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Rural Organizations, Agricultural Technologies and Production Efficiency of Teff in Ethiopia

Getu Hailu,
Department of Food, Agricultural and Resource Economics,
University of Guelph,
Guelph, Ontario, Canada, N1G 2W1,
Tel: 519-824-4120 ext 53890,
Fax: 519-767-1510,
e-mail: ghailu@uoguelph.ca

Alfons Weersink,
Department of Food, Agricultural and Resource Economics,
University of Guelph,
Guelph, Ontario, Canada, N1G 2W1,
e-mail: aweersin@uoguelph.ca

Bart Minten,
International Food Policy Research Institute (IFPRI),
Addis Ababa, Ethiopia
e-mail: b.minten@cgiar.org

Abstract: We study the production efficiency of teff in Ethiopia. Using a large cross-section of teff plots, we find that teff output could be increased by approximately 25 percent with the available inputs and technology through investments directed to improved gender-sensitive extension service and infrastructure development. The magnitude of technical inefficiency is robust to alternative functional form and various variable specifications. Community discussion groups and distance to the nearest agricultural co-operative are further shown to have a significant effect on technical efficiency. We conclude the paper by discussing the potential policy implications of our findings.

Keywords: Rural Institutions, Technology, Productivity, Efficiency, Teff

JEL codes: D02, D24, C54, P13, N57

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1. Introduction

Economists have conducted considerable theoretical and empirical research on the measurement and sources of differences in productivity. Productivity varies due to differences in technology, efficiency of the production process (Nishimizu and Page, 1982), and differences in the environment in which production occurs. Understanding of how much improvement in on-farm productivity can be achieved from the adoption of high-yielding technology and improved production efficiency has important policy implications. The main interest in this paper is to isolate the efficiency component in order to measure its contribution to productivity of a major staple food crop in Ethiopia, *i.e. teff*.[1] This is important as the Ethiopian government is actively engaged in developing appropriate agricultural strategies for higher production levels with the aim of attaining self-sufficiency in food to cope with the increasing growth in population and the demand for food. In recent years, teff is therefore at the forefront of the agricultural policy and rural development agenda. For example, a recent post in the *The Guardian* states that "[t]he Ethiopian government wants to double teff production by 2015. Its strategy,[…] argues that [teff] could play an important role in school meals and emergency aid programmes, and help reduce malnutrition – particularly among children." (January 21, 2014). The overall vision of The Ethiopian Agricultural Transformation Agency (2013) for the teff value chain states that "An efficient and well-functioning tef value chain that enables a sustainable increase in smallholder tef farmer productivity and profitability while providing high quality output at an affordable price to tef consumers."

Farmers' ability to improve farm productivity is constrained by limited access to better technologies and information about best management practices. Access to information regarding high-yielding technologies and best management practices are commonly provided through publicly funded agricultural extension programs, and through farmers' organizations – *e.g.,* agricultural co-operatives, production practice discussion groups. Farmers' organizations, in particular, link farmers to inputs, outputs and credit markets (Bernard *et al.,* 2010;), and are occasionally "cited as making a crucial contribution to the provision and enhancement of extension services" (FAO, 2010, p.4). The World Bank noted that (1) forming farmer

[1] Teff, *Eragrostis tef*, is one of the grains grow in Ethiopia that significantly contributes to domestic food supply and economy.

cooperatives as part of its smallholder commercialization strategy, (2) promoting extension and advisory services that provides farmer with farmers to receive information, training, demonstrations, and advice, (3) continued growth in public agricultural research expenditure, and (4) support civil society institutions (*i.e.,* community-based organizations) are key elements of rural development objectives (World Bank, 2007). Despite the increasing importance of and public investment in key rural institutions (*e.g.,* extension services and co-operatives), their effect on technical efficiency of participating farmers is limited and not well understood (Seyoum *et al.,* 1998; Khairo and Battese, 2005; Ayele *et al*., 2006; Alene and Hassan, 2008; Thangata and Mequaninte, 2011; Elias et al 2014; Bernard *et al.* 2008).

The majority of the empirical literature on the effect of producer co-operative focuses on examining the productivity effect of member participation and on profit sharing with limited theoretical guidance (Bonin *et al.,* 1993). If producer co-operatives provide technical skill support related to production practices, one may expect participation in co-operatives may enhance production efficiency and productivity. On the other hand, if cooperatives are used as a means of distributing modern inputs without any technical skill support, the activities of the co-op may not be technical efficiency enhancing, but may still enhance productivity through a shift in the production frontier. Producer co-operative may enhance productivity if they allow producers to have access to better technology. For example, Rahmato finds empirical evidence that the productivity of producer co-operatives is one-third lower than the productivity of private farmers (Rahmato, 1994: 289). Bernard *et al.* (2008) find that co-operative membership may not lead to a significant increase in the commercialization (*i.e.,* the share of output supplied to the market) of smallholders' output.

For developing countries the activities of agricultural cooperatives may reduce the overall costs of production in locations that are defined by high transaction costs (*e.g.,* land tenure insecurity, poor links to the market, imperfect information) and risk. Historically, the formation of agricultural co-operatives stemmed from economic concerns associated with market failures resulting from unequal distribution of economic power. The lack of market access or dissatisfaction with terms of trade associated with marketing farm outputs, input purchases, credit services, or other services negatively affects farmers' welfare (Cook, 1995; Hansmann 1988; LeVay, 1983; Goddard *et al*., 2002). Group of farmers acting together in cooperatives may be able to gain economic power associated with size, and maximize their welfare (Bateman et al., 1979; Enke, 1945; Taylor, 1971; Helmberger and Hoos, 1962). This is particularly important in sub-Saharan African countries where farms are typically fragmented in remote rural areas (Manyama *et al.,* 2009). Thus, agricultural cooperatives may provide information, technical assistance, marketing and storage services that are essential in enhancing farm productivity. In the mean time, if the formation of agricultural producer co-operative is mainly driven by political interest, with excessive government interventions as in former socialist systems, membership may reduce productive efficiency (Kodama, 2007). "[P]oliticization of leadership, elite capture, and breakdown in collective action..." (Bernard et al 2010, p. 4) are also cited as detrimental to the success of rural organizations (Tendler 1983; Banerjee et al. 2001).

In this paper we 1) examine the effect of adoption of high-yielding seed variety on teff productivity differences; 2) measure technical efficiency of teff at plot-levels; and 3) examine the effect of farmers' organizations and access to market on plot level technical efficiency of teff production. We use large-scale and detailed household and plot level agronomic data collected in 2012. Absent a genuinely randomized experiment, the plot level data provide a nearly ideal setting for investigating the relationship between farmers' organization and technical efficiency. A few studies have examined differences in technical efficiency for teff production using a variety of cross-sectional datasets. Few have examined the effect of agricultural co-operatives membership (*e.g.,* Abate *et al.,* 2014; Elias et al 2014), agricultural extensions (Seyoum *et al.* 1998; Backman, 2011; Elias *et al.* 2014) and the use of improved technology (*e.g.,* Alene and Hassan 2006; Alene and Manyong, 2006; Alene and Hassan 2008; Elias *et al.* 2014) in shaping efficiency and productivity gains, however, and these have typically not used plot level data at all. Unlike previous teff research that examined technical efficiency (*e.g.,* Elias *et al.,* 2014; Abate *et al*., 2014), we estimate this relationship using much more detailed plot level information. We take into account differences in production technology, plot characteristics, and weather shocks across plots, and investigate the robustness of the effects of farmers' organization on productivity across a variety of specifications.

The findings of the study have important implications for policies geared towards improvement in food and agricultural productivity. First, the measurement of efficiency informs the longstanding debate in the literature about the (*allocative*) efficiency of peasant farmers

(Schultz 1964; Lipton 1968), and interventions to improve food security. The measurement of technical efficiency is important in its own right because it may provide a short-run cost effective option to enhance food security when the adoption of improved technologies is costly. If cost of production efficiency enhancing interventions (*e.g.*, extension education, farm organizations, and infrastructure) outweighs the benefits, then an alternative long-run policy option is to use improved inputs and technologies (Ali and Byerlee, 1991).

The rest of the paper is organized as follows. Section 2 describes our estimation procedures and section 3 discusses data. Section 4 presents the major results. Conclusions are summarized in section 5.

2. Methods

In this study we draw from the welfare economics Pareto-Koopmans concept of efficiency (Koopmans, 1951) to define technical efficiency that focuses on the efficient subset of technology. A production is technically efficient if an increase in any output or a decrease in any input is impossible without a simultaneous decrease in at least one other output, or increase in at least one input. Debreu (1951) and Farrell (1957) provide input-oriented measures of technical efficiency as the maximum equiproportional reduction in all inputs. Considering n inputs and m outputs, the operation of any firm can be defined by a production set, ψ, in the Euclidean space R_+^{n+m}:

$$\psi = \{(y, \boldsymbol{x}) \mid x \in R_+^n, y \in R_+^m, (x, y) \text{ is feasible}\}, \quad [1]$$

where $\mathbf{x}$ is the vector of inputs, and y is the vector of outputs. The Farrell output measure of technical efficiency for a farm operating at level (x^0,y^0) is defined as:

$$\theta(x^0, y^0) = \sup\{\theta \mid \theta y^0 \mid x \in P(x^0)\} = \sup\{\theta \mid (x^0, \lambda y^0) \in \psi\}. \quad [2]$$

where $P(x) = \{y \in R_+^m \mid (x, y) \in \psi\}$ is the output correspondence set, and $\theta(x^0, y^0) \leq 1$ is a radial expansion of outputs the firm should achieve to be output-efficient in the sense that $(x^0, \theta(x^0, y^0)y^0)$ is on the frontier.

In practice, the production set, ψ, and the efficiency score $\theta(x^0, y^0)$ are unknown. The problem is thus how to estimate ψ and $\theta(x^0, y^0)$ for a random sample of decision making units: $\chi = \{(X_i, Y_i) \mid i = 1, \ldots, n\}$. Two major empirical approaches are developed and widely used to measure technical efficiency: a mathematical programming-based technique known as Data Envelopment Analysis (DEA) (Charnes *et al.,* 1978) and an econometric technique known as stochastic frontier analysis (SFA) (Aigner *et al.,* 1977; Meeusen and van den Broeck, 1977). Both methods involve estimation of "best practice" frontiers, with the efficiency of a specific decision making unit measured relative to the frontier. DEA places less structure on the frontier and is non-stochastic; that is, any departure from the frontier is measured as inefficiency.

The stochastic frontier involves specification of a functional form for production (Aigner *et al.,* 1977; Meeusen and van den Broeck, 1977). The methodology is stochastic in that firms can deviate from the frontier because of inefficient or random shocks. The error term that is associated with the frontier function is hypothesized to consist of an efficiency component and a purely random component. Efficiency is measured by deconvolution of the efficiency component from the overall error term. In this paper, we represent teff production technology by stochastic frontier (Kumbhakar and Lovell, 2000; Battese and Coelli, 1995):

$$ln(y_{ijp}) = f(\mathrm{x_{kijp}}, \mathrm{D_{ijp}};\ \beta_{ij}) + v_{ijp} - u_{ijp} \qquad [3]$$

$$v_{ijp} \sim N[0, \sigma_v^2],\ u_{ijp} = |U_{ijp}|, |U_{ijp} \sim N[\mu_{ijp}, \sigma_u^2], \mu_{ijp} = \delta_0 + \delta_1' z_{ijp}$$

where *i* indexes household, *j* indexes *kebele*[2] (village), and *p* indexes plot, k indexes inputs; y_{ijp} is the actual output; β_{ij} is the vector of kebele-fixed effect; $f(\mathrm{x_{kijp}}, \mathrm{D_{ijp}};\ \beta_{ij})$ is the production technology represented by a trans-log or Cobb-Douglas functional forms; x_{ijp} is a k×1 vector of input quantities; β is a vector of parameters to be estimated; D_{ijp} is a vector of plot technology and characteristics; v_{ijp} is assumed to be an independently and identically distributed $N(0,\sigma v^2)$ stochastic error term, and independent of u_{ij}; u_{ij} is assumed to be an independently and identically distributed non-negative truncation of the $N(\mu,\sigma_u^2)$ distribution, and thus accounts for production inefficiency in production. z_{ijp}'s are household-fixed effect variables hypothesized to affect efficiency, (*e.g.,* co-operative membership, community meetings, and urban proximity); δ's are parameters to be estimated. The production function and the inefficiency effects are estimated simultaneously in a single stage (Coelli, 1995; Wang and Schmidt 2002) using maximum likelihood technique. The procedure for estimating production efficiency using

[2] A *kebele* is the smallest administrative unit in Ethiopia. A kebele consists of a number of villages.

equation [3] is to first estimate β and $\varepsilon_{ijp} = v_{ijp} - u_{ijp}$ by applying the maximum likelihood and then to calculate production efficiency for each observation in the sample as the conditional expectation $E(\exp(-u_{ijp})| \varepsilon_{ijp})$ (See Kumbhakar and Lovell, 2000, for more details). This provides an estimate of production efficiency as the ratio of actual output to frontier (*i.e.,* efficient) output. If distributional assumptions are imposed on the error terms, the density function of ε_{ijp} , $f(\varepsilon_{ijp})$, and the joint density function $f(u_{ijp}, \varepsilon_{ijp})$ are first determined and then an expression for the conditional mean of $\exp(-u_{ijp})$ based on the distribution $f_u(u_{ijp}| \varepsilon_{ijp})$ is derived.

To assess the robustness of the estimated farmers' organization effects on technical efficiency, we estimate alternative econometric specifications. For example, we include a full set of *kebele*-fixed effects and plot characteristics to control for shocks that may be correlated with farmers' organization and technical efficiency. We evaluate these alternative specifications based on standard specification tests.

The marginal effects of the inefficiency effect variables (*i.e., z*-variables) can be obtained as (Wang, 2002):

$$\frac{\partial E[U_{ijp}]}{\partial z[k]} = -\frac{\partial E[\ln(y)]}{\partial z[k]} = \delta[k]\left[1 - \Lambda\left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] - \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right] \qquad [6]$$

where $\Lambda = \frac{\mu_{ijp}}{\sigma}$, and ϕ and Φ are the probability and cumulative density functions of a standard normal distribution, respectively. The marginal effects on $E[u_{ijp}]$ measure how an increase in a z-variable changes the expected inefficiency (Bera and Sharma 1999).

3. Background Teff

In spite of its low yield/productivity (see Table 1) relative to other cereals, teff's contribution to the national economy cannot be over emphasized. Teff ranks first in total production and total cultivated cropland among other major cereals grown in Ethiopia. Teff's land productivity, however, lags behind major cereals such as maize and wheat (Table 1). Consider, for example, in 2010/11 crop year, the national average yield for teff is approximately 100 percent below the national maize yield, and 38 percent lower the national wheat, and 140 percent lower than rice. Over the period 2004-2011, teff's land productivity growth has been lower than that of the top cereals grown in Ethiopia. Not only was there a gap in land productivity of teff and other major cereals, but also in many cases the gap had grown from 2004/05 to 2010/11. However, it is catching up more recently. The gap in productivity may reflect the low R&D investment in teff seed improvement, a short history of teff genotype improvement programs, limited resource for teff research as well as lack of spillover from international research given that teff is only produced in a major way in Ethiopia and Eritrea (Haile *et al*., 2004).

Teff is major crop in Ethiopia, as shown by production levels and area allocations (Table 1). Teff is widely grown in 46 zones and 9 special woredas in Ethiopia, and "[...] more than 83 percent of the country's Teff production comes from 19 zones [...] in Tigray, Amhara and Oromia regions." (Tadesse 2009: p.13). East Gojjam and West Gojjam zones are the two top teff producing zone with more than 17 percent of the national annual teff production (Table 2). Other major teff producing zones include North Gonder, North Shewa and West Gojjam zones (in Amhara region), and West Shewa, East Shewa and South West Shewa zones (in Oromia region).

With the growing interest in both a naturally gluten-free alternative to wheat flour and a nutrient-rich ingredient in the baby food industry, teff is set to be world's next 'super-food' and it is getting international attention (The Guardian, 2014). While the Ethiopian government wants to promote export agriculture, it is however concerned about the potential price effect for local consumers by opening up export markets for local cereals and it therefore does until now not allow teff exports. Boosting the productivity of teff would help local consumers by making teff more readily available as well as provide potential surplus towards exports.

Interest in policies geared toward the formation of agricultural producer cooperatives (PCs), community-based organizations and agricultural extension services in Ethiopia is growing, and are seen as integral part of the national strategy for agricultural transformation. The 1998 Cooperative Societies Proclamation (No. 147/1998(7)), and the Amendment act No. 402/2004, defines cooperatives as organizations “formed by individuals on voluntary basis,” and states that they “participate in the free market economic system.” The five year co-operative development programme demonstrates the recognition by both federal and regional governments of the key role co-operatives play in economic and social development, food security and poverty reduction (Emana, 2008).

For example, Participatory Demonstration and Training Extension System aims at increasing farm productivity through promotion of the adoption of improved seeds, fertilizers and on-farm demonstrations of improved farm practices (Gebremedhin *et al.,* 2009; Elias et al 2014).

4. Data

The data for the study come from 1,200 stratified randomly selected households survey conducted by the Economic Development Research Institute (EDRI) and International Food Policy Research Institute (IFPRI). The main purpose of the survey is to understand the teff value chains to make recommendations to policymakers to improve the performance of value chain for farmers, wholesalers, retailers, and consumers. The survey is conducted in 2012 in sixty villages (Kebele) in twenty districts (Woreda) in five major teff producing zones (regions) of Ethiopia (East Gojjam, West Gojjam, East Shewa, West Shewa, and South West Shewa). In 2007/08 cropping year, the five zones represent approximately 34 percent of national teff production area and 31 percent of teff cropped area (see Table 2).

To ensure that data would be representative of teff areas cultivated in these five zones, the following procedure was followed. First, within each production zone, the *woredas* were ranked from smallest to largest producer (in terms of area cultivated). We then divided the *woredas* in two, the less productive (cultivating all together 50 percent of the area) and the more productive *woredas* (cultivating all together 50 percent of the area). Two *woredas* were randomly selected from each group. Second, a list of all the *kebeles* of the selected *woredas* was then obtained. Two *kebeles* were randomly chosen from the top 50 percent producing *kebeles* and one from the low 50 percent producing *kebeles*. Third, a list of all teff producers in the selected *kebeles* was then made. They were ranked from small to large teff producers (based on areas cultivated). We then divided the farmers in two groups, the small production (cultivating all together 50 percent of the area) and the large production farmers (cultivating all together 50 percent of the area). A total of 20 farmers were then selected: 10 from the small production and 10 from the large production farmers. In total, 240 farmers were interviewed per zone.

Most teff growers usually cultivate multiple monoculture small plots. The detailed cross sectional data contains household and plot level information on teff production. The data includes 1) teff production inputs: land size, seed, labour, fertilizer, herbicides and oxen; 2) type and attributes of technologies: high-yielding seed variety (*quncho* and others) and traditional varieties, crop rotation, type; different colours of seeds, types of fertilizer, mobile phone; 3) plot characteristics: size, slope, soil colour, easy of ploughing, walking distance from homestead; 4) farmer characteristics: gender, age, education, household size; 5) Extension: extension visits, agricultural cooperative, community meeting, provision of non-governmental organization, being a model farmer; 6) weather crop shocks: rains level and timing, logging, frost/hailstorm; 7) access to market and services: distance to the nearest dry season road, all-weather road, asphalt/tar road, market place, administrative center, agricultural cooperative, agricultural input dealer. The data have been extensively cleaned to remove inconsistencies.

Summary statistics for the variables used to estimate the stochastic production frontier are provided by zone in Table 3. Household heads are almost exclusively male (95 percent), the average age of the household age is 45 years, 42 percent of the sample farmers did not complete any schooling, 64 percent of the households are co-operative member, the average distance from agricultural co-operative is approximately one hour with a range of 0 to 7 hours. Approximately 70 percent of the farmers participated in a community meeting to discuss about teff production practices in the year prior to the survey. Seventy-five percent of the sample farmers received one or more visits from extension agents in the two years prior to the survey. The large majority of the extension services is provided by the government while about 7 percent of the extension services are provided by non-governmental organizations (NGOs). The average number of number of plots per household is 1.2 with a range of 1 to 6 plots. Approximately 35 percent of the sample farmers are model farmers. Average yield per hectare is approximately 11 quintals or 1100 kgs, which is lower than the 2010/2011 national average yield of 1260 kilograms per hectare, but higher than the 2004/05 average national yield of 950 kilograms per hectare (Demeke and Marcantonio 2013).

5. Results and Discussions

5.1. Distribution of Production Efficiency

In this section we present the estimates of technical efficiency and discuss the distribution of technical efficiency. Table 4 provides the maximum likelihood parameter estimates of the stochastic trans-log and Cobb-Douglas teff production frontiers[3]. Unless indicated otherwise, the discussion in this paper is based on a *kebele*-fixed effect translog model with controls for weather shocks included (Model 4). The λ-parameters[4] are all statistically significant, meaning that the stochastic frontier model is an adequate representation of the data. The deviations from the frontier are explained by technical inefficiency and random events. We find that about 50 percent of the deviations from the frontier are explained by technical inefficiency effects whereas the rest 50 percent of the deviations are explained by random effects. We also find that the spearman rank correlation coefficients of the estimates of technical efficiency among the four models are 0.97 or higher.

Figure 2 presents the distribution of the levels of technical efficiency. Table 4 provides average technical efficiency by household characteristics. The mean technical efficiency for the sample plots is 74 percent with a standard deviation of 13 percent, and a range of 15 percent to 96 percent. This result is consistent with a farm technical efficiency meta-analysis conducted for 169 countries by Bravo-Ureta *et al.* (2007) where they find an average technical efficiency of 77 percent for 26 cases of Africa, 75 percent for 189 cases of Asia, 78 percent for 47 cases of Latin America, and 72 percent for 45 cases of East Europe. The average technical efficiency for 158 cases of low income countries is 75 percent (Bravo-Ureta *et. al.* 2007). A meta regression

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[3] The analysis in the study is conducted using STATA 12.1 Copyright 1985-2011 StataCorp LP.

[4] The λ-parameter (*i.e.,* $\lambda = \sigma_u / \sigma_v$) measures the relative contributions of inefficiency to the deviations from the frontier. If λ is closer to zero the random effect dominates, hence the deviation from the frontier is dominated by random effects beyond the control of the farmer. On the other hand, higher values of the λ-parameter suggest that the deviations from the frontier are mainly due to technical inefficiency effects. As well, the contribution of inefficiency to the overall variance is given by $\frac{var[u]}{var[\varepsilon]} = \frac{[\frac{\pi-2}{\pi}]\sigma_u^2}{[\frac{\pi-2}{\pi}]\sigma_u^2+\sigma_v^2}$ (Greene 2008).

analysis of African agricultural by Ogundari (2014) also shows a significant agricultural production inefficiency, with an average of approximately 68 percent production efficiency. In a recent study, Elias *et. al.* (2014) find technical efficiency of 72 percent with a range of 33 percent to 96 percent for teff producers in Gozamin district of East Gojjam zone (Ethiopia). A study conducted in Amhara, Oromia, SNNP and Tigray regions find average technical efficiency of 65 percent for teff producers (Abate *et al.* 2014).

Our estimated technical efficiency varies widely. The mean technical efficiency scores by quartile are 55 percent (with a standard deviation of (SD) 10 percent) in quartile 1 (the worst 25 percent of the plots), 72.5 percent (SD=3 percent) in quartile 2, 80.5 percent in quartile 3 (SD=1.8 percent), and 87 percent (SD = 2.5 percent) in quartile 4 (the best 25 percent of the plots).

5.2. Main Results

The main purpose of the study is to examine the effect of producer organizations and proximity to urban areas on plot level technical efficiency. With the exception of West Gojjam, the descriptive results in Table 5 show that co-operative membership may not have a significant effect on the technical efficiency of sample plots. The maximum likelihood parameter estimate for the coefficient of co-operative membership in Table 4 is statistically insignificant, meaning that there may not be differences in technical efficiency between plots managed by members and non-members. Proximity to agricultural co-operatives and participation in community meetings held to discuss teff production practices have positive and statistically significant effects on technical efficiency, and are robust to the choice of functional forms and weather shock specifications (Table 4). The magnitudes of the estimated effects are also robust to the specification of the stochastic frontier with only modest differences. Participation in extension services has a positive and statistically significant effect on technical efficiency at a 10 percent significance level for the Cobb-Douglas production function, but is statistically insignificant for the trans-log functional form.

5.2.1. Farmers' Organizations: Co-operatives, Community Groups & Extension

The stochastic frontier result in Table 4 is consistent with the observation in Table 5. The estimate for the coefficient of co-operative membership is statistically insignificant, meaning that there may not be differences in technical efficiency between members and non-members. However, participation in a community meeting held to discuss teff production practices has a positive effect on technical efficiency. The marginal effect for participation in a community meeting is -0.06, and this effect translates to a 6 percent increase in output or productivity (Table 6). The differences in the results for participation in producer co-operatives and community meetings may be explained by the purpose they are organized for. Co-operatives are mainly targeted at providing access to input markets and commercialization of the sector - in particular producer co-operatives provide access to fertilizer and other inputs. If there are not technical training component embodied in the distribution of inputs, the effect of producer co-operative membership might be captured by the effect of the use of fertilizer and other modern inputs. As well, the effect of producer co-operative may be more about *allocative (pricing) inefficiency* by correcting for market failure arising from information asymmetries and higher transaction costs in input and output markets.

The presence of producer co-operative may also have spillover (externality) effect on non-members in that both members and non-members may have equal access to the services of the co-operative. Elias *et al.* (2014) also find evidence that membership in producer co-operatives may not have a statistically significant effect on the technical efficiency of teff producers in Ethiopia. Meanwhile, community groups are organized to share technical skill supports about and the timing of teff production practices/process, and hence participants might be better at using the existing resources and technology more efficiently. Others find evidence that membership in producer clubs or associations have a positive effect on technical efficiency (Binam *et al.,* 2005, Chirwa, 2003, Idiong, 2007, Abate *et al.,* 2014) in cereal and oil crop production.

We find that plots operated by households with one or more visits from extension agents in the two years prior to the survey have higher technical efficiency than otherwise for the Cobb-Douglas production frontier. Alene and Hassan (2003) find that participation in extension programs has a positive but statistically insignificant effect on technical efficiency. Others find that farms in Crete "using both public and private extension services achieved a higher degree of technical efficiency than those using either public or private extension services, and farms with no extension services were found to be the least efficient." (Dinara et al., 2007). Plots operated by model farmers ('outstanding farmer') also have a higher technical efficiency, and the effect is statistically significant. The average marginal effect for being model farmer is -0.04, meaning that outputs for model farmers are higher by approximately 4 percent, all other things being constant.

5.2.2. Remoteness, access to markets and services

We included a number of variables to capture the effect of access to market and services using distance from the nearest dry season road, all-weather road, asphalt/tar road, market place, administrative center, agricultural co-operative and agricultural input dealer. A *priori* we do not have a clear directional hypothesis regarding distance variables. Distance to market/road or services may have negative or positive effects, and hence the relationship between technical efficiency and distance is ambiguous. Access to market/road can increase productivity by providing farmers with access to inputs, outputs and credit markets, and technology and relevant information. At the same time, access to market/road can increase the opportunity cost of labour (and or land) input, and can create disincentive to exert enough effort on production leading to a negative relationship between distance and technical efficiency.

We find mixed results for variables capturing access to market/road and services. The coefficients of distance from the nearest dry season road, all-weather road, asphalt/tar road, administrative center, and agricultural input dealer are all statistically insignificant. We find that distance to the nearest market has a positive effect on technical efficiency, meaning that proximity to the nearest market place reduces technical efficiency of teff production. The marginal effect for the nearest market place is -0.04, meaning that an hour increase in the distance to the nearest market increase output by 4 percent. This result is consistent with the finding by Nehring *et al.* (2006) according to which urban proximity negatively affects farmers' technical efficiency level. The closer a plot is to the nearest market place, the lower is the technical efficiency of the plot. Proximity to market place may allow farmers to participate in leisure and off-farm income generating activities, which may provide incentive to spend less time and efforts on the farm. In this situation, distance from the market place may create incentives and less distraction from off-farm activities for farmer to spend more time on managing teff plots. As well, farm labour supply tend to be scarce for farms in close proximity to market place as the labor force tend to migrate to urban areas to seek off-farm income opportunities. Further, often proximity to marketplace may not serve as a measure of remoteness, as “local markets often exist in the most remote communities, but they operate in isolation from the rest of the world....” (OECD, 2012; p.95). The local markets might be distant from urban centres where supplies of goods and services, and opportunities for social interaction are concentrated. Our result on proximity to market place contradicts our finding regarding proximity to agricultural co-operatives and studies that find positive relationship between distance from market and technical inefficiency (*e.g.,* Alene and Hassan 2003).

We find that distance from agricultural co-operative has a negative and statistically significant effect on the technical efficiency of plots. The marginal effect of distance from the nearest agricultural co-operative is 0.05, all other things constant, suggesting that an hour increase in distance from an agricultural co-operative may reduce output/productivity by approximately 5 percent. Closeness to input supplier or cities may help to reduce transaction costs and help exploit economies of scale (reference) and provide easy access to better information on management practices and available new technologies (Jacobs, 1969). Our finding regarding distance to the nearest agricultural co-operative may also speak to why “...a striking fact that remote rural areas suffer the most from poverty” (World Bank, 1992; Jalan and Ravallion, 2002). Our results for distance to the nearest agricultural co-operatives may also underscore the importance of the access to and availability of services provided by co-operatives in the local areas rather than membership per se, and a potential spillover effects in that non-members may receive benefits from the co-operative.

5.3. Technology and Input Use

It is important to recognize the heterogeneity in technologies used by teff producers in determining the frontier. The sign of the estimated coefficients of inputs for the Cobb-Douglas stochastic frontier are all positive as expected. For the trans-log stochastic production frontier most of the interaction terms are statistically significant, and LR test suggests that the trans-log specification outperforms the Cobb-Douglas specification. For the trans-log functional form, inputs and outputs are scaled to have a unit means so the first order coefficients can be interpreted as elasticities of output with respect to inputs. For example, the coefficient for the log of land is 0.604 and statistically significant at a 1 percent significance level, suggesting that a 10 percent increase in teff plot size, on average, may lead to an approximately 6 percent increase in teff output. This result underscore the vital role the expansion of land plays in growth in real agricultural output.

One of the key findings in the study is the positive effect of the use of improved teff seed varieties on plot productivity which results from a shift in the stochastic production frontiers. One recently released high-yielding teff variety is *quncho*, which means "top most". Officially released in 2006, *quncho* was developed by the Debre Zeit Agricultural Research Center (DZARC) (Tefera *et al*., 1995, 2001; Assefa *et al*., 2011). Yield performance on experimental trials with *quncho* was significantly higher than national average yields for teff (Assefa *et al.*, 2011). The coefficients of both *quncho* and other improved seed varieties are positive and statistically significant, suggesting that plots with improved seeds return higher yield or are more productive. Relative to traditional seeds, the use of improved seed varieties has a positive effect on teff production – teff output or productivity is higher by approximately 10 percent for plots with *quncho* and other improved varieties[5]. The observed increase in productivity attributed to the use of improved seeds underscores the role the adoption of improved agricultural technology may play in poverty reduction in sub-Saharan Africa. These results are robust to the inclusion of weather crop shocks and to functional forms. This finding is in agreement with Minten and Barrett's (2008) findings which showed that an increase in land-intensification technologies in Madagascar is associated with higher rice yields. The present findings seem to be consistent with other teff efficiency research that finds a positive relationship between improved seed varieties and technical efficiency (Elias *et al.* 2014). Despite the strong relationship between the use of improved seed varieties and productivity of the sample plots, "area covered by improved seeds [in Ethiopia] has been less than 1 percent" (Fufa et al., 2011; p.16) over the past decade.

We also find that walking distance from homestead to a plot has a negative effect on teff productivity, meaning that plots closer to homestead are on a higher frontier than remotely located plots. This phenomenon has also been shown in research conducted in other developing economies (Tittonell *et al.,* 2007). Output decreases by approximately 1.4 percent for a 10

[5] The interpretation of dummy variables in the model follows Halvorsen and Palmquist (1980): $100*(e^c-1)$, where c is the coefficient of the dummy variable.

minutes increase in the distance to a plot from homestead. We also find that both the frequency and ease of ploughing a plot have positive effects on land productivity, a unit increase in the number of ploughing may increase productivity of a plot by approximately 4 percent, whereas plots that are easier to plough are 4.5 percent more productive. The importance of ploughing for teff productivity might be related to the small size of the grain which makes it difficult for the seed to germinate (Assefa *et al.*, 2011) in heavy, unbroken soil (Fufa *et al.* 2011). Teff plot ploughing frequency ranges from 3 to 12 times depending on agricultural ecology. Meanwhile, Fufa *et al.* indicates that conservation tillage (*i.e.,* no tillage) promoted by Sasakawa Global 2000 has resulted in high teff yield.

5.4. Household and Farm Characteristics

We find that the estimate of the coefficient of age is positive and statistically significant, meaning that plots managed by younger farmers are technically more efficient than those managed by older farmers. The empirical result for age-efficiency relationship is mixed. For example, Mathijs and Vranken (2000) and Munroe (2001) consider age as a proxy for farming experience and find a positive relation with technical efficiency in samples of Hungarian and Polish crop farms, but a negative effect in Bulgarian crop farms and Hungarian dairy farms. Household size has a positive and statistically significant effect on technical efficiency at a 10 percent significant level. Plots managed by a female tend to have lower technical efficiency than those managed by male or both, and the gender effect is statistically significant. This study corroborates the findings in Burkina Faso that shows female farmers technically less efficient than male farmers. This is an important finding and emphasizes the need to gender-targeted services in the agricultural sector. These differences can be explained in part by limited access to productive resources due to tradition, culture and other institutional and economic constraints. In contrast, Simonyan *et al.* (2011) estimated separate frontiers for male and female farmers and find that female maize farmers in Nigeria are technically more efficient than their male counterpart. Dadzie and Dasmani (2010) as well find that the female farm entrepreneurs are technically more efficient than males in food crop production in Ghana. Our results also differ from of previous studies by Moock (1976) and Bindlish and Evenson (1993) in Kenya, Bindlish *et al.* (1993) in Burkina Faso, Saito *et al.* (1994) in Kenya and Nigeria, Adesina and Djato

(1997) in Cote d'Ivoire, and Tiruneh *et al.* (2000) in Ethiopia which show female managed farms are equally efficient as male managed crop farms.

Table 5 presents the distribution of technical efficiency by size categories, and shows that there are no discerned differences in the distribution of technical efficiency across farm size categories. Smaller plot are as efficient as larger plots. With the exception of West Gojjam, plots managed by female only tend to have a lower technical efficiency than plots managed by male or both male and female, which is consistent with the estimates of the inefficiency effects.

6. Concluding Remarks

The purpose of this paper is to examine the effects of producer organizations, access to market/road and services, on technical efficiency of teff producers; and the use of improved seed on teff productivity. For this, we use a stratified random sample of 1200 smallholders in five major teff growing regions. We find that relative to traditional seeds, the use of improved seed varieties has a positive effect on teff output or productivity – teff output is higher by approximately 10 percent for plots with improved seeds variety. To realize the full potential of agricultural innovations, our results suggest that intensifying efforts to scale up promising agricultural technologies (*e.g., quncho seeds* and fertilizer) through the use of "smart subsidies" (World Bank, 2007) to farmers can be an effective strategy for increasing agricultural productivity. Currently, only less than one percent of the cultivated teff area is covered by improved seed varieties in Ethiopia (Fufa *et al.* 2011).

We further find evidence that there is significant technical inefficiency (approximately 25 percent) in teff production for the sample plots. Several short-term and long-term policy implications can be drawn from evidence in this study. First, the 75 percent average technical efficiency suggest that there are significant short-term potential for increasing output or productivity of the sample plots by approximately 25 percent through reorganization of input utilization. Demeke and Marcantonio (2013) notes that a total of 6.2 million farmers grew teff grain, with a total production of 34.83 million quintals in 2011. If we assume the level of inefficiency we observed carries on to the population of teff growers, increasing in technical efficiency may translate into a significant gain in real output. To realize the 25 percent potential gain in real output from improvement in production efficiency, however, requires additional public investments in human capital (*e.g.,* education, technical training, extension) and public infrastructure, meaning the need for further analysis of the cost-effectiveness of improving technical efficiency. The net benefit hence depends on the difference between the benefits from improvement in efficiency and the cost of the interventions. Future research that explores whether the investment in training programs and other efficiency enhancing interventions are cost effective to justify the required interventions is warranted.

Second, given that we find limited evidence that co-operative membership and visits with extension agents have significant effects on technical efficiency of teff producers, our results suggest a need to re-visit the services of the extension program. However, we do find that interventions targeting self-organized farmers' groups and model farmers may make a significant contribution to productivity growth. This confirms recent work by Krishnan and Patnam (2014), who also document the large effects of neighbors for adoption, especially after the initial introduction of new technologies through extension agents. Moreover, we further show the importance of including and specifically targeting women in community discussions as well as extension and that closing the gender gap might lead to important teff productivity increases. Consequently, combining information provision for a targeted sub-population along with infrastructure and communication networks developments may provide an inexpensive way of expanding the take-up rate of yield enhancing technologies and practices.

We would like to end with a note of caution. While our analysis is based on a rare, large-scale, recent, and detailed dataset on teff production practices, the analysis is however hampered by lack of panel data which would allow for the control of household or plot fixed effects or by lack of access to randomized controlled trials. Such datasets would allow better control for endogeneity problems that might possibly be present in some of the presented analysis. Addressing such possible problems through the collection of such types of datasets is left for future research. While the caveats should be borne in mind, we believe that the results nonetheless provide important new evidence on the impact of rural institutions, infrastructure and technology on teff productivity.

7. References

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Table 1 : Estimates of production, area cultivated, and productivity of teff

	2004/2005			2010/2011		
	Production (000' tonnes)	Area (000' hectare)	Yield (quintals ha^{-1})	Production (000' tonnes)	Area (000' hectare)	Yield (quintal ha^{-1})
Teff	2026	2136	948.50	3483	2761	1261.50
Barley	1328	1095	1212.79	1703	1047	1626.55
Wheat	2177	1398	1557.22	2856	1553	1839.02
Maize	2394	1393	1718.59	4986	1963	2539.99
Sorghum	1726	1254	1376.40	3960	1898	2086.41
Millet	333	313	1063.90	635	408	1556.37
Oats	57	45	1266.67	48	31	1548.39
Rice				90	30	3000.00

Source: Demeke and Marcantonio (2013; p. 7)

Table 2 Major teff producing zones at national level

Region	Zone	Production in quintals	% share	Area in hectares	% share	Yield
Tigray	Central Tigray	694607.38	2.32	69262.03	2.7	10.03
	South Tigray	672192.75	2.25	59695.43	2.33	11.26
Amhara	North Gonder	1561611.93	5.22	143897.66	5.61	10.85
	South Gonder	1167656.4	3.9	126752.8	4.94	9.21
	North Wollo	861151.82	2.88	65744.04	2.56	13.1
	South Wollo	1273186.14	4.25	113828.84	4.44	11.19
	North Shewa	1680250.12	5.61	138755.42	5.41	12.11
	East Gojjam	*3018976.49*	*10.09*	*221752.56*	*8.64*	*13.61*
	West Gojjam	*2181529.41*	*7.29*	*142451.8*	*5.55*	*15.31*
	Awi	586836.59	1.96	59111.09	2.3	9.93
Oromia	East Wellega	865751.26	2.89	71121.17	2.77	12.17
	Illubabor	970097.94	3.24	66128.6	2.58	14.67
	Jimma	1374056.13	4.59	130698.04	5.1	10.51
	West shewa	*1599282.42*	*5.34*	*141809.87*	*5.53*	*11.28*
	East Shewa	*1978854.34*	*6.61*	*154506.02*	*6.02*	*12.81*
	S. west shewa	*1535776.12*	*5.13*	*126100.24*	*4.92*	*12.18*
	North Shewa	1100963.83	3.68	113056.99	4.41	9.74
	Arsi	951920.38	3.18	91128.81	3.55	10.45
	Horoguduro	895868.97	2.99	70296.51	2.74	12.74
	Total (19 zones)	24970570.42	83.43	2106097.92	82.1	11.86
	National total	29,929,234.99		2,565,155.22		11.67

Source: Tadesse (2009) (2007/08 annual agricultural sample survey, CSA). Note that the sample zones are in italics.

Table 3 Descriptive statistics of output and inputs by zone

Variables	East Gojjam	West Gojjam	East Shewa	West Shewa	SW Shewa
Inputs and output					
Output (Quintal/ha)	14.94	10.83	12.54	8.93	8.02
Seed (kg/ha)	33.41	45.42	59.97	49.47	38.02
Dap (kg/ha)	86	149	104	69	98
Labour (ME/ha)	159.64	194.67	110.28	169.27	93.4
UREA (kg/ha)	137	70	54	51	74
Herb ($/ha)	5.31	49.84	43.98	86.21	42.07
Plot Size (ha)	0.31	0.27	0.65	0.52	0.6
Oxen (#)	2.07	1.64	5	2.93	3.13
Seed characteristics					
Quncho seed variety (0/1)	0.175	0.297	0.301	0.062	0.142
Improved seed variety (0/1)	0.101		0.09	0.048	0.247
Traditional seed variety (0/1)	0.724	0.703	0.609	0.89	0.611
Magna seed colour (0/1)	0.151	0.002	0.282	0.052	0.278
White seed colour (0/1)	0.585	0.578	0.498	0.478	0.495
Mix seed colour (0/1)	0.041	0.27	0.031	0.133	0.115
Red seed colour (0/1)	0.223	0.149	0.19	0.337	0.112
Plot Characteristics					
Red soil (0/1)	0.267	0.334	0.092	0.305	0.044
Brown soil (0/1)	0.147	0.218	0.298	0.165	0.174
Black soil (0/1)	0.50	0.334	0.336	0.51	0.629
Mix soil (0/1)	0.086	0.114	0.275	0.02	0.153
Meda /level (slope) (0/1)	0.853	0.807	0.84	0.641	0.936
Dagetama (hilly) (0/1)	0.106	0.18	0.128	0.327	0.05
Gedel – very steep (0/1)	0.041	0.013	0.033	0.032	0.014
Crop Rotation (0/1)	0.477	0.56	0.565	0.912	0.511
Walking distance (mins)	24.579	13.752	22.304	12.976	14
Household characteristics					
Distance - all weather (hrs)	1.231	1.164	0.51	0.913	0.77
Distance to coop (hrs)					
Mobile Ownership (0/1)	0.223	0.105	0.632	0.267	0.471
Household Head Education (#)	5.242	6.796	3.784	3.998	4.185
Household Head Male(0/1)	0.985	0.954	0.962	0.946	0.944
Household Head Age (#)	43.445	45.273	46.502	45.806	46.224
# Visits with extension agents	2.55	1.648	1.118	1.838	1.872
# Community meetings	2.998	3.035	1.834	2.776	2.677
Cooperative member (0/1)	0.765	0.666	0.505	0.531	0.741
Model Farmer (0/1)	0.43	0.374	0.351	0.299	0.494
Number of plots	596	455	612	501	664

Table 4 Stochastic teff production frontier

	(Model 1: CD)		(Model 2: CD-Shock)		(Model 3: TL)		(Model 4: TL-Shock)	
				Production Frontier				
Ln(Land)	0.643***	(20.75)	0.643***	(21.02)	0.638***	(14.46)	0.637***	(14.85)
Ln(Seed)	0.178***	(6.98)	0.174***	(6.91)	0.0891***	(2.88)	0.0870***	(2.82)
Ln(Labor)	0.0619**	(2.39)	0.0666**	(2.53)	0.00887	(0.30)	0.0136	(0.45)
Ln(Loxen)	0.0188**	(2.03)	0.0198**	(2.19)	0.0605***	(2.95)	0.0553***	(2.75)
Ln(Dap)	0.0103**	(2.37)	0.00920**	(2.10)	0.105***	(3.55)	0.100***	(3.75)
Ln(UREA)	0.00526	(1.59)	0.00574*	(1.75)	0.00651	(0.30)	0.00671	(0.32)
Ln(Herbicide)	0.00452*	(1.76)	0.00447*	(1.77)	0.0700***	(3.20)	0.0767***	(3.50)
Qunchov	0.0980***	(3.02)	0.0947***	(2.91)	0.0929***	(2.98)	0.0929***	(2.98)
Improved	0.112***	(3.01)	0.113***	(3.05)	0.109***	(3.06)	0.109***	(3.06)
White_seed	-0.0338	(-1.08)	-0.0258	(-0.81)	-0.0306	(-1.02)	-0.0229	(-0.76)
Mix_seed	-0.0778*	(-1.75)	-0.0788*	(-1.77)	-0.0800*	(-1.89)	-0.0821*	(-1.93)
Red_seed	-0.0800**	(-2.12)	-0.0799**	(-2.13)	-0.0782**	(-2.18)	-0.0787**	(-2.19)
Brown_soil	0.0409	(1.36)	0.0320	(1.08)	0.0515*	(1.75)	0.0433	(1.50)
Black_soil	0.0530**	(1.97)	0.0551**	(2.09)	0.0568**	(2.18)	0.0584**	(2.27)
Mix_soil	0.0322	(0.90)	0.0410	(1.15)	0.0218	(0.63)	0.0301	(0.88)
Hilly	-0.0746***	(-2.82)	-0.0642**	(-2.41)	-0.0750***	(-2.82)	-0.0645**	(-2.43)
Very Steep	0.0639	(1.12)	0.0797	(1.39)	0.0582	(0.99)	0.0734	(1.25)
Rotation	0.0177	(0.82)	0.0232	(1.08)	0.0125	(0.58)	0.0177	(0.82)
Plough_easy	0.0471**	(1.96)	0.0487**	(1.97)	0.0420*	(1.76)	0.0436*	(1.79)
Plough_freq	0.0462***	(4.23)	0.0448***	(4.15)	0.0394***	(3.76)	0.0384***	(3.78)
Manure	0.0564	(1.53)	0.0659*	(1.80)	0.0670*	(1.85)	0.0758**	(2.13)
Walk_min	-0.00127**	(-2.47)	-0.00126**	(-2.43)	-0.00135***	(-2.61)	-0.00135***	(-2.60)
Ln(Seed^2)					0.00612	(0.37)	0.00349	(0.22)
Ln(Seed*land)					-0.00865	(-0.20)	-0.00519	(-0.12)
Ln(Seed*dap)					-0.00255	(-0.33)	-0.00152	(-0.20)
Ln(Seed*urea)					-0.00951	(-1.53)	-0.00876	(-1.42)
Ln(Seed*herb)					-0.00459	(-1.19)	-0.00482	(-1.27)
Ln(Seed*labor)					0.0160	(0.38)	0.0132	(0.31)
Ln(Seed*oxen)					-0.0218	(-1.19)	-0.0180	(-1.00)
Ln(land$^{2)}$					-0.0162	(-0.40)	-0.0169	(-0.43)
Ln(Land*dap)					0.0245***	(2.81)	0.0242***	(2.91)
Ln(Land*urea)					0.00406	(0.59)	0.00252	(0.37)
Ln(Land*herb)					0.00850*	(1.96)	0.00834*	(1.96)
Ln(Land*labor)					0.0755	(1.26)	0.0824	(1.37)
Ln(Land*oxen)					-0.00801	(-0.38)	-0.0102	(-0.49)
Ln(dap^2)					0.00903***	(3.03)	0.00861***	(3.31)
Ln(Dap*urea)					-0.0000307	(-0.03)	-0.0000945	(-0.10)
Ln(Dap*herb)					-0.000486	(-0.60)	-0.000411	(-0.52)
Ln(Dap*labor)					-0.0276***	(-3.35)	-0.0282***	(-3.38)
Ln(Dap*oxen)					-0.000306	(-0.12)	-0.000145	(-0.06)
Ln(urea^2)					0.000359	(0.18)	0.000340	(0.17)
Ln(Urea*herb)					0.000453	(0.74)	0.000526	(0.86)
Ln(Urea*labor)					0.00169	(0.31)	0.00158	(0.30)
Ln(Urea*oxen)					-0.00175	(-0.83)	-0.00172	(-0.89)
Ln(herb^2)					0.00564***	(3.05)	0.00621***	(3.36)
Ln(Herb*labor)					-0.0107***	(-2.59)	-0.0105**	(-2.53)

Ln(Herb*oxen)					0.000653	(0.43)	0.000151	(0.11)
Ln(labor^{2})					-0.0524*	(-1.83)	-0.0515*	(-1.76)
Ln(Labor*oxen)					0.0360**	(2.16)	0.0370**	(2.30)
Ln(oxen^{2})					0.00964**	(2.46)	0.00835**	(2.17)
Constant	-0.00545	(-0.04)	0.0105	(0.07)	-0.0601	(-0.40)	-0.0580	(-0.39)
Kebele fixed effect	Yes		Yes		Yes		Yes	
Technical Inefficiency Effects								
Cooperative	0.0406	(0.62)	0.0470	(0.68)	0.0758	(0.98)	0.0861	(1.04)
Community	-0.134*	(-1.84)	-0.135*	(-1.73)	-0.189*	(-1.96)	-0.196*	(-1.94)
Distance coop	0.157***	(2.79)	0.158***	(2.75)	0.164**	(2.38)	0.168**	(2.46)
Distance market	-0.129**	(-1.97)	-0.140**	(-2.17)	-0.122	(-1.09)	-0.148*	(-1.73)
Distance all-w	0.0247	(0.63)	0.0168	(0.42)	0.0283	(0.67)	0.0181	(0.42)
Distance dry	-0.0183	(-0.31)	-0.0136	(-0.22)	-0.0382	(-0.56)	-0.0361	(-0.51)
Distance input	-0.00762	(-0.17)	-0.0000711	(-0.00)	0.00664	(0.14)	0.0198	(0.42)
Distance city	0.00293	(0.08)	-0.000788	(-0.02)	0.00509	(0.11)	0.00242	(0.06)
Distance asphalt	0.0164	(1.63)	0.0151	(1.45)	0.0207*	(1.91)	0.0190*	(1.70)
Extension	-0.117*	(-1.68)	-0.124*	(-1.71)	-0.119	(-1.36)	-0.125	(-1.39)
NGO-Ext	-0.119	(-0.74)	-0.134	(-0.79)	-0.120	(-0.62)	-0.120	(-0.59)
Model	-0.133*	(-1.95)	-0.138*	(-1.90)	-0.126	(-1.59)	-0.144*	(-1.69)
Mobile	-0.0755	(-0.95)	-0.0571	(-0.70)	-0.0678	(-0.76)	-0.0447	(-0.48)
No School	0.161*	(1.82)	0.174*	(1.87)	0.159	(1.48)	0.180	(1.60)
Adult Edu	0.178	(1.57)	0.197	(1.61)	0.137	(1.08)	0.169	(1.21)
Church school	0.223	(1.21)	0.249	(1.32)	0.201	(0.99)	0.238	(1.13)
Head Age	0.00831***	(3.15)	0.00837***	(3.15)	0.00955***	(2.94)	0.00957***	(3.01)
Own Donkey	-0.0567	(-0.87)	-0.0331	(-0.49)	-0.0368	(-0.48)	-0.00887	(-0.11)
Male Manage	-0.268**	(-2.09)	-0.254*	(-1.88)	-0.286*	(-1.93)	-0.278*	(-1.77)
M/F Manage	-0.302**	(-2.10)	-0.299**	(-1.98)	-0.346**	(-2.04)	-0.352**	(-2.02)
Household s.	-0.00996*	(-1.95)	-0.0100*	(-1.94)	-0.00902	(-1.64)	-0.00895	(-1.59)
Constant	0.0978	(0.32)	0.0539	(0.17)	-0.119	(-0.30)	-0.161	(-0.40)
σ_u	0.442***	(6.83)	0.443***	(6.39)	0.468***	(6.460)	0.467***	(6.18)
σ_v	0.289***	(20.9)	0.287***	(20.98)	0.280***	(16.86)	0.280***	(19.56)
λ	1.530***	(22.44)	1.545***	(21.25)	1.670***	(22.72)	1.667***	(21.35)
LLF	-1220.321		-1198.179		-1151.510		-1129.155	
TE(%)	72.46	13.43	72.75	13.36	73.96	13.20	74.56	12.99
N	2596		2596		2596		2596	

Note: t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. TE: Technical efficiency; TL: Trans-log; CD: Cobb-Duglas.

Table 5 Average production efficiency by zone and household characteristics

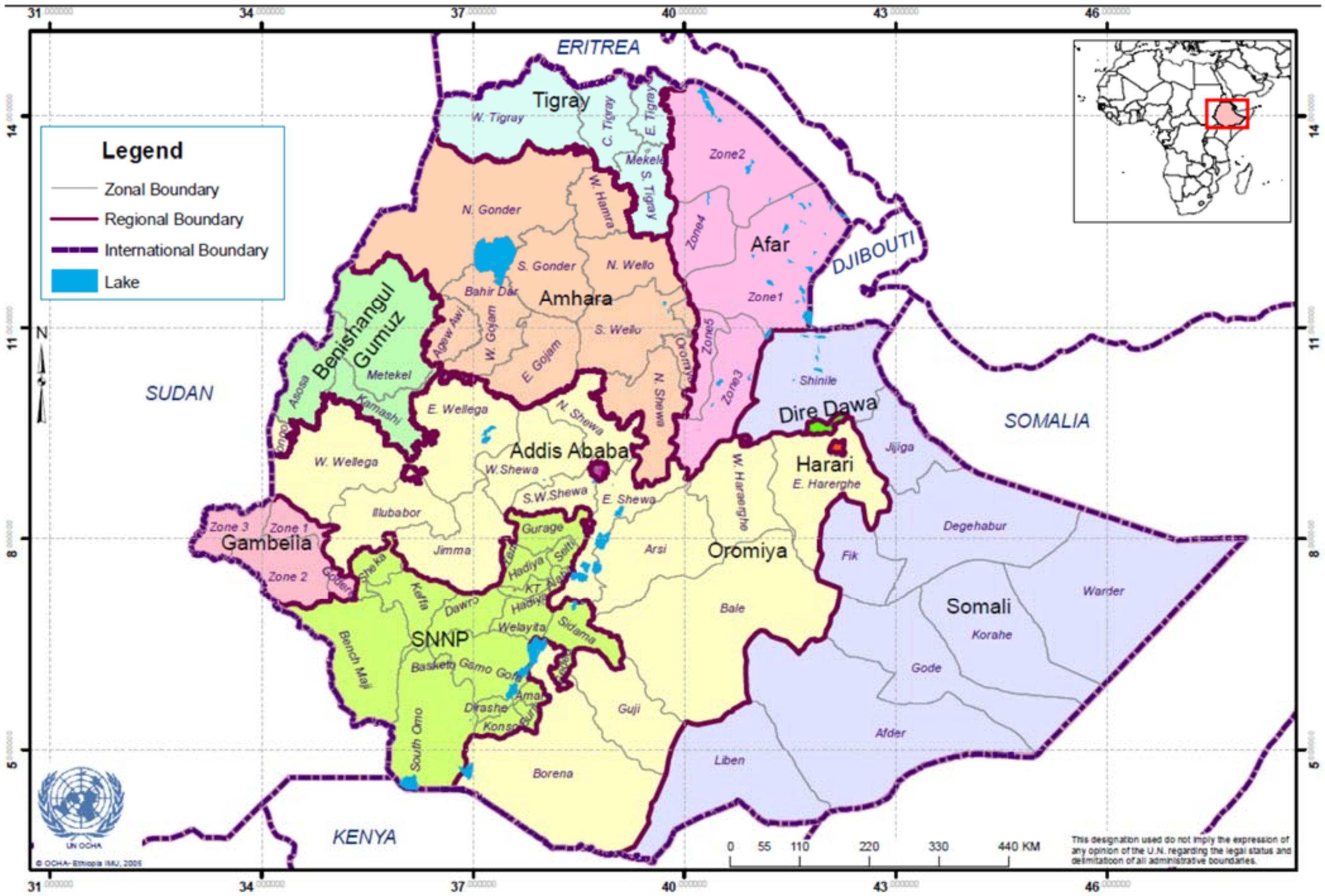
	East Gojjam	West Gojjam	East Shewa	West Shewa	SW Shewa	Overall
Coop						
No	0.734	0.706	0.753	0.756	0.740	0.742
Yes	0.732	0.739	0.743	0.734	0.727	0.734
Community						
No	0.698	0.700	0.706	0.737	0.695	0.707
Yes	0.747	0.738	0.769	0.748	0.747	0.750
Extension						
Yes	0.707	0.700	0.701	0.686	0.722	0.706
No	0.737	0.740	0.764	0.755	0.734	0.746
NGO_Extension						
No	0.731	0.726	0.747	0.743	0.729	0.735
Yes	0.776	0.799	0.824	0.768	0.747	0.772
Model						
No	0.720	0.713	0.729	0.734	0.707	0.721
Yes	0.748	0.752	0.784	0.770	0.754	0.760
Mobile						
No	0.722	0.720	0.733	0.733	0.712	0.723
Yes	0.767	0.794	0.758	0.777	0.752	0.761
Plot Manager						
Male	0.736	0.679	0.752	0.736	0.730	0.734
Female	0.600	0.697	0.559	0.718	0.634	0.666
Both	0.683	0.745	0.742	0.758	0.752	0.747
Plot Size						
<0.25ha	0.702	0.747	0.699	0.712	0.740	0.723
0.25-0.499ha	0.745	0.722	0.740	0.751	0.734	0.738
0.50 – 0.749ha	0.732	0.708	0.760	0.740	0.725	0.737
≥ 0.75ha	0.722	0.734	0.753	0.752	0.730	0.742
Overall	0.732	0.728	0.748	0.745	0.730	**0.737**

Table 6 Average, minimum and maximum marginal effects of inefficiency effects

Variable	Mean	Minimum	Maximum
Extension visit (0/1)	-0.035	-0.110	-0.005
Model Farmer (0/1)	-0.038	-0.119	-0.005
Extension services provided by NGO (0/1)	-0.031	-0.099	-0.004
Participate in a community meeting (0/1)	-0.058	-0.183	-0.008
Member of a co-operative (0/1)	0.021	0.003	0.066
Own mobile phone (0/1)	-0.020	-0.063	-0.003
Did not attend any school (0/1)	0.033	0.005	0.105
Plots Managed by Female	0.064	0.009	0.202
Plots Managed by Male	0.048	0.007	0.151
Plots Managed by Both	-0.039	-0.123	-0.005
Age of the head of the family	0.003	0.000	0.010
Number of household members	-0.003	-0.009	0.000
Own donkeys	-0.008	-0.024	-0.001
Distance from the nearest cooperative	0.049	0.007	0.154
Distance from the nearest market place	-0.045	-0.141	-0.006
Distance from the nearest all-weather road	0.005	0.001	0.017
Distance from the nearest dry road	-0.008	-0.026	-0.001
Distance from the nearest agro. input supplier	0.005	0.001	0.017
Distance from the nearest admin. town	0.002	0.000	0.007
Distance from the nearest asphalt/tar road	0.005	0.001	0.017

The marginal effect is given by $\frac{\partial E[U_{ijp}]}{\partial z[k]} = -\frac{\partial E[\ln(y)]}{\partial z[k]}$ (equations [6]). Negative signs are interpreted as inefficiency-reducing or output-enhancing.

Figure 1 Map of Ethiopia



Source: http://www.idp-uk.org/Resources/Maps/Maps.htm

Figure 2 Distribution of plot level technical efficiency