fertilizer elasticity. Technological regress is the single most contributors to output decline amounting to 84.4 % of the total output decline. This corresponds to an annual decline of 9.4%. The rate of technological regress during the period was –49.3%. There could be many factors to which this result could be attributed. While lack of achievement of the desired goals with the recent extension campaign could be responsible for technological regress or gradual declines, the observed rate of technological regress can not be attributed to the slow pace of intensification in agriculture. There seems to be some counteracting forces which more than offsets the little achievement in agricultural intensification, the most probable being soil degradation. The continuing rate of soil degradation through soil erosion and nutrient depletion continues to threaten agricultural productivity. Little is done to stop soil erosion and nutrient depletion is not being matched by use of organic and inorganic fertilizer because the rate of application of these inputs is far below optimal levels. Thus, the fact that used inputs lose quality as a result of repeated use (such as improved seeds), low rate of innovation and adoption of new technologies and deteriorating soil fertility seem to be the reinforcing factors responsible for the observed technological regress.

Recent study by Holden et al. (2003) which used computable general equilibrium (CGE) model to simulate the impact of different policy measures on soil degradation indicate that these policy measures tended to increase land degradation externally (measured by its impact on land productivity). Specifically the simulation results for fertilizer subsidy decrease showed adverse impacts both on soil degradation and farm household income. They call for a complimentary policy intervention to stimulate land conservation.

Having accounted for input change and technological regress, the remaining residual is attributed to a change in technical efficiency since technical efficiency is a residual concept (Liu and Zhuang, 2000; Lin, 1992). One part of this change can be explained in the efficiency effects regression and another part remains unexplained as residual. Thus the change in technical efficiency is about 24% of the total output change, which might be insignificant given that the time-variance efficiency was rejected in Table 4. Following the convention of growth accounting, the increase in total factor productivity growth $\left(T\dot{F}P\right)$ reported in Table 9 is –35.3%.[13] This study shows that technological regress dominates the TFP growth in the model, suggesting that the production frontier has shifted down while the gap between standard practice and the best practice remains.

8. Summary and Conclusion

This paper attempts to investigate the performance of agriculture in post reform Ethiopia by investigating several performance measures such as technical, allocative and economic efficiency, productivity growth, and technological progress. We used stochastic frontier production function to obtain estimates of the above performance measures. The results indicate that there is evidence of significant technical and allocative inefficiencies among the farmers. From the findings, there is no evidence that policy reforms

[13] The total factor productivity growth using equation 16 is calculated as: -49.3+14.0=-35.3 percent.

have improved technical efficiency in production over the period significantly. On the other hand allocative and economic efficiency have deteriorated over the period.

The findings from the growth accounting exercise suggest that technological regress contributed the largest share of output decline during the period. Increased fertilizer use by 105.9 percent didn't contribute much to output growth because of the small size of elasticity of output with respect to fertilizer. All other inputs have declined during the period but their contribution to output fall is low compared to the large neutral technological regress. Following the convention of growth accounting, the rate of total factor productivity growth is found to be negative. The gain from improving technical efficiency is limited since the persistent inefficiency dominates and inefficiency was found to be time-invariant. The small values of the elasticity estimates of agricultural output with respect to different inputs and the limited size of potential efficiency gain suggest that there is a major counteracting force to productivity growth. The key policy agenda should be to reverse the land degradation process, which is taking place at an alarming rate if the country is to achieve sustainable productivity growth.

The preceding results and discussions imply that a strategy aimed at breaking the cycle of poverty and famine should target both the supply and demand-side factors of agricultural productivity growth. The supply-side factors include reduction of pressure on land through improved and sustainable cultural practices that include organic matter and crop rotation to improve soil fertility, improved livestock husbandry with minimal grazing, planting multipurpose tree crops on degraded lands and intensification of high potential areas using complete package of modern inputs (fertilizer, improved seeds and chemicals to control weeds and pests), investment on irrigation by government, individuals and community to produce two or three harvests per year. In addition, investments in agricultural research, training, transport and communication infrastructure, rehabilitation and conservation and human capital are needed.

To encourage optimal investment, the government should ensure availability of credits and tenure security. The staggering Ethiopian agriculture needs an injection of a sizable dose of external capital investment to avoid poverty trap and increase production and productivity that outweigh population growth and environmental degradation on a sustainable basis. Development aid can be used to transform agriculture such that it can take advantage of modern faming knowledge and technology through provision of financial and technical resources. Finally, efficient market institutions and provision of accurate and timely market information are other important factors required for agricultural transformation.

Despite the limitation of our data owing to the small number of time of observations, which makes it impossible to estimate the year-to-year effects of policy reforms on productivity, this study sheds lights on the trend of agricultural productivity and the broad sources of output change in the post reform Ethiopian agriculture. To get insight into a clearer picture of the trends, we will pursue a follow up study in the future with longer panel.

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Appendix A. Crop seeds produced by the Ethiopian Seed Enterprise, yields per hectare and fertilizer use, 1979-2002.

Year	Production of crop seeds in Quintals								Yield in quintals / hectare			F
	Wheat	Maize	Barley	Sor-ghum	Teff	Haricot bean	Others	Total crops	Cereals	Pulses	Oil-seeds	
1979	194792	11996	2597	250	4147	612	1420	215814	-	-	-	
1980	224413	25746	12597	1757	1384	595	966	267458	11.91	10.60	5.19	
1981	253104	16967	23431	3046	1490	2797	717	301612	11.69	10.13	3.33	
1982	186158	26156	8936	3256	1047	860	86	226499	13.36	10.97	4.57	
1983	116830	14472	22553	576	2817	1532	511	159291	11.72	9.20	3.81	
1984	255288	170578	22673	10235	851	5080	934	465639	8.81	6.97	3.41	
1985	319215	147311	26056	14019	6944	2710	11429	527684	9.66	6.27	3.56	
1986	336035	121000	29951	16450	5975	3460	5647	518518	12.26	8.17	3.41	
1987	212555	76277	48617	35493	6274	6059	6277	391552	11.83	7.01	3.78	
1988	96843	43696	22806	18630	10057	1602	182	193816	12.05	7.15	3.67	
1989	92062	65126	30713	8975	16897	4415	3001	221189	12.27	8.28	3.15	
1990	81680	18659	22881	6331	910	1914	5144	137519	12.76	8.79	3.20	
1991	81160	7145	7995	-	1994	910	3583	102787	11.91	8.91	4.18	
1992	161109	24008	3750	27449	22154	1443	4317	244230	13.43	8.23	3.34	
1993	110125	43337	1600	3084	1227	1767	1120	162260	12.91	7.38	3.80	
1994	87369	53478	1667	4832	4355	2819	1396	155916	10.71	8.79	3.43	
1995	138140	40422	12740	7300	3665	4457	944	207674	12.43	9.00	4.99	
1996	206682	26961	10209	-	8837	608	1165	254462	12.90	8.87	4.46	
1997	125801	48185	6622	-	4005	24	1715	186352	11.60	8.12	4.48	
1998	84844	48940	623	378	4983	312	962	141042	11.40	5.10	3.60	
1999	161708	103638	1956	1338	4447	523	2065	275675	11.40	8.40	4.00	
2000	150358	100672	752	341	2593	5408	3226	263348	11.50	9.20	4.10	
2001	-	-	-	-	-	-	-	-	12.17	8.70	4.30	
2002	-	-	-	-	-	-	-	-	-	-	-	

Source: Afrint (2003)

Appendix B. Description of variables and their constructions

Value of total crop output (crop): This is the aggregate value of all crops weighted by their respective prices. This was transformed to constant 2001 prices using price indices

Operated land holding (land): this is the area dedicated to crop production measured in kert. It includes both rented in and own land minus rented out land.

Value of oxen days (oxen): this is the value of oxen days spent on crop production. It includes both own and rental oxen days. The value is transformed into constant 2001 prices using price indices. This includes all oxen days including ploughing and threshing.

Total cash income (cash income): this is the sum of cash income earned by the farm household family members from different sources during the production period. This does not include the sale of crops produced during the same year and the sale of animals. It is transformed to constant 2001 prices using price indices.

Labour input (labour): this is the total cost of family and hired labour used exclusively in crop production. The total labour is converted to values by multiplying by wage rates. This value was transformed into constant 2001 prices using price indices. Labour input includes all crop production activities such as planting, ploughing, sowing, spraying, threshing, weeding, transporting and harvesting.

Fertilizer (fertilizer): this is the value of DAP and UREA fertilizers used in crop production. The value was transferred into constant 2001 prices using price indices.

Seed (seed): this is defined as the total expenditure on the purchase of seed plus the value of own seed. Again the total value was transformed to constant 2001 prices.

Cash expenditure (expenditure): this is the aggregate value of cash expenditure items purchased and used mainly in the production of crops. This consists of costs induced by the use of herbicides, pesticides, animal medicines, and animal salt for oxen, animal feed for oxen, marketing, and cash expenditure on transportation. This was transformed to constant 2001 prices using price indices.

All values are measured in Ethiopian Birr which is currently exchanged at the rate 1USD ≅8.6 Birr.

Total work force (work force): each household's family size was converted to standardized household size using the FAO/WHO coefficients for converting family size into standardized labour unit. According to this, each age category has a weight by which it has to be multiplied to be converted into standardized family size.

Tropical livestock unit (tropical): this is the unit of measuring the total livestock size owned by a household. Each animal's age category and type is multiplied by a conversion factor to convert it into a standardized unit in oxen equivalents.

Total Farm Size (size): this is the size of the total land owned by a household and is measured in "kert" excluding homestead.

Number of oxen (N-oxen): this measures the number of oxen (head count) owned by each household. There is no conversion factor here. Oxen are counted equally regardless of size.

Education (education): education of household head is measured by the level of formal education the farm household head has achieved measured by the number of formal schooling years. If the farmer can read and write without going to formal school, 1 is assigned and if the farmer is illiterate, 0 is assigned.

Age (age): this is the age of the farm household head in years.

Ratio of rented in land to total operated holding (rent): this is the ratio of the rented in land to total operated holding.

Consumer worker ratio (consumer): this is the ratio of the total consumer unit of the household to total labour unit (work force). Both consumer unit and labour unit are standardized to combine different age and sex groups.

Time (t): this is the time trend, which takes 1 for 1994 and 2 for 2001.

Village dummy (village): is a dummy variable accounting for the differences in location of the two villages. The two villages are Hidi and Hora. The dummy variable assumes a value of 1 if the farm household is located in Hidi and 0 otherwise. Hidi is closer to market area

Sex (sex): this is a dummy variable indicating the sex of household head. It equals 1 for males and 0 for females.

Net rental cost (rental cost): this is the net rental expenditure (difference between total rental cost and total rental income) on oxen days, labour days, and land. The net rental costs are transformed into constant 2001 prices using price indices. Net rental costs reflect net input to the farm.

Table 1. Oxen ownership status of sample households.

Number of oxen	Percentage of farmers	
	1993/94	2000/01
0	22.7	17.3
1	25.3	13.3
2	26.7	40.0
3 and more	25.3	29.4
Total	100.0	100.0

Table 2. Types of crops planted and use of modern inputs during the survey.

Activity	Percent of farmers	
	1993/94	2000/01
Type of crop:		
Teff	100.0	100.0
Wheat	73.8	81.2
Barley	29.3	21.7
Maize	34.6	11.3
Bean	68.2	75.5
Chickpea	0.0	67.0
Lentil	12.1	3.8
Peas	65.4	1.9
Use of fertilizer for:		
Teff	96.3	98.1
Wheat	54.2	81.1
Barley	1.9	6.6
Maize	0.0	0.9
Bean	0.0	0.9
Chickpea	0.0	0.0
Lentil	0.0	0.0
Peas	0.0	0.0
Use of herbicide	44.9	50.0
Use of pesticide	18.7	19.8
Use of improved seed	Not available	11.3

Table 3. Descriptive statistics of variables used in estimations, NT=61x2=122 observations.[1]

Variable name	Description of variable	Mean 1994	Mean 2001	Std. dev. 1994	Std. dev. 2001
Production function variables:					
Tcy:dependent Var.	Aggregate value of crop output	10814.610	4492.310	6467.600	3075.600
Fertilizer	Total value of fertilizer used for crop	411.040	846.550	276.800	455.780
Seed	Value of total seeds used	331.110	449.940	211.510	321.950
Expenditure	expenditure to purchase other inputs	80.740	53.731	105.360	73.800
Labour	Value of man days used in crop production	2887.721	671.470	1383.800	390.650
No oxen	Value oxen days used in crop production	955.310	609.460	470.970	371.820
Land	Total operated land for crop prod.	8.580	6.950	4.070	3.440
Efficiency effects variables:					
Age	Age of household head in years	45.245	52.570	16.740	16.908
Age dummy	Dummy variable, 1 if age>55 & 0 otherwise	0.245	0.377	0.434	0.488
Land dummy	Dummy variable, 1 if land>average, 0 otherwise	0.622	0.491	488.000	0.504
Oxen	Number of oxen owned by a household	2.020	2.470	1.330	1.450
Sex	Sex of household head: male=1; female=0	0.950	0.950	0.218	0.210
Cash income	Total non-crop and non-livestock income	241.860	483.930	434.520	1281.600
Village dummy	A dummy variable: Hidi=1; Hora=0	0.508	0.508	0.504	0.504
Rent	Ratio of rented in land to total operated land	0.202	0.061	0.180	0.155
Work force	Total work force of the household	3.040	3.160	1.306	1.312

Note 1: All values are in 2000/01 constant prices.

Table 4. Production function parameter estimates, dependent variable is log of crop output, NT=122 observations.

Explanatory variables	Description of variables	Pooled OLS (Model 1)	MLE (Model 2)	MLE (Model 3)
Ln(fertilizer)	Value of organic fertilizer	0.0860 (0.0490) c	0.0810 (0.0461) c	0.0891 (0.0416) b
Ln(cash expenditure)	Amount of cash expenditure	0.0417 (0.0216) c	0.0468 (0.0205) b	0.0484 (0.0199) b
Ln(seed)	Value of seeds	0.0413 (0.0611) .	0.0265 (0.0633) .	-
Ln(oxen days)	Value of oxen days	0.2889 (0.1124) b	0.2934 (0.1098) a	0.3072 (0.1058) a
Ln(labour)	Value of labour days	0.1062 (0.0644) .	0.1359 (0.0641) b	0.1316 (0.0632) b
Ln(land)	Size of total operated land	0.5126 (0.1378) a	0.5040 (0.1273) a	0.5153 (0.1254) a
T	Time trend	-0.5776 (0.1294) a	0.5242 (0.1822) a	0.4930 (0.1640) a
constant		4.3534 (0.7660) a	4.9943 (0.6055) a	4.9663 (0.6019) a
L	Log likelihood		-38.2819	-38.3699
$\gamma^{Ŧ}$			0.4123 (0.3074) c	0.4364 (0.2995) c
Function coefficient	Sum of elasticity of output with respect to inputs		1.0870	
H_0: CRS			$\chi2=1.4400$, p=0.2299	
η			0.0099 (0.5543)	
Rit,it-1			-0.0777 (0.0905)	
σ^2			(0.1411 (0.0711)	
Adjusted R^2		0.7969		
H0:All fixed effects=0		F-stat=1.6400 b		

Notes: ln: indicates the natural logarithm; CRS: constant returns to scale; a, b, c: indicate significance at 1, 5 and 10 percent levels of significance, respectively. Numbers in parentheses are standard errors. Ŧ since γ can't be negative, this is a one-sided test indicating significance at 10%.

Table 5. Summary statistics of various efficiency components by size and over time, based on estimation results from Model 2.

Efficiency	Year of obs		No of oxen ownership			Size of operated land in kert			Total workforce size			Average
	1993/94 (n=61)	2000/01 (n=61)	0 n=12	1 n=23	2- n=87	1.5-4.0 n=24	4.1-7.7 n=43	7.8- n=55	1.0-1.8 N=22	1.9-3.0 n=46	3.1- n=54	(N=122)
Technical												
Mean	77.8	78.00	76.6	77.0	78.3	79.6	76.7	78.5	76.7	78.5	77.8	77.9
Minimum	59.0	59.3	59.9	59.6	59.0	59.3	59.6	59.0	59.6	59.0	61.5	59.0
Maximum	90.9	91.0	83.7	90.2	91.0	90.3	91.0	89.7	89.4	90.9	91.0	91.0
Economic												
Mean	52.4	49.7	49.2	50.0	51.6	49.5	50.9	51.8	49.4	50.2	52.5	51.1
Minimum	33.6	39.4	33.6	34.6	39.4	33.6	39.3	42.8	33.6	34.6	39.4	33.6
Maximum	63.7	59.4	57.1	62.4	63.7	59.7	62.4	63.7	57.9	62.4	63.7	63.7
Allocative												
Mean	68.2	64.8	65.5	65.3	67.0	63.9	67.4	67.0	76.7	64.8	68.5	66.5
Minimum	41.0	43.4	41.4	45.1	43.4	41.3	43.4	49.9	59.6	43.0	43.4	41.4
Maximum	92.7	94.3	91.1	87.4	94.3	87.6	94.3	92.8	89.4	91.1	94.3	63.7

Table 6. Previous estimates of farm efficiency using stochastic frontier functions.

Author	Country studied	Product type	Technical	Allocative	Economic
This study	Ethiopia	Crops	77.87	66.5	51.05
Bravo-Ureta and Pinheiro (1997)	Dominican Republic	Crops	70.0	44.0	31.0
Seyoum and Battese (1998)	Ethiopia	Maize	79.4	-	-
Ali and Chaudhry (1990)	Pakistan	Crops	84.7	63.0	53.0
Taylor and Shonkwiler (1986)	Brazil	Whole farm	70.4	-	-
Abdulahi and Eberlin (2001)	Nicaragua	Maize/Beans	69.7/74.2	-	-
Battese and Coelli (1992)	India	Rice	89.05	-	-
Wu (1995)	China	Agriculture	52.05	-	-
Taylor et al. (1986)	Brazil	Crops	71.0	76.5	-
Kalirajan and Shand (1986)	Malaysia	Rice	67.0	-	-

Table 7. Tobit parameter estimates of determinants of efficiency. Dependent variables are technical, allocation and economic efficiencies.

Variable Ŧ	Description of variables	Mean	Technical Coefficient (Std.err)	Allocative Coefficient (Std.err)	Economic Coefficient (Std.err)
Constant		-	4.3415 (0.0127) a	4.1989 (0.0949) a	3.9356 (0.0721) a
Agedum	Dummy variable age of head 55+	0.3114 (0.4650)	0.0033 (0.0043) .	0.0031 (0.0352) .	-0.0008 (0.0219) .
Ln(cash inc)	log of non-farm cash income	2.3346 (3.0839)	0.0014 (0.0006) b	-0.0036 (0.0045) .	-0.0008 (0.0034) .
Locatdum	Dummy for location,1=Hidi, 0=Hora	0.5081 (0.5019)	0.0298 (0.0042) a	-0.0643 (0.0363) c	-0.0077 (0.0212) .
Ln(land)	log of operated land holding	2.0734 (0.4532)	0.0036 (0.0049) .	-0.0051 (0.0408) .	-0.0049 (0.0301) .
Ln(oxen)	log of No. of oxen divided by land	0.2559 (0.1425)	-	-0.1044 (0.1124) .	-
Oxendum	Dummy variable oxen ownership,1+	0.7131 (0.4541)	0.0031 (0.0049) .	-	0.0482 (0.0278) c
Ln(labour)	log of total workforce	1.3606 (0.3208)	-	0.0996 (0.0506) b	0.0528 (0.0383) .
Rented land	Ratio of rented to total operated land	0.0832 (0.1748)	-	-0.0650 (0.0900) .	-0.0752 (0.0606) .
Time dummy	Time dummy, 2000/01=1	1.500 (0.5020)	0.0023 (0.0039) .	-0.0454 (0.0249) c	-0.0618 (0.0218) b
log likelihood			194.5477	58.0395	98.1137

Ŧ Education and sex of the household head were included in the model. But they were insignificant in all regressions and we found them to be collinear with some of the variables and hence omitted them from the models. a, b, c: indicate significance at 1, 5 and 10 percent levels of significance, respectively.

Table 8. Index of crop output and inputs use (1993/94=100).

Year	Crop output	Fertilizer	Cash exp.	seed	Labour	Oxen days	Land
1993/94	100	100	100	100	100	100	100
2000/01	41.6	205.9	66.6	135.8	23.3	63.8	81.1

Table 9. Accounting for crop output change using stochastic frontier production function, Model 3, based on NT=122 observations.[1]

Explanatory variable	Definition of variables	Estimated coefficient (1)	Change in variable % (2)	Contribution to growth % (3) = (1)x(2)
Inputs*				-23.1343 (-39.6)
Fertilizer	Value of fertilizer	0.0891	105.9	9.4356 (16.2)
Cash expenditure	Cash expenditure	0.0484	-33.4	-1.6065 (-2.8)
Labour	Value of labour input	0.1316	-76.7	-10.0937 (-17.3)
Oxen days	Value of oxen days	0.3072	-36.2	-11.1206 (-19.0)
Land	Size of operated land holding	0.5153	-18.9	-9.7391 (-16.7)
Time	Time period	-49.3054	1.0	-49.3054 (-84.4)
Residual				14.0397 (24.0)
Total growth				-58.4000 (-100.0)

Notes: 1 The estimated coefficients are those of Model 3 of Table 4. To calculate the contribution of time to output growth in terms of percentage, 100 multiply the estimated coefficient of time since time is in semi-log form in the production function. For the conventional inputs, the change in explanatory variable refers to the percentage change of the inputs during the two periods. Changes in output and input are calculated from Table 12. The numbers in parentheses are the percentage shares of contribution to total output change with total output change set normalized to 100 percent. * Seed is omitted from growth accounting calculation because it is not significant in the estimation of production function.

Appendix C1. Frequency distribution of different components of efficiency over time based on Model 2, N=61.

	Technical efficiency				Allocative efficiency				Economic efficiency			
Efficiency	1993/94		2000/01		1993/94		2000/01		1993/94		2000/01	
Interval	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
30.0-35.0	0	0	0	0	0	0	0	0	2	3.3	0	0
35.1-40.0	0	0	0	0	0	0	0	0	2	3.3	1	1.6
40.1-45.0	0	0	0	0	2	3.2	1	1.6	5	8.2	6	9.9
45.1-50.0	0	0	0	0	2	3.2	1	1.6	8	13.1	24	39.3
50.1-55.0	0	0	0	0	2	3.1	7	11.5	22	36.1	24	39.3
55.1-60.0	2	3.3	2	3.3	7	11.5	12	19.7	16	26.2	6	9.9
60.1-65.0	7	11.5	7	11.5	11	18.5	18	29.5	6	9.8	0	0
65.1-70.0	5	8.2	5	8.2	13	21.3	9	14.8	0	0	0	0
70.1-75.0	4	6.5	4	6.5	9	14.7	3	4.9	0	0	0	0
75.1-80.0	12	19.7	12	19.7	4	6.5	2	3.3	0	0	0	0
80.1-85.0	19	31.1	18	29.5	5	8.2	3	4.9	0	0	0	0
85.1-90.0	10	16.4	11	18.0	4	6.5	3	4.9	0	0	0	0
90.1-95.0	2	3.3	2	3.3	2	3.3	2	3.3	0	0	0	0
95.1-100.0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C2. Frequency distribution of efficiency indices by size of oxen ownership, based on Model 2, N=61.

Efficiency	Technical efficiency						Allocative efficiency						Economic efficiency					
Oxen	0		1		2-		0		1		2-		0		1		2-	
No, %	No.	%	No.	%	No.	%	No	%	No.	%	No.	%	No.	%	No.	%	No.	%
30.0-35.0	0	0	0	0	0	0	0	0	0	0	0	0	1	.8	1	0.8	0	0
35.1-40.0	0	0	0	0	0	0	0	0	0	0	0	0	1	.8	1	0.8	1	0.8
40.1-45.0	0	0	0	0	0	0	2	1.7	0	0	1	0.8	2	1.6	2	1.6	7	5.8
45.1-50.0	0	0	0	0	0	0	0	0	1	.8	2	1.6	0	0	9	7.4	23	18.9
50.1-55.0	0	0	0	0	0	0	1	.8	1	.8	7	5.7	5	4.1	5	4.1	36	29.5
55.1-60.0	1	0.8	1	.8	2	1.6	0	0	3	2.5	16	13.1	3	2.5	4	3.3	15	12.3
60.1-65.0	1	0.8	3	2.5	10	8.2	3	2.5	7	5.7	19	15.6	0	0	1	0.8	5	4.1
65.1-70.0	1	0.8	2	1.6	7	5.7	3	2.5	5	4.1	14	11.5	0	0	0	0	0	0
70.1-75.0	1	0.8	0	0	7	5.8	0	0	3	2.5	9	7.4	0	0	0	0	0	0
75.1-80.0	0	0	5	4.1	19	15.6	0	0	2	1.6	4	3.3	0	0	0	0	0	0
80.1-85.0	8	6.6	9	7.4	20	16.4	2	1.6	0	0	6	4.9	0	0	0	0	0	0
85.1-90.0	0	0	2	1.6	19	15.6	0	0	1	0.8	6	4.9	0	0	0	0	0	0
90.1-95.0	0	0	1	0.8	3	2.5	1	0.8	0	0	3	2.5	0	0	0	0	0	0

Appendix C3. Frequency distribution of efficiency indices by size of areable land, based on Model 2, N=61.

Efficiency	Technical efficiency						Allocative efficiency						Economic efficiency					
Land	1.5-4.0 kert		4.1-7.7		7.8-		1.5-4.0		4.1-7.7		7.8-		1.5-4.0		4.1-7.7		7.8-	
No, %	No.	%	No.	%	No.	%	No	%	No.	%	No.	%	No.	%	No.	%	No.	%
30.0-35.0	0	0	0	0	0	0	0	0	0	0	0	0	2	1.7	0	0	0	0
35.1-40.0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.8	2	1.6	0	0
40.1-45.0	0	0	0	0	0	0	2	1.7	1	0.8	0	0	3	2.5	2	1.6	6	4.9
45.1-50.0	0	0	0	0	0	0	2	1.7	0	0	1	0.8	2	1.7	16	13.1	14	11.5
50.1-55.0	0	0	0	0	0	0	2	1.7	2	1.7	5	4.1	10	8.2	15	12.3	21	17.2
55.1-60.0	1	0.8	2	1.6	1	0.8	2	1.6	7	5.7	10	8.2	6	4.9	6	4.9	10	8.2
60.1-65.0	2	1.7	6	4.9	6	4.9	6	4.9	12	9.9	11	9.0	0	0	2	1.6	4	3.3
65.1-70.0	2	1.6	4	3.3	4	3.3	4	3.3	8	6.6	10	8.2	0	0	0	0	0	0
70.1-75.0	1	0.8	3	2.5	4	3.3	2	1.6	4	3.3	6	4.9	0	0	0	0	0	0
75.1-80.0	3	2.5	10	8.2	11	9.0	0	0	1	0.8	5	4.1	0	0	0	0	0	0
80.1-85.0	11	9.0	11	9.0	15	12.3	2	1.6	4	3.3	2	1.6	0	0	0	0	0	0
85.1-90.0	2	1.6	5	4.1	14	11.5	2	1.6	2	1.6	3	2.5	0	0	0	0	0	0
90.1-95.0	2	1.6	2	1.7	0	0	0	0	2	1.6	2	1.6	0	0	0	0	0	0

Appendix C4. Frequency distribution of efficiency indices by size of labour force, based Model 2, N=61.

Efficiency (%)	Technical efficiency						Allocative efficiency						Economic efficiency					
	1.0-1.8		1.9-3.0		3.1-		1.0-1.8		1.9-3.0		3.1-		1.0-1.8		1.9-3.0		3.1-	
	No.	%	No.	%	No.	%	No	%	No.	%	No.	%	No.	%	No.	%	No.	%
30.0-35.0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.8	1	0.8	0	0
35.1-40.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1.6	1	0.8
40.1-45.0	0	0	0	0	0	0	1	0.8	1	0.8	1	0.8	3	2.5	4	3.3	4	3.3
45.1-50.0	0	0	0	0	0	0	0	0	3	2.5	0	0	6	4.9	15	12.3	11	9.0
50.1-55.0	0	0	0	0	0	0	1	0.8	4	3.3	4	3.3	10	8.2	14	11.5	12	18.1
55.1-60.0	1	0.8	3	2.5	0	0	2	1.6	6	4.9	11	9.0	2	1.6	9	7.4	11	9.0
60.1-65.0	2	1.6	3	2.5	9	7.4	9	7.4	14	11.5	6	4.9	0	0	1	0.8	5	4.1
65.1-70.0	2	1.6	3	2.5	5	4.1	3	2.5	7	5.7	12	9.8	0	0	0	0	0	0
70.1-75.0	2	1.6	2	1.6	4	3.3	4	3.3	3	2.5	5	4.1	0	0	0	0	0	0
75.1-80.0	4	3.3	12	9.8	8	6.6	0	0	2	1.6	4	3.3	0	0	0	0	0	0
80.1-85.0	9	7.4	13	10.7	15	12.3	2	1.6	1	0.8	5	4.1	0	0	0	0	0	0
85.1-90.0	2	1.6	7	5.7	12	9.8	0	0	4	3.3	3	2.5	0	0	0	0	0	0
90.1-95.0	0	0	3	2.5	1	0.8	0	0	1	0.8	3	2.5	0	0	0	0	0	0