Productivity and Efficiency of Small Scale Agriculture in Ethiopia

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☆Selected paper prepared for presentation at the Southern Agricultural Economics Association (SAEA) Annual Meeting, Orlando, Florida, 3-5 February 2013.

Abstract

We estimate a distance function of grains production using generalized method of moments that enables us to accommodate multiple outputs of farmers as well as address the endogeneity issues that are related with the use of distance functions for multi-output production. Using a panel data set of Ethiopian subsistence farmers, we find that the most important factors determining farmers' efficiency in Ethiopia are having access to the public extension system, participation in off-farm activities, participation in labor sharing arrangements, gender of the household head, and the extent to which farmers are forced to produce on marginal and steeply sloped plots. Average farmers in Ethiopia are producing less than 60% of the most efficient farmers. Annual technical change between 1999 and 2004 is about one percent while annual efficiency change during the same period is insignificant.

Keywords: Distance Function, Productivity, Efficiency, GMM, Ethiopia

1. Introduction

It stands to reason that agricultural productivity gains can help reduce rural poverty by raising real income from farming and keeping food prices from increasing excessively by improving the availability of food. The economic importance of improving agricultural productivity is even more evident in a country like Ethiopia where agriculture accounts for 47% of its GDP 85% of its employment. Although Ethiopia successfully increased its crop production in the first decade of the 2000s, increasingly binding land and water constraints will make it increasingly difficult to achieve production gains of both crops and livestock in the highlands without major investments in productivity-increasing technologies (Dorosh, 2012). Taffesse, Dorosh, and Gemessa (2012) also argued that with little suitable land available for the expansion of crop cultivation, especially in the highlands, future cereal production growth will need to come increasingly from yield improvements.

Policy recommendations on how to actually improve agricultural productivity, however, require reliable estimates of the current level of farmers' productivity and efficiency as well as what it takes for a farmer to be more productive. Thus, in this study, we provide reliable efficiency estimates for the multiple output producing farmers using recent econometric developments in the area. We estimate a distance function of grains production using generalized method of moments that enables us to accommodate multiple outputs of farmers as well as avoid the endogeneity issues that are related to the use of distance functions for multi-output production.

Different representations of the production technologies of multi-output producing agents such as monetary aggregation or the dual cost approaches require behavioral assumptions such as revenue maximization, profit maximization, or cost minimization. At times, any of these behavioral assumptions may not properly represent some producers such as the small scale producers that we are considering in this study. Distance functions, on the other hand, allow one to describe a multi-input, multi-output production technology without the need to specify a behavioral objective such as cost minimization or profit-maximization (Coelli et al., 2005).

As a result, distance functions have been used in a wide range of applications that include technology adoption and farmers' efficiency in Ethiopia (Alene and Zeller, 2005), decomposition of productivity growth in Chinese agriculture (Brummer, Glauben, and Lu, 2006), performance of European railways (Coelli and Perelman, 2000), and measuring students' test performance across public and private-voucher schools in Spain (Perelman and Santin, 2011).

The usual implementation of output distance functions that takes one of the outputs to the left-hand-side of the equation is likely to cause inconsistent estimates as it ignores the presence of the remaining endogenous outputs on the right hand side of the equation (Coelli et al., 2005).[1] Atkinson, Cornwell, and Honerkamp (2003) have shown that Generalized Method of Moments (GMM) can be used to address the possibility of endogeneity of either outputs or inputs with the composite error term inherent in distance functions. The GMM approach has an additional advantage that it doesn't require distributional assumption on the error term. Thus we follow the GMM approach of Atkinson, Cornwell, and Honerkamp (2003) aiming to accommodate the multiple output nature of production in the farming system under study through distance functions as well as address the endogeneity inherent in distance function estimation by instrumenting the endogenous right-hand-side outputs.

2. Empirical Model

Let X be a vector of inputs $X = (x_1, ..., x_L) \in R^L_+$ and let Y be a vector of outputs denoted by $Y = (y_1, ..., y_M) \in R^M_+$. The output distance function is defined as

(1) $$D^o(X,Y,t) = inf_\theta\{\theta > 0 : (X, \frac{Y}{\theta}) \in S(X,Y,t)\}$$

where S(X,Y,t) is the technology set such that X can produce Y at time t. $D^o(X,Y,t)$ is the inverse of the factor by which the production of all output quantities could be increased while still remaining within the feasible production set for the given input level (O'Donnell and Coelli, 2005). θ, and hence, the distance function, $D^o(X,Y,t)$, takes a value less than or equal to 1, where a value of 1 means that the farmer is operating at the frontier of the technology set. The output distance function is non-decreasing, linearly homogeneous and convex in output, and non-increasing and quasi-convex in inputs (O'Donnell and Coelli, 2005).

Given M outputs and L inputs, we have chosen a generalized quadratic Box-Cox model to represent the distance function, $D^o(.)$, as

[1]The same can be said with input distance functions.

$$
(2) \quad \begin{aligned} D_{it}^{o} = exp(\gamma_o^* + \sum_{m}^{M} \gamma_m^* y_{mit}^{\lambda} + .5 \sum_{m}^{M} \sum_{r}^{M} \gamma_{mr}^* y_{mit}^{\lambda} y_{rit}^{\lambda} + \sum_{l}^{L} \gamma_l^* x_{lit}^{\lambda} \\ + .5 \sum_{p}^{L} \sum_{l}^{L} \gamma_{pl}^* x_{pit}^{\lambda} x_{lit}^{\lambda} + \sum_{m}^{M} \sum_{l}^{L} \gamma_{ml}^* y_{mit}^{\lambda} x_{lit}^{\lambda}) exp(v_{it}) \end{aligned}
$$

where y_{mit}^{λ} and x_{nit}^{λ} are the Box-Cox transformations of outputs and inputs, defined by Box and Cox (1964) as $y_{mit}^{\lambda} = \frac{y_{mit}^{\lambda} - 1}{\lambda}$ and $x_{nit}^{\lambda} = \frac{x_{nit}^{\lambda} - 1}{\lambda}$, λ is the transformation parameter to be estimated, and v_{it} is the usual two sided error term with zero mean that captures the noise in production. The generalized quadratic Box-Cox distance function has a form similar to a translog distance function but with a Box-Cox, instead of logarithmic, transformation. If $\lambda = 0$, the Box-Cox transformation reduces to a log transformation, and hence the generalized Box-Cox distance function incorporates the translog distance function as a special case. The Box-Cox transformation is continuous around zero and hence allows us to include output and input variables with zero values for which log transformation is not possible. This is an important feature of the model because it is likely that most farmers only produce some of the crops or do not use some inputs such as fertilizer.

The actual distance D_{it}^{o} is equal to θ. If a farm is on the frontier, then $D_{it}^{o} = \theta = 1$. Otherwise, $D_{it}^{o} = exp(-u_{it})$, where u_{it} is a non-negative random variable associated with technical inefficiency. Thus, substituting $exp(-u_{it})$ for D_{it}^{o} in equation 2, taking the natural logarithm of both sides, and re-arranging the equation gives

$$
(3) \quad \begin{aligned} 0 = \gamma_o^* + \sum_{m}^{M} \gamma_m^* y_{mit}^{\lambda} + .5 \sum_{m}^{M} \sum_{r}^{M} \gamma_{mr}^* y_{mit}^{\lambda} y_{rit}^{\lambda} + \sum_{l}^{L} \gamma_l^* x_{lit}^{\lambda} \\ + .5 \sum_{p}^{L} \sum_{l}^{L} \gamma_{pl}^* x_{pit}^{\lambda} x_{lit}^{\lambda} + \sum_{m}^{M} \sum_{l}^{L} \gamma_{ml}^* y_{mit}^{\lambda} x_{lit}^{\lambda} + v_{it} + u_{it} \end{aligned}
$$

Next, take one of the outputs, y_{1it}, to the left hand side in order to obtain an observable variable on the left hand side (Brummer, Glauben, and Lu, 2006; Coelli and Perelman, 2000). In addition, factors that affect the inefficiency of farmer i are incorporated in the model by defining u_{it} in terms of household specific variables that are believed to affect the productivity and efficiency of a farmer. These include whether the farmer has called for labor sharing on at least one of his plots and other informal social networks such as funeral associations (*idir*) and off-farm activities. In addition, these efficiency explaining factors include whether the farmer has access to government extension services, the highest level of education among members of the household, the average slope and soil fertility of the farmer's plots, as well as the household head's age, gender, education, marital status, access to irrigation, and soil conservation practices. Thus, the resulting empirical model for farm i in period t can be written as:

$$\begin{aligned} y_{1it}^{\lambda} &= -[\gamma_o + \sum_{m}^{M-1} \gamma_m y_{mit}^{\lambda} + .5 \sum_{m}^{M-1} \sum_{r}^{M-1} \gamma_{mr} y_{mit}^{\lambda} y_{rit}^{\lambda} + \sum_{l}^{L} \gamma_l x_{lit}^{\lambda} \\ &+ .5 \sum_{p}^{L} \sum_{l}^{L} \gamma_{pl} x_{pit}^{\lambda} x_{lit}^{\lambda} + \sum_{m}^{M-1} \sum_{l}^{L} \gamma_{ml} y_{mit}^{\lambda} x_{lit}^{\lambda} + v_{it}] - [\sum_{j} \beta_j w_{ijt}] \end{aligned} \tag{4}$$

where w_{ijt} refers to $j=1,...,J$ efficiency explaining variables for farmer i at time t and β_j refers to their corresponding coefficients.

The coefficients in equation 4 are different from 3 to note that they are normalized by γ_1^*, the coefficient of the output transferred to the left hand side. We also imposed homogeneity and symmetry restrictions on the above distance function (O'Donnell and Coelli, 2005). Following Atkinson, Cornwell, and Honerkamp (2003) and Atkinson and Dorfman (2005), the non-negativity of the u_{it} is imposed after estimation by adding and subtracting from the fitted model $\hat{u}_t = min_i(\hat{u}_{it})$, which defines the frontier intercept.

Given these estimates, Atkinson and Dorfman (2005) showed how to compute technical efficiency (TE_{it}), efficiency change (EC_{it}), technical change (TC_{it}), and productivity change (PC_{it}) as follows.

Farmer i's level of technical efficiency in period t is TE_{it}:

(5) $$TE_{it} = exp(-\hat{u}^*_{it})$$

where the normalization of $\hat{u}^*_{it}$ guarantees that $0 < TE_{it} \leq 1$.

Productivity can increase by farmers getting more efficient or by moving the the production frontier outward. Thus, productivity change is defined as the sum of technical change and efficiency change:

(6) $$PC = TC + EC.$$

Efficiency change is the change in the technical efficiency over time, so

(7) $$EC_{it} = \triangle TE_{it} = TE_{it} - TE_{i,t-1}.$$

Technical change is measured as the difference between the estimated frontier distance function in periods t and t - 1 holding output and input quantities constant:

(8) $$TC_{it} = \hat{D}^*_i(Y, X, t) - \hat{D}^*_i(Y, X, t-1).$$

3. Data

For this study, we have used the 1999 and 2004 rounds of the Ethiopian Rural Household Survey (ERHS) data, which is a longitudinal household data set covering households in 15 peasant associations in rural Ethiopia. We focus on the five major cereals - teff, wheat, maize, sorghum, and barley - that according to Taffesse, Dorosh, and Gemessa (2012) occupy almost three-fourths of the total area cultivated and represent almost 70% of the total value-added in recent years.

The study focuses on the main (*Meher*) rainy season that runs between June and September. This helps to reduce the noise in the data as the agricultural production system in terms of crops in the field, intensity of the rain, and utilization of inputs are markedly different from the second small showers (*Belg* rains) season between February and May (Admassu, 2004). In addition, the five cereals that are the focus of this study are mainly produced during the main rainy season. According to data from the Central Statistical Agency of Ethiopia, between 1995 and 2008, close to 99% of teff production, 98% of wheat production, 90% of barley production, and 89% of maize production was done during the main rainy season (CSA, 2009). These qualifications in the data in terms of crops produced and seasons resulted in a sample size of 815 farmers in each of the 1999 and 2004 survey rounds.

There is a regional specialization in the type of cereals farmers produce. For instance, the production of teff and sorghum is not common in Tigray. The farmers in Tigray focus on the production of barley and wheat, and to a lesser extent maize. Barley and sorghum are not commonly produced among the sampled households in the SNNP region. There is a fair distribution of farmers producing the five cereal crops in Amhara and Oromiya regions (Table 1).

Table 1: Cereal Production by Region

	Percentage of Farmers Producing					
Region	Teff	Barley	Wheat	Maize	Sorghum	No. of farmers
Tigray	4.3	96.5	33.3	9.2	2.1	141
Amhara	43.1	56.0	44.8	17.6	31.3	364
Oromiya	53.6	14.0	40.7	69.6	28.9	349
SNNPR	67.5	0.6	14.6	33.7	0.0	166

Results are based on the 2004 survey only.
Source: Authors' computation from ERHS (2011)

Table 1 show that in Amhara region, 43% of the farmers in the sample produce teff, 45% produce wheat, 56% produce barely, 31% produce sorghum and less than 18% produce maize. In Oromiya region, 55% of the sampled households produce teff, about 40% produce wheat, 70% produce maize, 29% produce sorghum but only about 14% produce barley. Among farmers in SNNP region, 68% of them produce teff, 34% of them produce maize, less than 15% produce wheat and less than 1% produce either barley or sorghum.

Access to irrigation among the sampled farmers increased from about 6 percent in 1999 to about 29 percent in 2004. The share of farmers with access to the public extension system has almost doubled in the five years between 1999 and 2004. More than three quarters of the household heads are male and less than 10 percent completed primary school. More than three quarters of the households heads are members of *idir* (funeral associations), and 23 to 37 % of the farmers are engaged in off-farm activities in 1999 and 2004. About three quarters of the household heads are married.

The ERHS data show significant variation in labor sharing participation among the four regions covered by the study. Labor sharing is not common in the Tigray region where only 13% of the households participate in such type of arrangements. Labor sharing is common in the other three regions with participation rates ranging from 40% to 61% .

All the output variables (Teff, Wheat, Barley, Maize, and Sorghum) as well as the two most used chemical fertilizers (Urea and DAP) are measured in Kilograms. Average production is the highest for teff and the lowest for Sorghum but the averages would obviously be higher if we consider only the farmers that produce the specific crop. Average DAP use is approximately three times more than that of Urea. The highest level of education in the household is around 4 years on average and it is expected to capture intra-household schooling externality. The average age of a household head is about 50 years. Soil fertility is measured in a 1 to 3 scale where 1 refers to fertile, 2 medium fertile, and 3 infertile soil, and it is averaged among the different plots of the farmer. Labor is measured in labor days and it includes family, hired, and shared labor. While computing labor days, we follow Arega (2009) to account for the physical hardship in crop production by giving adult men a weight of 1, adult women a weight of 0.8, and child labor a weight of 0.35.

Oromiya has the highest average land holding size under the five crops which was about nine fold higher than Tigray, followed by Amhara and SNNPR (Table 2). As one would expect, average labor days used in these crops also follow the same distribution across regions as that of land size under the five crops. Urea and DAP are the two chemical fertilizers commonly used in Ethiopia and farmers in Amhara and Oromiya regions use significantly higher amounts of these fertilizers as compared to Tigray and SNNP regions.

Table 2: Average Input Use on the Selected Cereals (Std. Dev. in brackets)

Region	Land (ha)	Urea (Kg)	DAP (Kg)	Labor days	Livestock (TLUs)	Other Inputs (Br)
Tigray	0.4	2.4	8.6	39.7	8.5	20.5
	(0.3)	(15.0)	(42.5)	(51.8)	(10.1)	(82.8)
Amhara	1.8	65.6	202.2	165.2	23.8	33.5
	(7.1)	(233.8)	(441.8)	(184.3)	(30.0)	(136.9)
Oromiya	4.0	86.8	179.9	190.7	13.1	305.8
	(18.3)	(315.3)	(734.8)	(242.0)	(23.3)	(1461.7)
SNNPR	1.5	4.9	17.1	90.2	3.7	42.8
	(9.9)	(19.0)	(38.2)	(165.4)	(3.5)	(195.7)

Results are based on the 2004 survey only.
TLUs ≡ Tropical livestock Units.
Br ≡ Birr, Ethiopian currency. 1USD= 8.3Br in 2005
Source: Authors' computation from ERHS (2011)

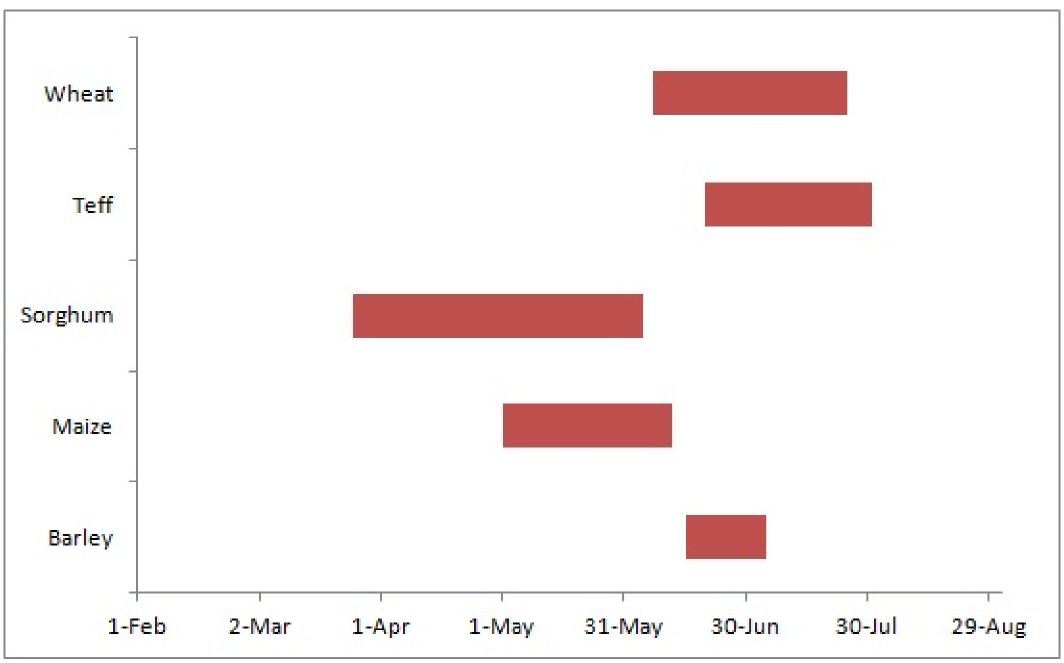
4. Results

4.1. Instruments

In the final estimated model, teff is the output used as the dependent variable while barley, wheat, maize, and sorghum are the endogenous outputs on the right-hand-side of the equation. Weather related events such as the amount and distribution of rainfall are the initial candidates to be used as instruments for the endogenous outputs because of their strong relationships with the amount of output produced of these crops and because they are exogenous to the farmer. However, we need to ensure the weather-related instruments do not simultaneously affect the dependent variable, teff. The Ethiopian crop calendar

(Figure 1) indicates legitimate weather related variables that can be used as instruments for the endogenous output variables. Teff is sown between the end of June and end of July (FAO, 2012) and for better productivity it is advisable to sow teff during the last two weeks of July (Admassu, 2004). Maize and sorghum are sown in the months that correspond to the previous small showers (*belg*) season which spans between February and May. Admassu (2004) noted that sowing for maize should take place in the first two weeks of May or as early as possible after the onset of the main rainy season (end of May or early June). Bewket (2009) stated that maize appears to require a more even distribution of rainfall throughout the *belg* season and the main rainy season. Sorghum production is particularly related to the *belg* rains because sorghum is sown in early May or even late April, which makes the *belg* rainfall critically important (Bewket, 2009).

Figure 1: Sowing Periods for the Main Rainy Season for the Sub-moist Agro-ecological Zone in Ethiopia



Source: Extracted from FAO's (2012) Crop Calendar.
The sub-moist agro-ecological zone has two farming systems, cereal based and *enset* (false banana) based agriculture, along with livestock rearing and corresponds with the peasant associations of the cereal producing households in the data set.

In the ERHS data set, farmers were asked if *belg* crops were adversely affected by weather.

We used this variable and its interactions with other exogenous variables as instruments for maize and sorghum production. That is, *belg* rains affect maize and sorghum production because the sowing of these two crops and part of their growing season correspond with the *belg* season but *belg* rains don't simultaneously affect teff production because sowing for teff begins at the end of July, making the instrument relevant as well as legitimate.

The sowing time for wheat is the end of June and the early days of July while sowing for barley should take place soon after the main rainy season begins in June (Admassu, 2004; FAO, 2012). Thus, the performance of the rain at the beginning of the main rainy season (late May and early June) is important both for wheat and barley (as well as sorghum and maize which are in their growing stage at this time) but is not directly related with teff, which is sown after two weeks into July (i.e, the middle of the main rainy season). The ERHS data set is helpful in this regard because farmers were asked if the first rains of the main rainy season came on time and if there was enough rain on the farmer's plot at the beginning of the rainy season. These two variables, along with their interactions with other exogenous variables, are used to instrument for wheat and barley because they are related to the endogenous variables but not directly related to the left-hand-side variable, making them pass the legitimacy and relevance criteria for good instruments.

4.2. Model Estimates

The model is estimated using heteroscedasticity and autocorrelation consistent iterated GMM with the instruments mentioned above and it fits the data well with an overall R^2 of 0.598. Using the Sargen-Hansen or J test of overidentification (Baum, Schaffer, and Stillman, 2003; Wooldridge, 2002), we fail to reject the validity of the over-identifying restrictions. The J-test resulted in a GMM criterion function value of 41.74 which has a χ^2 distribution of 40 degrees of freedom, which gives a p-value of 0.395. A rejection of this test would have cast a doubt on the validity of our instruments.

Other than the validity of instruments, the other condition needed in GMM estimation is that the instruments be sufficiently related to the endogenous variables. When instruments are weak, the orthogonality conditions hold even at non-optimal values of the estimated parameters when in fact they should hold or get close to zero only at the optimal values. Our instruments do not exhibit the pathologies that GMM estimators demonstrate in the presence of weak identification as suggested by Stock, Wright, and Yogo (2002). For instance, two-step GMM estimators and iterated GMM point estimators can vary significantly and produce very different confidence sets in the presence of weak identification. As shown in Table Appendix A.1 and Table Appendix A.2 in the appendix, the two step GMM and the iterated GMM estimators are almost identical in our case, which differ only after two digits for almost all of the coefficients. Thus, we believe the estimates are based on a suitable set of instruments and are credible.

Table 3: Inefficiency Effects

Parameter	Estimate	Std. Error	t-stat
Age of household head	0.064	0.103	0.627
Male household head	-0.153	0.079	-1.929
Labor Sharing	-0.103	0.057	-1.789
Poor quality soil	0.068	0.041	1.663
Irrigation	-0.088	0.091	-0.970
Conservation	-0.025	0.067	-0.375
Extension	-0.213	0.089	-2.387
Head completed primary school	0.016	0.137	0.119
Household members' highest education	-0.042	0.043	-0.993
Steep plots	0.002	0.060	0.039
Steeper plots	0.236	0.105	2.240
Off-farm income	-0.115	0.049	-2.337
Idir membership	0.003	0.094	0.029
Single	-0.035	0.142	-0.246
Divorced	-0.004	0.125	-0.036
Widowed	-0.094	0.075	-1.242
Separated	0.065	0.169	0.382
>1 spouse	-0.110	0.194	-0.569

4.3. Inefficiency Effects

We have presented the variables that explain farmers' inefficiency in Table 3 even though they were estimated simultaneously in one step with the full set of the distance function variables presented in Table Appendix A.1. As explained in the empirical model, these variables are explaining farmers' inefficiency and hence negative signs show that technical efficiency increases as the explanatory variable increases and positive signs are associated with efficiency reducing effects.

We find that farmers' efficiency in Ethiopia is highly responsive to having access to the public extension system. Farmers with access to extension are found to be about 26% more efficient than those that don't have access to extension (Tables 3 and 4). This gives support to the government of Ethiopia's effort to increase the number of public extension staff almost three-fold in the five years preceding 2008 and to the claim that agricultural extension services are what tie improved seed, chemical fertilizers, and credit together for the Ethiopian smallholder (Spielman, Kelemework, and Alemu, 2011).

Farmers engaged in labor sharing arrangements are found to be 13 to 14% more efficient than those who work alone (Tables 3 and 4). This is due to what Mekonnen and Dorfman (2013) called the synergy effect of labor sharing arrangements, which refers to productivity gains that come from working together such as speed gains and being less bored by tedious agricultural activities or working harder while observed by the labor sharing partners. The synergy effect of labor sharing arrangements is recognized by the farmers as more than two-thirds of the farmers call for labor sharing parties for quick completion of tasks or because a group is the best way of completing the task. In addition, labor sharing schemes appear to be an indigenous response by the farming community to labor and credit market constraints in rural Ethiopia because about a fourth of the farmers participate in labor sharing arrangements either because it is the only way to get large amount of labor, they can not afford paid labor, or no paid labor is available.

Male-headed households are found to be more efficient than female headed households which implies that the design of extension systems in Ethiopia should have a gender component that addresses efficiency-reducing challenges that women household heads in particular face. As shown in Table 4, male headed households are on average about 15% and 14% more efficient than female headed households in 1999 and 2004.

We also find that farmers exposed to external information through off-farm activities are 7 to 13% more efficient than those that don't have such exposures (Tables 3 and 4). The most important kind of off-farm activities among the sampled households is food-for-work, which accounts for 39% and 54.4% of all off-farm activities in 1999 and 2004. The food-for-work program in Ethiopia is a welfare safety net for food insecure areas and instead of distributing food aid to those in need, the program involves able-bodied people performing public work in exchange for a food wage. The food-for-work program focuses on rehabilitation of forest, grazing, and agricultural lands as well as construction of wells, ponds, dams, terraces, and roads. The efficiency-enhancing effects of off-farm activities suggests that farmers involved in the food-for-work program have taken home productivity-improving methods from the public works to their individual plots.

Table 4: Technical Efficiency Scores by Determinants of Inefficiency

	1999		2004	
	Yes	No	Yes	No
Male household head	0.60	0.51	0.60	0.52
Labor sharing	0.61	0.53	0.63	0.54
Extension	0.76	0.56	0.74	0.55
Off-farm income	0.62	0.57	0.64	0.55
Steeper plots	0.42	0.59	0.43	0.59

Even more troubling is the efficiency differentials between farmers who claimed their plots to be flat and those who are forced to harvest on steeper plots. On the ERHS survey, farmers were asked to classify their plots to be flat, sloped, or steep. We find no statistically significant efficiency differential between those whose plots are flat and those whose plots are sloped. However, farmers with steep plots are found to be 42% and 36% less efficient in 1999 and 2004 as compared to those whose plots are on average flat (Tables 3 and 4).

In addition, the average fertility of the farmers' plot plays a role in determining the technical efficiency of farmers. The soil fertility variable was measured in such a way that higher values refer to less fertility and hence the positive coefficient in Table 3 shows that farmers with plots of inferior quality are less efficient than farmers whose plots are more fertile.

Table 5: PARTIAL EFFECTS AND ELASTICITIES EVALUATED AT 2004 VALUES

	Marginal Productivity	Std. Error	Elasticity
Land	0.844	0.493	1.033
Oxen	0.115	0.305	0.139
Urea	-0.014	0.214	-0.016
DAP	0.037	0.294	0.049
Other Purchased Inputs	0.008	0.201	0.064
Labor	0.133	0.384	0.191
Wheat	-0.548	0.266	-0.649
Barley	-0.231	0.202	-0.414
Maize	-0.295	0.232	-0.340
Sorghum	0.073	0.249	0.080

Among the sampled households in 2004, the average land size used for teff, wheat, barley, sorghum, and maize was 0.4 hectares in Tigray region, 1.5 hectares in the SNNPR region, 1.8 hectares in Amhara region, and 4 hectares in Oromiya region. Given the small landholding of small scale farmers in Ethiopia, agricultural output is expected to be responsive to acreage expansion. The result from this study also confirms that a percentage increase in land size increases teff production by a little more than one percent, implying slightly increasing returns to scale.

Land is owned by the government and farmers can't sell or mortgage agricultural farm lands. Although renting agricultural land is allowed, all regions except Amhara, where land can be rented for up to 25 years, have legal provisions limiting the amount of land to be rented out to 50% of holding size with a maximum duration for rental contracts of 3 years (Deininger et al., 2008). Population pressure and lack of alternative non-agricultural jobs in villages have forced household heads to further redistribute part of their farming land to their adult kids when the kids form their own family. The (near) absence of land markets and land fragmentation have forced farmers to harvest on small plots of lands, making land the most valuable input of all and production to be highly constrained by small land size. The trade-off between teff production versus wheat production is also presented in Table 5. The relationships with the other crops are statistically insignificant.

4.4. Farmer Technical Efficiency Scores

The average technical efficiency of the 815 farmers included in the final estimation was found to be about 58.4% both in 1999 and 2004. These figures imply that at the current level of inputs use, farmers are producing, on average, less than 60% of the output of the most efficient farmer in the sample. Thus, there is room to increase farmers' production by over two thirds through better management of the existing resources. The evidence in Table 3 suggests the government needs to intensify efficiency-enhancing investments such as extension, irrigation, and off-farm activities, as well as facilitating venues for farmers to work together.

For the years between 1999 and 2004, the annual efficiency change is close to zero while the average technical change is close to one percent per year. As a result, the productivity change, which is the sum of efficiency change and technical change, is also about one percent per year.

As shown in Figure 2, there is significant variation in the efficiency scores of farmers in different peasant associations (PAs) in 2004, from 46.4% in *Geblen* PA of *Tigray* Regional State to about 69.2% in *Doma* PA of the Southern Nations, Nationalities, and Peoples Regional (SNNPR) State. In terms of average efficiency scores, the two lowest performing PAs (*Geblen* and *Haresaw*) are found in *Tigray*, whereas *Korodegaga* PA of *Oromiya* Regional State closely follows the best performing *Doma* PA with 69.1% efficiency score. However, such direct comparisons of the efficiency scores of peasant associations can't be conclusive because it doesn't take into account the variance of efficiency scores within the

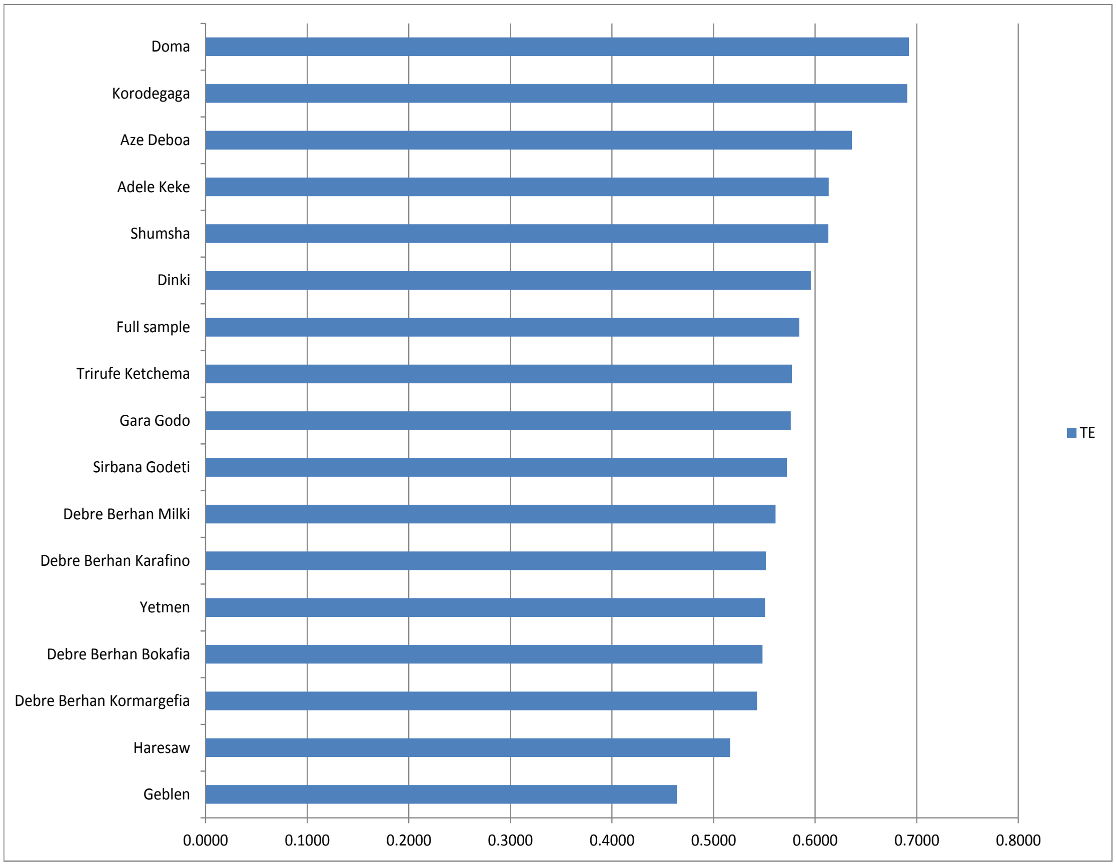


Figure 2: Mean Technical Efficiency in 2004 by Peasant Association

PA. From the econometric results, the three PAs whose efficiency scores are statistically significantly different from our base PA of *Debre-Berhan Bokafia* are *Yetmen, Sirbana Godeti*, and *Trirufe Ketchema*. These three PAs are known in the country for their high quality *teff* production and have long experience with improved *teff* production technologies. *Yetmen* is located about 248 kms north west of Addis Ababa between the towns of *Dejen* and *Bichena*. An improved variety of *teff* was introduced in *Yetmen* three decades ago by development agents and was tried first by the producers' cooperatives, and soon adopted by all the peasants following its success (ERHS, 2011). *Sirba na Godeti* PA, located about halfway between *Debre Zeit* and *Mojo* towns and with generally fertile soil

(ERHS, 2011), is known for its *teff* production and supply to the capital Addis Ababa. *Turufe Kecheme* is a PA located about 12.5 km north east of the town of Shashemene in the area of the Great Lakes of Zwai, Langano, Abiyata and Shalla, a plain area with fertile soil suitable for agriculture (ERHS, 2011).

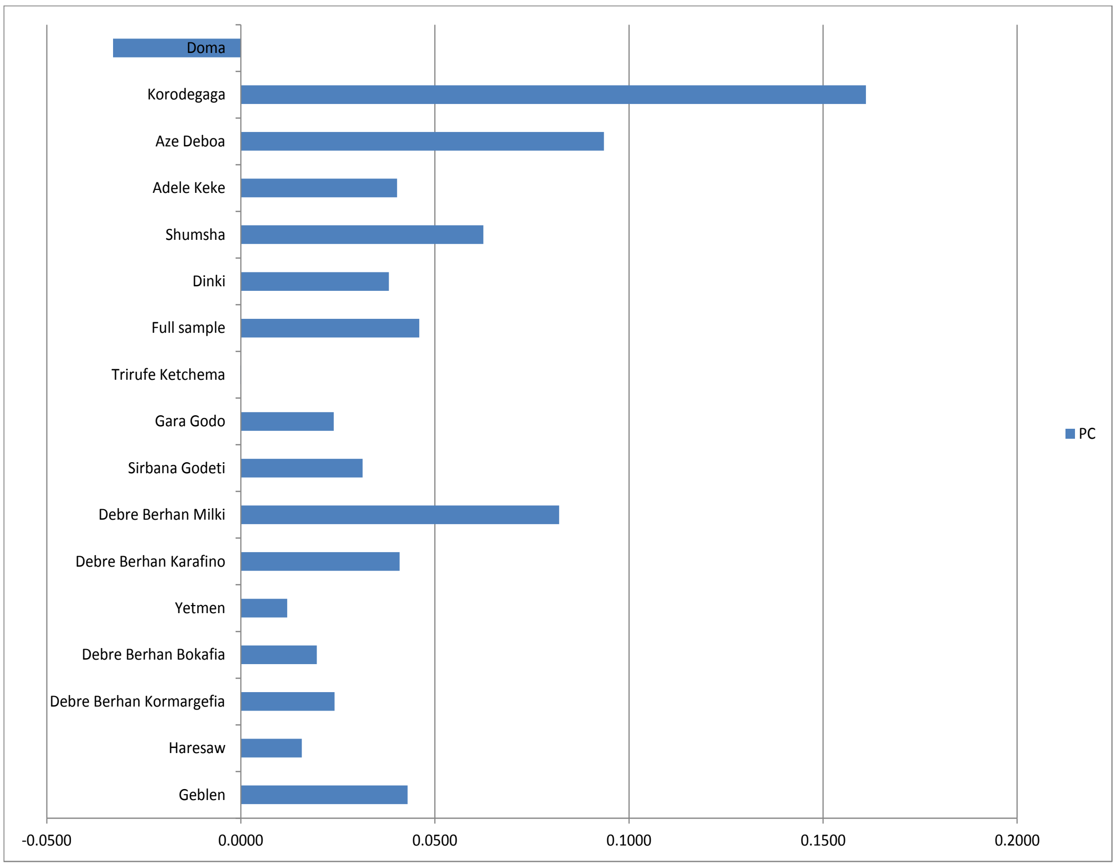


Figure 3: Mean Productivity Change between 1999 and 2004 by Peasant Association

Except for the *Doma* PA, all the other PAs exhibit positive productivity changes between 1999 and 2004 as shown in Figure 3. The positive values for productivity change reflect the outward shift of the frontier. Though farmers display no efficiency improvement, it is not as dismal as it first seems since farmers are able to maintain their efficiency score while the production frontier is being pushed outward at one percent per year by the best performing farmers.

5. Conclusion

We have estimated a distance function of grains production that explicitly takes into account the interdependence among the different crops farmers produce. We have used Box-Cox transformations, instead of logarithmic transformations, of variables to be able to include variables with zero values in the distance function. The generalized method of moments estimation that we follow allows us to control for the endogeneity among the different outputs in the distance function.

The average technical efficiency of the sampled farmers is about 58.4%, implying the potential of increasing agricultural production by over two thirds by investing the government's focus on efficiency-enhancing factors. The results indicate that the most important factors determining farmers' efficiency in Ethiopia are having access to the public extension system, participation in off-farm activities, participation in labor sharing parties, gender of the household head, and the extent to which farmers are forced to produce on marginal and steeply sloped plots.

Technical change in Ethiopia's agriculture is found to be less than one percent per year between 1999 and 2004, while efficiency change is insignificant between the two periods. This calls for a double sword agricultural development policy: measures that can bring about an outward shift of the production technology such as intensification of input use and measures that improve farmers' efficiency given their current level of input use. Efficiency enhancing policies in Ethiopia should emphasize an even greater expansion of the public extension system, an extension system that has a gender component that addresses efficiency-reducing challenges that women household heads in particular face, that understands the traditional wisdom of farmers to work together in the face of labor and credit market constraints, as well as one that gives due consideration to the availability and generation of off-farm opportunities in rural Ethiopia.

Appendix A. Appendix

Table Appendix A.1: Full Set of Coefficients for Production and Inefficiency Effects (Iterated GMM)

Dep. Var. = teff; Overid. test = 41.74, p-value = 0.395, degrees of freedom= 40; $R^2 = 0.598$

	est.	s.e.		est.	s.e.		est.	s.e.		est.	s.e.
λ	0.65	0.08	c	1.89	0.49	pa1	-0.19	0.30	Age	0.06	0.10
b_lab	0.11	0.07	land	-0.75	0.16	pa2	-0.02	0.33	Male	-0.15	0.08
m_lab	0.02	0.05	oxen	-0.14	0.07	pa3	-0.06	0.53	Labor Sharing	-0.10	0.06
s_lab	-0.05	0.05	input	0.02	0.07	pa4	-2.75	0.51	Soil	0.07	0.04
b_d	-0.06	0.05	urea	0.00	0.08	pa5	-0.56	0.43	Irrigation	-0.09	0.09
m_d	0.13	0.08	dap	-0.03	0.08	pa6	-2.01	0.46	Conserv.	-0.03	0.07
s_d	-0.12	0.07	labor	-0.29	0.12	pa7	0.50	0.49	Extension	-0.21	0.09
b_u	0.01	0.04	l_o	-0.18	0.11	pa8	-0.27	0.45	Education	0.02	0.14
m__u	-0.03	0.05	l_i	-0.08	0.11	pa9	-1.06	0.50	Mem Educ	-0.04	0.04
s_u	0.07	0.06	l_u	-0.15	0.12	pa10	-0.34	0.38	Steep	0.00	0.06
b_i	-0.01	0.03	l_d	-0.02	0.09	pa11	-0.21	0.37	Steeper	0.24	0.11
m_i	-0.03	0.03	l_lab	-0.03	0.11	pa12	0.52	0.41	Off-farm	-0.11	0.05
s_i	0.08	0.04	l_sq	0.22	0.06	pa13	-0.10	0.22	*Idir*	0.00	0.09
b_o	0.15	0.08	o_i	-0.05	0.06	pa14	0.24	0.27	Single	-0.03	0.14
m_o	0.06	0.05	o_u	0.16	0.11	pa15	0.11	0.24	Divorced	0.00	0.12
s_o	0.00	0.07	o_d	-0.04	0.11	t_d	-0.06	0.08	Widowed	-0.09	0.08
b_l	-0.06	0.09	o_lab	0.07	0.15	w_sq	-0.07	0.07	Separated	0.06	0.17
m_land	-0.14	0.08	o_sq	-0.09	0.14	b_sq	-0.02	0.05	$>$ 1 Spouse	-0.11	0.19
s_l	0.20	0.08	i_u	-0.02	0.05	m_sq	-0.07	0.05			
w_s	-0.03	0.07	i_d	0.13	0.06	s_sq	0.02	0.01			
b_s	0.01	0.05	i_lab	0.00	0.08	w_l	0.00	0.10			
m_s	0.00	0.04	i_sq	-0.02	0.03	w_o	-0.20	0.09			
b_m	-0.01	0.05	u_d	0.05	0.04	w_i	-0.04	0.04			
w_m	0.08	0.04	u_lab	-0.13	0.08	w_u	-0.05	0.05			
w_b	0.02	0.05	u_sq	-0.02	0.05	w_d	0.05	0.07			
b	0.29	0.15	d_lab	-0.04	0.10	w_lab	-0.08	0.08			
m	0.29	0.13	d_sq	-0.03	0.11	lab_sq	-0.01	0.12			
s	0.01	0.10	wheat	0.40	0.15						

s $\equiv$ sorghum; m $\equiv$ maize; b $\equiv$ barley; w $\equiv$ wheat; o $\equiv$ oxen; i $\equiv$ purchased inputs; u $\equiv$ urea; d $\equiv$ dap; lab $\equiv$ labor; l$\equiv$ land; _ $\equiv$ interacting with; sq $\equiv$ squared; pa $\equiv$ village $\lambda \equiv$ Box-Cox transformation parameter; c $\equiv$ constant; Conserv. $\equiv$ conservation; Mem Educ $\equiv$ highest years of schooling in the household; steep $\equiv$ average slope of the plots; soil $\equiv$ average soil fertility (lower values more fertile).

Table Appendix A.2: Full Set of Coefficients for Production and Inefficiency Effects (Two-step GMM)

Dep. Var. = teff; Overid. test = 47.87, p-value = 0.184, degrees of freedom= 40; $R^2 = 0.637$

	est.	s.e.		est.	s.e.		est.	s.e.		est.	s.e.
λ	0.66	0.08	c	1.74	0.51	pa1	-0.14	0.31	Age	0.04	0.11
b_lab	0.15	0.08	land	-0.69	0.17	pa2	0.06	0.33	Male	-0.18	0.08
m_lab	0.03	0.05	oxen	-0.14	0.08	pa3	0.00	0.56	Labor Sharing	-0.11	0.06
s_lab	-0.07	0.05	input	-0.02	0.07	pa4	-2.49	0.54	Soil	0.07	0.04
b_d	-0.07	0.05	urea	0.01	0.08	pa5	-0.42	0.44	Irrigation	-0.13	0.09
m_d	0.11	0.08	dap	-0.08	0.08	pa6	-1.61	0.47	Conserv.	-0.05	0.07
s_d	-0.12	0.07	labor	-0.31	0.13	pa7	0.53	0.50	Extension	-0.21	0.09
b_u	0.01	0.04	l_o	-0.11	0.11	pa8	-0.17	0.46	Education	-0.02	0.14
m__u	-0.01	0.05	l_i	-0.14	0.11	pa9	-0.88	0.51	Mem Educ	-0.04	0.04
s_u	0.06	0.06	l_u	-0.10	0.12	pa10	-0.23	0.39	Steep	0.01	0.06
b_i	-0.01	0.03	l_d	0.04	0.08	pa11	-0.08	0.38	Steeper	0.24	0.11
m_i	-0.03	0.03	l_lab	0.04	0.11	pa12	0.76	0.41	Off-farm	-0.10	0.05
s_i	0.05	0.04	l_sq	0.14	0.04	pa13	0.00	0.24	*Idir*	-0.02	0.10
b_o	0.14	0.08	o_i	0.00	0.06	pa14	0.41	0.28	Single	-0.08	0.14
m_o	0.05	0.05	o_u	0.16	0.11	pa15	0.28	0.26	Divorced	-0.07	0.12
s_o	-0.01	0.07	o_d	-0.06	0.12	t_d	-0.11	0.08	Widowed	-0.11	0.08
b_l	-0.07	0.09	o_lab	0.00	0.15	w_sq	-0.10	0.08	Separated	-0.04	0.16
m_land	-0.03	0.08	o_sq	-0.12	0.15	b_sq	-0.03	0.05	> 1 Spouse	-0.10	0.20
s_l	0.16	0.08	i_u	-0.01	0.05	m_sq	-0.09	0.05			
w_s	-0.06	0.07	i_d	0.11	0.06	s_sq	0.01	0.01			
b_s	0.02	0.06	i_lab	0.01	0.09	w_l	-0.05	0.09			
m_s	0.03	0.04	i_sq	-0.02	0.03	w_o	-0.18	0.09			
b_m	-0.05	0.05	u_d	0.02	0.04	w_i	-0.02	0.04			
w_m	0.11	0.04	u_lab	-0.14	0.09	w_u	-0.06	0.05			
w_b	0.05	0.05	u_sq	-0.01	0.05	w_d	0.08	0.08			
b	0.29	0.16	d_lab	-0.05	0.11	w_lab	-0.11	0.09			
m	0.35	0.13	d_sq	-0.02	0.12	lab_sq	0.02	0.13			
s	-0.02	0.10	wheat	0.39	0.15						

s ≡ sorghum; m ≡ maize; b ≡ barley; w ≡ wheat; o ≡ oxen; i ≡ purchased inputs; u ≡ urea; d ≡ dap; lab ≡ labor; l≡ land; _ ≡ interacting with; sq ≡ squared; pa ≡ village λ ≡ Box-Cox transformation parameter; c ≡ constant; Conserv. ≡ conservation; Mem Educ ≡ highest years of schooling in the household; steep ≡ average slope of the plots; soil ≡ average soil fertility (lower values more fertile).

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