Smallholder Teff Productivity and Efficiency: Evidence from High-Potential Districts of Ethiopia

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Abstract.

Smallholder agriculture focused policies predominated Ethiopia in the last two decades. Such policies are being questioned recently on grounds including research that show large-holders perform better in multi-factor productivity indices. We apply data envelopment analysis on recently collected data set to measure smallholder teff producers' relative productivity and efficiency. The results indicate that an average household is less than half as productive as optimal households and that there is therefore a considerable opportunity for output growth at current acreage. Analyses explaining differences in productivity indicate that productivity improves with, among others, schooling, specialising in few crops, access to credits, access to information on modern production methods directly through extension and indirectly through neighbourhood learning effects. While the data used is not inconsistent with the inverse farm size-yield relationship results of analyses indicate multi-factor productivity measures improve after a threshold of teff area.

Keywords: data envelopment analysis, productivity, efficiency, smallholder farmers, Africa, Ethiopia.

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1. Introduction

Smallholder agriculture dominates sub-Saharan Africa where a large proportion of the population and poor reside in rural areas (Diao et al., 2010; Henderson, 2014). These features are salient in Ethiopia where 85 percent of the population lived in rural areas and were engaged in agriculture in 2010 (Diao, 2010). The proportion residing in rural areas is predicted to remain higher than 70 percent until 2040, when there will be 54 more people per 100 that lived in rural areas in 2010 (UN, 2014). Agriculture in Ethiopia is dominated by smallholder farming households that cultivated 94 percent of the national cropped area in 2013/14. During the decade between 2004/05 and 2013/14 landholding size has generally declined and the number of farm-households increased (Central Statistical Agency (CSA), 2005a-2014a). That a large majority of Ethiopians engaged in agriculture has provided impetus for major agricultural and rural development policy initiatives of the Ethiopian Government that placed smallholder agriculture at the centre since the launch of the Agricultural Development Led Industrialization strategy in mid-1990s (Government of Ethiopia, 1993).

Development economists in the past broadly agreed on the need for policy support to smallholder agriculture owing largely to its effectiveness in poverty reduction and contribution to economic growth in a number of Asian countries during the green revolution (Diao et al., 2010; Hazell et al., 2010). Increased public investments in smallholder agriculture therefore are mostly favoured by policy analysts that give priority to achieving poverty reduction and food security goals (FAO, 2010; Gates Foundation, 2011; Fan et al., 2013). However, such policies are being increasingly challenged in Africa on a number of grounds (Collier and Dercon, 2009; Dercon and Zeitlin, 2009). These challenges arise from research that shows medium and large scale farmers are more productive than smallholders (Helfand and Levine, 2004; Rios and Shively, 2005; Padilla-Fernandez and Nuthall, 2012), and that the poor might benefit from improved labour markets generated by more efficient larger farms (Maertens and Swinnen, 2009). Even those that promote smallholder focused policies as necessary for growth and poverty reduction point to the diversity within smallholder farmers and underline the need for tailoring agricultural development policies to specific conditions and targeting farmers with a viable future in agriculture (Birner and Resnick, 2010; Fan et al., 2013; Hazell, 2013).

Growth in agriculture was one of the major drivers of the remarkable economic growth recorded in Ethiopia in the last decade (National Bank of Ethiopia, 2014). Teff accounted for about a fifth of the nationwide agricultural area and was cultivated by nearly half of smallholder farmers during the 2004/05-2013/14 period. During the same period teff output grew at average annual rate of 9.3 percent and yields at 5.2 percent (CSA, 2005b-2014b). Evidences indicate that part of the growth in teff output has been driven by increases in cultivated area (Dorosh et al., 2015). However, it is not well understood whether there were improvements in productivity and the contribution of such improvements for growth in output. In particular, doubts exist on the possibility of rural development on declining landholdings and whether the growth so generated will enable reduce poverty (Diao, 2010).

This study aims to fill the gap in the evidence using data envelopment analyses (DEA) to measure relative total factor productivity (TFP) and efficiency of teff producing households. The analyses use a dataset collected in the baseline survey of the Agricultural Growth Program (AGP) of Ethiopia.[1] Moreover, econometric analyses are conducted to identify factors that influence TFP and efficiency. Despite declining landholdings in Ethiopia, there is surprisingly

[1] The AGP commenced in 2011 as a component of the government's broad effort to achieve the targets of the Growth and Transformation Plan. It is mainly aimed at sustainably increasing smallholder productivity and value-addition in agriculture (Ministry of Agriculture, 2010).

little empirical evidence on the link between farm size and productivity. This study investigates the effect on productivity of farm size and level of specialization in crop production.

This study makes multiple contributions to the research literature. First, it uses a recent large-scale dataset of farm households in Ethiopia cultivating an important crop. Second, the study uniquely integrates a number of variables to inform the debate on the farm size-productivity relationship that is being revisited recently. Third, the study provides insight on the relationship between productivity and levels of specialization. Finally, the study complements other policy research on teff and informs recent efforts made by the Ethiopian Government to increase teff productivity (Minten and Taffesse, forthcoming).

The remainder of this paper is organized as follows. In Section 2, the theoretical and empirical model used is described. Next, the data is described, followed by a discussion of the results. The last section summarizes key findings and indicates their policy implication.

2. Method of Analysis

Input and output distance functions are key relative performance measurement tools employed in DEA. In the first part of this section we define input and output distance functions and provide the empirical distance function. In the second part we define the relative total factor productivity (RTFP) and efficiency indices computed using the distance functions. Finally, the model employed to investigate factors that explain RTFP and efficiency is provided.

2.1 Output and Input Distance Functions

Consider a production technology T that describes the relationship between an input vector $X = [x_1, x_2, \dots, x_N]$ and an output vector $Y = [y_1, y_2, \dots, y_M]$:

$$T = \{(X, Y): X \in \Re_+^N, \quad Y \in \Re_+^M, \quad X\ can\ produce\ Y\}$$

An output distance function is defined, under some regularity conditions, as:[2]

$$D_O^j(X_j, Y_j) = \inf_\theta\{\theta^j:\ (X_j, Y_j/\theta) \in T\} \text{ for all } j \in [1,2,\dots,J] \quad (1)$$

where j indexes teff producers, and $D_O^j(.) \in (0,1]$ stands for the output distance function of j.

Similarly, an input distance function is defined as:

$$\mathrm{D_I^j}(\mathrm{X_j}, \mathrm{Y_j}) = \sup_\beta\{\beta^j:\ (X_j/\beta, Y_j) \in T\} \text{ for all } j \in [1,2,\dots,J] \quad (2)$$

where $D_I^j(.) \geq 1$ stands for j's input distance function. Furthermore, the output and input distance functions are a complete representation of the production technology in the sense that:

$$D_O^j(X_j, Y_j) \leq 1 \Leftrightarrow (X_j, Y_j) \in T \Leftrightarrow D_I^j(X_j, Y_j) \geq 1$$

whereby $D_O^j(.)$ and $D_I^j(.)$ inherit the properties of T (Fare and Grosskopf, 2000 p. 611).

Translog distance functions are often employed in DEA, which we also adopt in this study. The empirical output distance function of teff producers is then defined as:

$$D_O^j(X_j, Y_j) = \alpha_0 + \alpha_1 \ln y_j + \frac{1}{2}\alpha_{1,1}\ln y_j^2 + \sum_{n=1}^{10}\beta_n \ln x_{n,j} + \frac{1}{2}\sum_{n'=1}^{10}\sum_{n=1}^{10}\beta_{n',n}\ln x_{n',j}\ln x_{n,j} +$$
$$\sum_{n=1}^{10}\delta_n \ln x_{n,j}\ln y_j + \sum_r \gamma_r\, Region_{r,j} \qquad \text{for all } j \in [1,\dots,J] \quad (3)$$

where $\sum_r \gamma_r\, Region_{r,j}$ in the last summation stands for region dummies. $\mathrm{y_j}$ is the quantity of teff household j produced using $x_{n,j}$ quantity of input type n, with $x_{n,j} \in X = [x_{1,j}\ \ x_{2,j} \dots x_{10,j}]$. We formally define and summarize the variables in Table 1.

DEA employs linear programming methods on input-output data to construct non-parametric piece-wise linear production or input requirement frontiers and compute output and input distance functions. Relative productivity of farmers away from the frontier is then measured by way of their distance to the frontier or relative to optimal producers on the frontier. In Appendix 1 of this paper we provide the linear programming problem that solves for the output distance function given by (3) and a similarly specified input distance function.

[2] See Fare and Primont (1995 pp.12-13) for regularity conditions.

2.2 Productivity and Efficiency Indices

The indices used to measure teff producers' relative productivity and efficiency are defined here. Among classes of productivity indices the Färe-Primont and Lowe indices satisfy all economically-relevant axioms and tests in the index number theory (O'Donnell, 2011a; 2011b). We employ the Färe-Primont index, which is suitable for input-output data used in this work. According to this index the TFP of household j is defined as:

$$TFP_j = \frac{Q_j}{I_j} \tag{4}$$

where $Q_j = Q(y_{m,j})$ is the aggregate output index and $y_{m,j}$ is the magnitude of type m output, such that $y_{m,j} \in Y_j = [y_{1,j}\ y_{2,j} \dots y_{M,j}]$. Similarly, $I_j = I(x_{n,j})$ is an aggregate input index and $x_{n,j}$ is quantity of input type n, where $x_{n,j} \in X_j = [x_{1,j}\ x_{2,j} \dots x_{N,j}]$. The aggregator functions $Q(.)$ and $I(.)$ are assumed to be nonnegative, non-decreasing, and linearly homogenous functions of their respective arguments (O'Donnell, 2008).

Suppose *k* indexes optimal household/s. Then, $RTFP_{k,j}$, which denotes the TFP of household *j* (TFP_j) relative to the TFP of *k*, (TFP^*) is given as:

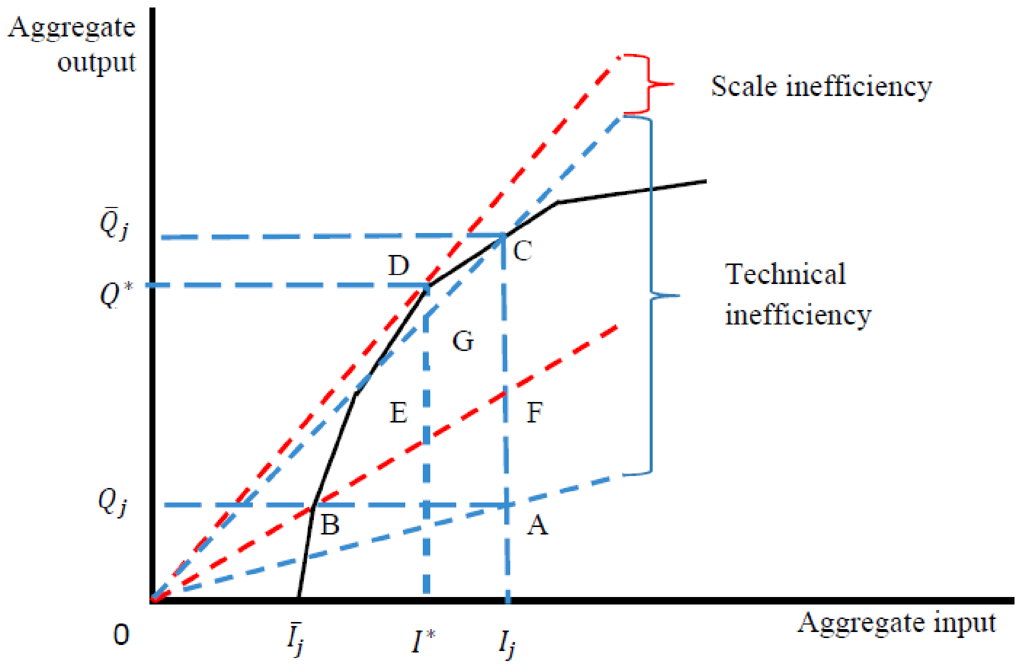
$$RTFP_{k,j} = \frac{TFP_j}{TFP^*} = \frac{Q_j/I_j}{Q_k^*/I_k^*} = \frac{Q_{k,j}}{I_{k,j}} \tag{5}$$

The index at (5) is multiplicatively complete or can be decomposed into technical and scale efficiency indices that obtain $RTFP_{k,j}$ multiplicatively (O'Donnell 2009; 2011a). We use Figure 1 to illustrate technical and scale efficiency components of RTFP.

Suppose household *j* operates at point A where it produces Q_j using I_j. The household at A is inferior relative to that at C, which is producing $\bar{Q}_j \geq Q_j$ using I_j. $\bar{Q}_j$ is the maximum output that is a scalar multiple of Q_j possible to produce using I_j. The output-oriented technical efficiency (OTE) of A is given as:

$$\mathrm{OTE_j} = \frac{\mathrm{Q_j/I_j}}{\mathrm{\bar{Q}_j/I_j}} = \frac{\mathrm{TFP_j}}{\mathrm{TFP_C}} = \frac{\mathrm{Q_j}}{\mathrm{\bar{Q}_j}} = \mathrm{D_O^j(X_j, Y_j)} \leq 1 \qquad (6)$$

Figure 1. Output-oriented measures of efficiency for a multiple-input multiple-output firm



Source: Modified from Figures 1 and 2 of O'Donnell (2011c).

The household at B is superior to A in input technical efficiency because it is producing Q_j using $\bar{I}_j \leq I_j$, where $\bar{I}_j$ is the minimum aggregate input that is a scalar multiple of I_j possible to produce Q_j. Therefore, the input-oriented technical efficiency (ITE) of household j is given as:

$$ITE_j = \frac{Q_j/I_j}{Q_j/\bar{I}_j} = \frac{TFP_j}{TFP_B} = \frac{\bar{I}_j}{I_j} = D_I^j(X_j, Y_j)^{-1} \leq 1 \qquad (7)$$

Although the households at B and C are superior to A they have lower TFP relative to D, which has the maximum TFP of Q^*/I^*, which is apparent from the line that is tangent to the production frontier at point D. Producer D is superior relative to C due to output oriented scale efficiency (OSE) and relative to B in input oriented scale efficiency (ISE).[3]

[3] We define the TFP of households relative to technically and scale efficient producers operating on the production frontier constructed from the dataset. The comparison can also be made relative to households that operate on mix-unrestricted

Performance in OSE and ISE of the respective households at C and B is given by:

$$OSE_j = \frac{\bar{Q}_j/I_j}{Q^*/I^*} = \frac{TFP_C}{TFP^*} \leq 1 \qquad \text{and} \qquad ISE_j = \frac{Q_j/\bar{I}_j}{Q^*/I^*} = \frac{TFP_B}{TFP^*} \leq 1 \qquad (8)$$

Equations (5), (6), and (7) can be manipulated to obtain the aggregate outputs that the household at point A could produce if it were as efficient as households at D, C, and B in RTFP, OTE, and ITE, respectively, which we denote by $\bar{Q}_j^*$, $\bar{Q}_j^O$, and $\bar{Q}_j^I$. The resulting equations are:

$$\bar{Q}_j^* = TFP_k^* * I_j; \qquad \bar{Q}_j^O = \frac{Q_j}{OTE_j}; \qquad \text{and} \qquad \bar{Q}_j^I = TFP_B * I_j \qquad (9)$$

The hypothetical optimal outputs given by equations (9) are aggregate units. We convert these aggregate outputs into quantity of teff in two steps. First, for each efficiency index, we compute the factor by which aggregate output increases as a ratio of the optimal aggregate output obtained from (9) and actual aggregate output. The optimal quantity of teff is obtained in the second step by multiplying the factor calculated in the first step with household j's actual teff output. The method is justified because the output aggregator function is non-decreasing and linearly homogenous in teff output.

2.3 Factors Explaining Efficiency and Productivity

We use a Tobit model to explain teff productivity and efficiency. The empirical equation used for this purpose is given as:

$$Efficiency_j = \delta_0 + \sum_{i=1}^{4} \delta_i\, Demography_{i,j} + \delta_5\, Area_{m,j} + \delta_6\, Area_{m,j}^2 + \delta_7\, Own\ land_j +$$
$$\delta_8\, Damage_j + \delta_9\, Partial\ Spec_j + \delta_{10}\, Ful\ Spec_j + \delta_{11} Off\text{-}farm\ work_j + \delta_{12}\, TLU_j +$$
$$\delta_{13}\, Production\ info_j + \delta_{14}\, Fert\ users_z + \delta_{15}\, Imp\ seed\ users_z + \delta_{16}\, Ext\ users_z +$$

production frontier lying above the current frontier (O'Donnell 2008; 2011c). The objective of comparing households within the current production possibility frontier justifies our approach.

$$\delta_{17}\, Credit\ inst\ in\ FA_j + \delta_{18}\, Ext\ center\ in\ FA_j + \delta_{19}\, PAs\ in\ FA_j + \delta_{20}\, Time\ to\ market_j + \delta_{21}\, black\ teff_j + \sum_r \delta_r\, Region_{r,j} + \delta_{25}\, AGP_j + \sum_z \delta_z AEZ_{z,j} + e_j \qquad (10)$$

where $Efficiency_j$ stands for RTFP, OTE, OSE, ITE, and ISE. Equation (10) relates RTFP and efficiency of the households obtained from the data envelopment analyses, with crop, household, and location specific factors. Included as explanatory variables are 4 demographic variables given in the first summation, $\sum_{i=1}^{4} \delta_i\, Demography_{i,j}$. About 53 percent of the households cultivated black teff variety, represented by the $black\ teff_j$ dummy while white teff is omitted. The AGP baseline survey dataset used in this study was collected from households in 93 woredas (districts) of 4 regions: Tigray, Amhara, Oromiya, and Southern Nations, Nationalities, and Peoples (SNNP). $Region\ dummy_{r,j}$ are region dummies, where Tigray is omitted. Similarly, AGP_j takes a value of 1 if household j resided in one of the 62 AGP beneficiary districts. Provided in the last summation are agroecologic zone (AEZ) dummies. The households resided in AEZs locally known as Kolla, which is omitted, and Woina dega, and Dega.[4] The error term, e_j, is assumed to be distributed as: $e_j \sim N(0, \sigma_e^2)$. The remaining variables are defined in Table 2.

3. Data

The four regions included in this study accounted for over 90 percent of the nationwide agricultural output and area during 2004/04-2013/14 (CSA 2005a-2014a). Out of 7,928 households interviewed in the AGP baseline survey our study includes 2,942 teff producing households. The data pertains to the 2010/11 main agricultural season. Table 1 summarizes

[4]This classification divides Ethiopia into five agroecologic zones (AEZs) based on elevation, annual rainfall, and temperature. In general, Wurch AEZ has the highest elevation and lowest temperature followed respectively by Dega, Woina Dega, and Kolla while Berha AEZ represents lowland areas with lowest precipitation and highest temperature (Ministry of Agriculture 2000). No household in our data resided in Berha AEZ. About 59 percent resided in Woina dega, 25 percent in Dega, and 15 percent in Kolla. The Wurch dummy is excluded from the analyses because only 1.1 percent of the households resided in the AEZ.

variables used in the data envelopment analyses while Table 2 summarizes the data used in the econometric analyses.

Table 1. Definition and summary of variables used in DEA.

Variable	Definition	Aggregation	Mean	SD
y	Teff output (KGs)	Crop	320	372
Explanatory variables				
X_1	Teff area (ha)	Crop	0.50	0.47
X_2	Total work days (number)	Crop	55	107
X_3	Number of oxen used to plough land (number)	HH	1.37	1.36
X_4	Total chemical fertilizers (KGs)	Crop	31	52
X_5	Total improved seeds (KGs)	Crop	1.0	6.5
X_6	Dummy=1 if pesticides, herbicides, or fungicides used	Crop	35	48
X_7	Dummy=1 if cropland is irrigated	Crop	1.9	13.5
X_8	Land quality index=Land fertility × Slope of land[a]	Crop	6.5	2.3
X_9*	Total sum of daily rainfall during 1/5/2010-31/10/2010 (mm)	District	1,497	609
X_{10}*	Growing degree days=sum of daily beneficial heat[b]	District	0.90	0.34

Source: The AGP Baseline Survey (2011) except those with *, which are from NASA (2014).
Notes: a) Land fertility∈[1=infertile, 2=semi-fertile, 3=fertile] and Slope of land∈[1=steep, 2=gentle, 3=flat].
b) *Daily beneficial heat* is the contribution to yields of any given day's average temperature that lies within a given bound, generally 8^0C -32^0C. Growing degree days is the sum over days in the cropping season (1/5/2010-31/10/2010) of daily beneficial heat [resulting from the excess of average daily temperature over the lower bound] times the probability of the average temperature to occur on that day in that area (Schlenker and Roberts 2006, Roberts, Schlenker, and Eyer 2013).

The summary in Table 1 indicates that teff area averaged 0.5 hectares and output 3.2 quintals. Fertilizer application averaged 31 kilograms and labour use 55 working days. An average household head was 43 years old in May 2011 and about 77 percent of the households have male heads (Table 2). About 43 percent of household heads are literate. In the econometric analyses we use a dummy variable that takes a value of 1 if a household head is educated in grades 4 or higher. This follows Wier's (1999) finding that a minimum of 4 years of schooling is required for education to meaningfully affect productivity.

Table 2. Summary of factors that influence productivity and efficiency.[a]

Variables	Definition	Aggregation	Mean	SD
Demography$_1$	HH head gender (1 if male)	HH	0.77	0.42

$Demography_2$	HH head age (years)	HH	43	15
$Demography_3$	HH head education (1 if educated in grades 4 or higher)	HH	29	46
$Demography_4$	HH size (number of members)	HH	5.0	2.2
Own land	Dummy=0 if land is rented-in or sharecropped; =1 otherwise	Crop	75.1	43.3
Damage	Crop output damaged by bad weather, diseases, and pests (%)	Crop	11	20
Partially spec	Dummy=1 if HH cultivated two crops (partially specialised)	HH	13	34
Fully spec	Dummy=1 if HH cultivated one crop (fully specialised)	HH	3.3	17.9
Off-farm work	Dummy=1 if HH member/s are employed off/non-farm	HH	40	49
TLU	Tropical livestock units, total livestock normalized to cattle	HH	3.7	3.9
Production info	Dummy=1 if farmer accessed production information from media	HH	26	44
*Fert users**	Cereal growers in zone that used fertilizer last meher (%)	Zone-crop	24.1	18.3
*Imp seeds users**	Cereal growers in zone that used improved seeds last meher (%)	Zone-crop	2.4	4.1
*Ext users**	Cereal growers in zone that used extension service last meher (%)	Zone-crop	24.9	20.5
Credit inst in FA	Dummy=1 if PAs, MFIs, and/or SLAs in FA extend credits.	FA	52.3	50.0
Ext centre in FA	Dummy=1 if FA has extension service centre.	FA	90	30
PAs in FA	Dummy=1 producers' associations (PAs) active in FA.	FA	24	43
Time to market	Travel time to closest market (hours)	FA	1.15	0.68

Source: The AGP Baseline Survey dataset (2011) except those with *, which are from CSA (2010c).
Notes: a) HH, FA, PAs, MFIs, SLAs, stand respectively for *household, farmers' association, producers' associations*, *Money and financial institution*, and *Saving and loan associations.*

4. Results and Discussion

In the first part of this section we discuss the RTFP and efficiency levels obtained from DEA. Also discussed in the first part are optimal yields and output implied by the performance indices. DPIN 3.0, a program designed to decompose productivity and index numbers (O'Donnell 2011c) is used to compute the indices. The second part discusses results of econometric analyses conducted to investigate factors influencing RTFP and efficiency.

4.1 Relative Total Factor Productivity and Efficiency

Table 3 summarizes teff producers' performance in RTFP, output-oriented technical and scale efficiency (OTE and OSE), and input-oriented technical and scale efficiency (ITE and ISE). We summarize in Table 4 output and yields computed assuming the households are fully optimal and allocate at least half or all of their total landholdings to produce teff.

Average RTFP of teff production is about 0.36. That is, average RTFP can potentially increase by 177 percent =((1-0.361)/0.361). However, improvements in RTFP computed at household level indicate a potential increase of about 386 percent. The latter indicates that RTFP is skewed to lower values, which is corroborated also by a skeweness test of RTFP. OTE and ITE averaged 0.41 and 0.65 while OSE and ISE averaged 0.91 and 0.53, respectively.

Table 3. Summary of relative total factor productivity and efficiency.

		Performance in productivity/efficiency					Land management characteristics		
Household category (in percent)	Statistics	RTFP	OTE	OSE	ITE	ISE	Teff area (ha)	Number of crops	Total household area (ha)
All households	Mean	0.36	0.41	0.91	0.65	0.53	0.50	4.22	1.58
	SD	0.24	0.27	0.15	0.19	0.26	0.47	1.85	1.27
Household area in teff									
Less than half (77.1%)	Mean	0.35	0.40	0.91	0.651	0.52	0.42	4.65	1.70
	SD	0.24	0.27	0.15	0.19	0.26	0.38	1.75	1.33
At least half (19.7%)	Mean	0.39	0.43	0.93	0.654	0.58	0.77	3.06	1.24
	SD	0.25	0.27	0.12	0.20	0.26	0.64	1.25	0.99
Number of crops cultivated									
Three or more (83.7%)	Mean	0.35	0.40	0.91	0.64	0.53	0.49	4.69	1.70
	SD	0.24	0.27	0.15	0.19	0.26	0.47	1.64	1.32
Two (13.1%)	Mean	0.41	0.47	0.90	0.73	0.55	0.52	2.0	1.02
	SD	0.24	0.28	0.16	0.20	0.26	0.44	0.00	0.73
Single crop (teff) (3.2%)	Mean	0.42	0.49	0.90	0.71	0.58	0.69	1.0	0.69
	SD	0.27	0.30	0.18	0.22	0.27	0.52	0.00	0.51

Source: Authors' analyses using the AGP Baseline Survey data (2011).
b) *RTFP* stands for *relative total factor productivity*; *OTE* and *OSE* stand for *output oriented technical* and *scale efficiency*; and *ITE* and *ISE* and *input oriented technical* and *scale efficiency*, respectively.

Performance in the indices also indicate the output each household could produce if it were optimal or achieved a score of 1 in the index. We use the set of equations at (9) to compute the optimal outputs each household could produce assuming the inefficiencies implied by RTFP, OTE, and ITE were removed. The results are summarized in the third (Optimum) column of Table 4. Optimal teff yields implied by RTFP and OTE, are about 2 metric tons/ha (MT/ha) or at least 160 percent higher than actual yields, 0.77 MT/ha. Optimal yields implied by ITE are lower, 0.11 MT/ha, because households perform relatively well in ITE. Teff output could potentially increase to at least 0.82 MT per household if all households were optimal in RTFP and OTE. ITE implied optimal teff output averaged 0.5 MT.

Table 4. Teff output at optimal productivity and at partial and full specialization in teff.

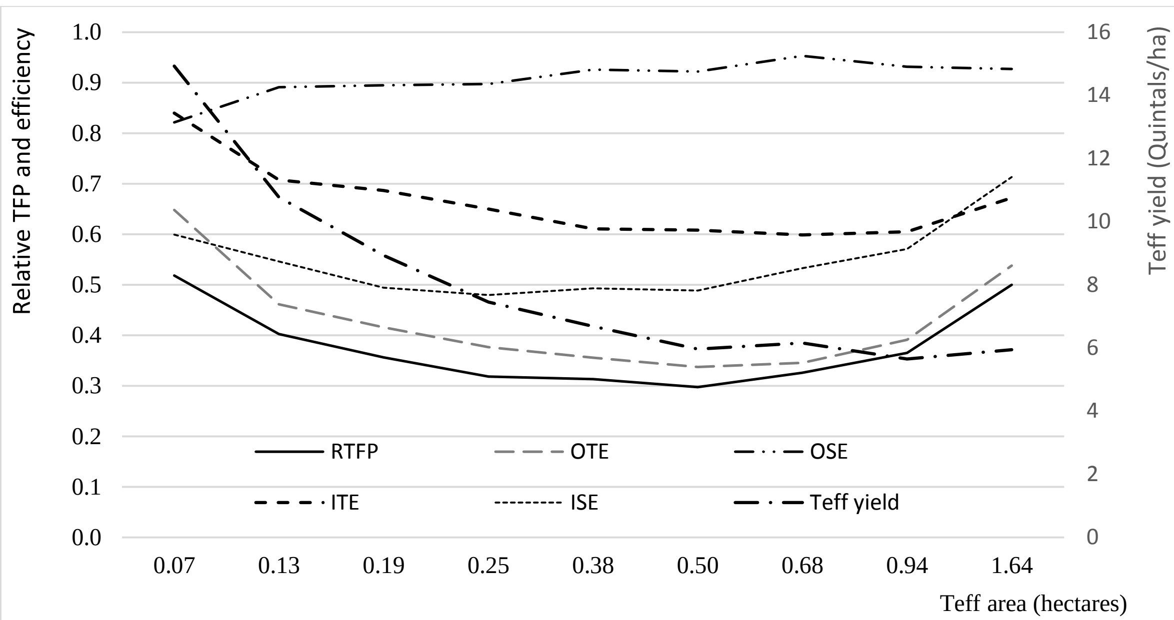
Variable	Efficiency index or indicator	Yields and output at		
		Optimum (index=1)	Partial specialization (teff area=1/2 household area)	Full specialization (teff area=household area)
First Panel				
Teff area (ha)	Actual or with specialization	0.50	0.79	1.58
Yields (KG/ha)	Actual (current productivity)	769	769	769
	RTFP	2,162	954	1,037
	OTE	1,977	960	1,038
	ITE	1,143	825	836
Second Panel				
Output (KGs)	Actual or with specialization	320	554	1,058
	RTFP	887	735	1,538
	OTE	825	737	1,539
	ITE	495	608	1,185

Source: Authors analyses using the AGP Baseline Survey data (2011) and NASA (2014).

Table 3 also summarizes the performance indices across specialization and proportion of household area allocated to produce teff. Performance in all productivity indices except OSE improves with specialization and household area sown to teff. Total household landholding is inversely related with both scale of teff production (proportion of area allocated for teff) and level of specialization, implying that there is considerable room for increasing the scale of operation and to specialise in fewer crops. Moreover, households that use half or larger area to produce teff, 57 percent of which grew at least 3 crops, cultivate larger teff area but have lower RTFP, OTE, and ITE than those fully specialized. The latter may imply that gains in productivity may improve with simultaneous specialization and increase in the scale of production.

Figure 2 depicts the productivity indices across average teff area of 9 household groups. Each group constitutes about 10 percent, or a decile, of the 2,942 households, except those cultivating 0.25 and 0.5 hectares, which accounted for 18 percent and 14 percent, respectively. The figure shows that RTFP, OTE, and ISE decline with teff area up to 0.5 hectares and increase thereafter. OSE increases up to 0.68 hectares and then declines and the reverse holds for ITE. It appears that overall productivity improves if households use 0.5 hectares or larger teff area. In this dataset only 29 percent of the households use teff area larger than half a hectare.

Figure 2. Patterns of relationship between teff area and productivity indices



Source: Authors' analyses using the AGP Baseline Survey data (2011) and NASA (2014).

Gains in output that could result if households partially (fully) specialise in teff production are computed using equations (9) under the assuming that households allocate half (all) of their total landholdings to teff and move into one of the higher teff area deciles in Figure 2, and become as efficient, in RTFP, OTE, and ITE, as an average household in the new teff area decile.[5] Results of these computations, which ignore the benefits of diversification, are provided in the last two columns of Table 4. The fourth ("Partial specialization") column of the table indicates that average area will increase to 0.79 hectares if all households use at least half of their landholdings to produce teff. At current productivity levels and assumed teff area, an average household could produce 5.5 quintals. Teff output and yields could increase to about 0.74 MT and 0.95 MT/ha due to gains in RTFP and OTE when partially specializing in teff. That is, both teff output and yields could potentially increase by over 0.18 MT and MT/ha. If all households used their landholdings, which averaged 1.58 hectares, to produce teff an average household could produce 1.1 MT at current productivity levels. Teff output of an average household could increase by about 0.48 MT and yields by about 0.27 MT/ha due fully specializing in teff production. That is, gains in teff yields are higher at full specialization than at partial specialization.

A number of studies that measure efficiency, mostly output-oriented technical efficiency, of farmers cultivating different crops in Ethiopia obtain results similar to those obtained in this study. For instance, Yami et al. (2013) find average wheat production OTE of 0.55 for the 2010/11 main agricultural season. Similarly, Mekonnen et al. (2013) find average OTE of 0.58 for 1999/2000 and 2004/05 while the average Nisrane et al. (2011) obtained was 0.46 for 2009/10. Suleiman and Morrissey (2006) find average technical efficiency of 0.51, 0.54, and 0.57 for 1994/95, 1996/97, and 1999/2000, respectively. Gebregziabher et al. (2012) find an average OTE of 0.45 for farmers that used irrigation in the 2004/5 main cropping season. In a cross-country study of 42 countries including Ethiopia and covering the 2004-2011 period, Mekonnen et al (2015) find an average agricultural technical efficiency of 0.44. With average

[5] Households that use half of their landholdings to produce teff and the other half to grow another crop can be described as partially specializing in teff. The term describes households that use the second half of their landholding to grow multiple crops only loosely and can only be justified given they use a larger proportion of their landholdings to grow teff.

technical efficiency of 0.22, Ethiopia ranked 36th and in the year it performed best, 2008/09, its technical efficiency was only 52 percent of the average efficiency.

In addition to the persistence gap in efficiency among farmers in Ethiopia implied by the studies referred to above, the following two observations can be discerned from the results presented in this part. First, an average teff producer is considerably less productive relative to optimal households and, hence, there is large room for productivity improvements. Second, the descriptions indicate that productivity and efficiency improve with increases in both specialization and scale of operation. The latter is also supported by findings that imply increasing returns from expansion in the scale of teff production (Fare and Lovell, 1978).

4.2 Factors Explaining Efficiency and Productivity

This part discusses estimates of equation (10) obtained using a Tobit model. The results, which are provided in Table 5, indicate that household size, and the age and gender of the household head have no effect on productivity. However, households with better educated heads perform better in RTFP, OTE, and ISE.

Access to information on production and services

Information on production obtained from media positively impact efficiency. The results indicate that households exposed to such information perform better in RTFP, OTE, and ISE. Performance of households in places where government extension offices provide services is higher in all indices except one. Increases in the proportion of farmers with previous experience using modern inputs and exposure to modern production methods in a given area is expected to positively influence the efficiency of other farmers through neighbourhood learning (knowledge spill-over) effects and by positively influencing modern input adoption (Krishnan and Patnam, 2014). The results indicate that farmers in places where a higher proportion of teff producers used fertilizer and improved seeds in the last cropping season perform better in efficiency.

Access to institutions that extend credits reduces borrowing and search costs and thereby influence efficiency positively. The results indicate that all efficiency indices except OSE improve in areas where producers' associations; money and financial institutions, and saving and loan associations extend credits. These findings are similar to those in Solís et al. (2007) and Helfand and Levine (2004). It was anticipated that performance in productivity would improve with proximity to markets, since this improves access to marketed inputs and reduces transaction costs associated with the sale of outputs. However, none of the performance indices improve with proximity to market. TFP and ISE are lower among households residing in FAs with active producers' associations. This is contrary to what we expected, and to the positive relationship between efficiency and cooperative membership that Helfand and Levine (2004) found.

Land management and risk

The dataset used in this study indicates that an average household cultivated 4.3 crops. Results of the econometric analyses indicate that partially specializing households perform better in all indices and those fully specializing perform better in all indices except one. Moreover, where significant, the full specialization dummy variable is statistically significantly higher than the partial specialization dummy, indicating productivity improves with specialization. The latter was also implied by our simple computations that show teff yields increase faster when households fully specialise than when they partially specialise.

The households reported 11 percent of their teff output suffered damages due to bad weather, diseases, and pests (Table 2). Results of our analyses also indicate that most performance indices decline due to crop damages. Households cope with variability of income

Table 5. Factors explaining relative TFP and efficiency.[a]

	Dependent variable:				
		Output oriented		Input oriented	
Variables	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency
Household characteristics					
Gender of household head	-0.14	-1.51	0.96	-0.94	0.65
	(1.12)	(1.35)	(0.72)	(0.87)	(1.21)
Age of household head	0.01	0.02	-0.02	0.01	0.01
	(0.03)	(0.04)	(0.02)	(0.02)	(0.03)
Head education	1.67*	3.26***	-1.16*	0.64	2.58**
	(0.98)	(1.18)	(0.63)	(0.76)	(1.06)
Household size	0.19	0.16	0.07	-0.16	0.26
	(0.22)	(0.27)	(0.14)	(0.17)	(0.24)
Land management and risk					
Crop area	-8.57***	-18.96***	7.22***	-22.22***	4.44**
	(2.01)	(2.47)	(1.09)	(1.58)	(2.20)
Crop area squared	6.24***	9.67***	-1.29***	8.09***	2.94***
	(0.79)	(0.99)	(0.35)	(0.63)	(0.88)
Proportion of land owned	-0.40	-1.24	1.08	-1.23	0.34
	(1.05)	(1.27)	(0.68)	(0.82)	(1.13)
Total crop damage (percent)	-12.80***	-12.42***	-2.56*	-0.51	-19.40***
	(2.09)	(2.52)	(1.35)	(1.63)	(2.26)
Partially specialised	5.27***	4.47***	1.63*	2.97***	4.99***
	(1.31)	(1.59)	(0.85)	(1.04)	(1.42)
Fully specialised	8.04***	9.31***	1.35	5.18***	7.67***
	(2.41)	(2.94)	(1.57)	(1.92)	(2.62)
HH member works off-farm	-0.73*	-0.42	-0.67**	0.43	-1.17**
	(0.43)	(0.52)	(0.28)	(0.33)	(0.46)
Tropical livestock units	0.03	-0.06	0.20**	-0.17*	0.16
	(0.12)	(0.15)	(0.08)	(0.10)	(0.14)
Access to information and services					
Production information	2.46**	2.93**	-0.51	1.14	2.84***
	(1.01)	(1.23)	(0.66)	(0.79)	(1.10)
Fertilizer users in zone (lagged)	0.09**	0.11***	-0.03	0.06**	0.14***
	(0.03)	(0.04)	(0.02)	(0.03)	(0.04)
Improved seed users in zone (lagged)	0.15	0.24	-0.05	0.24**	0.12
	(0.13)	(0.15)	(0.08)	(0.10)	(0.14)
Extension users in zone (lagged)	0.10**	0.005	0.13***	-0.05	0.10**
	(0.04)	(0.05)	(0.03)	(0.03)	(0.04)
DA centre available in FA	5.76***	5.04***	1.16	3.22***	5.67***
	(1.55)	(1.88)	(1.01)	(1.20)	(1.68)
PAs available in FA	-1.75*	-1.58	0.47	-1.21	-2.21**
	(1.04)	(1.26)	(0.67)	(0.81)	(1.12)
Creditor institutions available FA	1.94**	2.91**	-0.61	1.93**	2.65**
	(0.97)	(1.17)	(0.63)	(0.75)	(1.05)
Travel time to closest market (Hrs)	-0.69	-0.60	-0.22	-0.65	0.11
	(0.67)	(0.81)	(0.43)	(0.52)	(0.73)
Constant	18.54***	38.61***	71.80***	88.74***	18.22***
	(3.82)	(4.62)	(2.46)	(2.98)	(4.13)
Log-Likelihood	-13,194	-13,120	-11,204	-11,419	-13,282

Source: Authors' analyses using the AGP Baseline Survey data (2011), NASA (2014), and CSA(2010c).
Coefficients with ***, **, and * are significant at 1, 5, and 10 percent level of significance, respectively
Notes: a) Equations estimated including region and agroecologic zone dummies specified in equation (13).

generated from the production of teff and other crops by engaging in other activities, such as livestock production and off-farm/non-farm employment. The results indicate that input technical efficiency declines and output scale efficiency improves with the number of livestock kept by households. The latter may be because those who own more livestock have good access to ploughing power. Households with members that participate in off-farm employment or non-farming activities have lower RTFP and scale efficiency, which is consistent with labour bottlenecks such households face. The last result is similar to the negative relationship between off-farm work and efficiency found by Coelli et al. (2002). Moreover, Mariano et al. (2011) found that efficiency of rice farmers declines with increase in non-rice farming and non-farming income.

We investigate whether scale of operation, defined by teff area, affects productivity. Estimated coefficients of area and its square term imply that OTE and ITE decline until 1 and 1.4 hectares and then increase, respectively. Moreover, OSE increases until 2.8 hectares before declining, while ISE increases quadratically with teff area. Consequently, RTFP declines until 0.7 hectares and increases thereafter. That is, the area at which the RTFP starts increasing implied by the descriptive analyses (Figure 2), is close to that obtained in the econometric analyses, even though the latter consider the effects of a number of factors besides area.

The inverse farm size-productivity relationship has been well documented. However, most studies establish the relationship using 'partial measures of productivity such as yield' and such a relationship may not hold 'if a measure of total factor productivity (TFP) were used instead' (Helfand and Levine, 2004: 241). The latter observation is corroborated by a number of works that find a positive relationship between farm size and multi-factor productivity measures. This includes Padilla-Fernandez and Nuthall (2012), Rios and Shively (2005), and Coelli et al.

(2002). In particular, the u-shaped efficiency-area relationship implied in the econometric analyses and depicted in Figure 2 is similar to that obtained in Helfand and Levine (2004) and Latruffe et al. (2005). Bachewe et al. (2015) show that productivity improves with farm size among cereals producers in Ethiopia while they also find an inverse relationship between cereals area and yields. The data used in this study also indicate that teff yield generally declines with teff area. (Figure 2). Bachewe et al. (2015) examine application levels and partial productivities of four inputs to explain the apparently contradictory inverse farm size-yield relationship on the one hand, and positive farm size-multi factor productivity relationship on the other. Accordingly, the study attributes the apparent contradiction to per hectare application of non-land inputs, which is higher among smallholders and declines with area, and partial productivity of the inputs, which is lower among smallholders and increases with cereals area.

This study further investigates the farm size-productivity relationship and examines whether the impact of factors that explain productivity and efficiency differ across farm size. For this purpose the econometric analyses applied on the aggregate data (Table 5) are redone after dividing the households in the dataset into two groups: smallholders and large-holders. Households cultivating the median teff area of 0.375 hectares or less, which constitute 51.5 percent of the total, are categorized as smallholders. Results of these analyses are provided in Appendix 2.

When significant, almost all estimates in Appendix 2 have implications similar to those in Table 5. There are two exceptions to the latter. First, smallholders with younger and female heads perform better in OSE and technical efficiency, respectively. Secondly, OSE of smallholders and technical efficiency of large-holders is impacted positively by proximity to markets. Despite the similarity in the implications of the remaining variables, a number of them impact the productivity of either small- or large-holders. This includes access to media information on production, which positively impacts four productivity indices of only large-holders. Similarly, off-farm employment impacts negatively only smallholders. Four of the five performance indices of only large-holders are impacted negatively by producers' associations. The proportion that used fertilizer in the last main agricultural season positively influences only smallholders' efficiency while the proportion that used improved seeds and extension services positively affect efficiency of only large-holders.

These results also indicate that the relationship between area and productivity, implied by estimates of area and area-squared, observed for smallholders is distinct from that for large-holders. Accordingly, input- and output-oriented technical efficiency of large-holders increase linearly and quadratically, respectively, and ISE increases until 7.8 hectares before declining. Consequently, the RTFP of large-holders increases linearly in all teff areas. In contrast, all efficiency indices of smallholders, except OSE, first decline and then increase with area while the reverse is true for OSE. Accordingly, the RTFP of smallholders declines until 0.32 hectares and increases thereafter.

5. Key findings and Policy Implications

Data envelopment analysis (DEA) is employed on input-output data of teff producing households in Ethiopia. The dataset was collected in the baseline survey of the Agricultural Growth Program (AGP) of Ethiopia and pertains to the 2010/11 main agricultural season. Results of the DEA indicate that current relative total factor productivity (RTFP) could nearly triple if inefficiencies are removed. Performance in output oriented technical efficiency was also found to be low. Despite differences in magnitudes, the performance measures imply a significant potential for increases in output produced on current acreage, if inefficiencies were removed. Moreover, analyses conducted reveal that considerable gains in teff yields and output could be made by partially or fully specializing in teff production.

Analyses conducted to indicate factors influencing relative productivity indicate that performance improves with education, and with access to credit, production information, and extension services. Productivity improves with level of specialization in crop production while off-farm income generation activities that help reduce income variability adversely affect productivity. The results also indicate that productivity improves with teff area cultivated. The latter, unlike the inverse farm size-productivity hypotheses, implies that large-holders are more productive than smallholder teff farmers. The results also show that large-holders' productivity increases linearly with cultivated area while smallholders' productivity first declines with increase in area and then increases.

A number of factors that influence productivity are amenable to policy interventions. This includes improving access of farmers to formal education, possibly through training programs delivered during off-seasons. Improving farmers' access to information on production methods and extension services would also improve productivity. The decision on the type and number of crops households cultivate, and consequently the tendency to specialise depends, among others, on their subsistence requirements, profitability of the crops, risks associated with cultivating few crop types, and the size of their total land holdings. Further research is required on the factors that determine the level of specialization and the scale of operation in order to make formal recommendations. However, the results in this study indicate that productivity improves with both scale of operation and level of specialization. Furthermore, well established findings in international trade and development economics, imply that access to and participation in markets, along with low risks of crop failure, help farmers to specialise in their crop production.

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Appendices

Appendix 1. Linear programming problems that solve output and input distance functions

To specify the linear programming problems that obtain the output and input distance functions defined by equations (1) and (2) in the text let us first redefine the respective equations as:

(1') $\quad (1/\mathrm{D}_{\mathrm{O}}^{\mathrm{j}}(\mathrm{X_j}, \mathrm{Y_j})) = \max_{\lambda}\{\lambda\colon\ (X_j, \lambda Y_j) \in T$ } such that $0 < \mathrm{D}_{\mathrm{O}}^{\mathrm{j}}(\mathrm{X_j}, \mathrm{Y_j}) \leq 1\}$

(2') $\quad (1/\mathrm{D}_{\mathrm{I}}^{\mathrm{j}}(\mathrm{X_j}, \mathrm{Y_j})) = \min_{\mu}\{\mu\colon\ \mu X_j \in L(y_j)\ \ and\ Y_j \in \Re_{+}^{M}\}$ such that $\mathrm{D}_{\mathrm{I}}^{\mathrm{j}}(\mathrm{X_j}, \mathrm{Y_j}) \geq 1$

In applied works output and input distance functions are computed using a dual linear programming (LP) problem. Accordingly, output distance functions are obtained by solving:

(A.1) $\quad A^{*} = \max_{\lambda, A} \lambda \quad$ subject to

$\lambda y_{j,m} - \sum_{j'=1}^{J} A_{j'} y_{j'} \leq 0 \quad$ for $j \in (1, \ldots, J)$ and $m = [1, \ldots, M]$

$x_{j,n} - \sum_{j'=1}^{J} A_{j'} x_{j'} \geq 0 \quad$ for $j \in (1, \ldots, J)$ and $n = [1, \ldots, N]$

$\lambda, A_{j'} \geq 0 \quad j \in (1, \ldots, J)$

Problem (A.1) seeks a scalar λ that transforms household j's output to the maximum possible in the production possibility frontier that can be produced using a given input vector.

The dual LP problem that obtains the input distance function is given as:

(A.2) $\quad B^{*} = \min_{\mu, B} \mu$

Such that $\quad \mu x_{j,n} - \sum_{j'=1}^{J} B_{j'} x_{j'} \geq 0 \quad$ for $j \in (1, \ldots, J)$ and $n = [1, \ldots, N]$

$y_{j,m} - \sum_{j'=1}^{J} B_{j'} y_{j'} \leq 0 \quad$ for $j \in (1, \ldots, J)$ and $m = [1, \ldots, M]$

$\mu, B_{j'} \geq 0 \quad j \in (1, \ldots, J)$

Problem (A.2) seeks a value of μ that minimizes the vector of inputs used by household j to a level that can feasibly produce a given output vector.

Appendix 2. Factors explaining relative TFP and efficiency of small and medium/large-holders.

	Smallholders (51.5% observations with area ≤0.38 ha)					Large-holders (48.5% observations with area >0.38 ha)				
	Dependent variable:					Dependent variable:				
		Output oriented		Input oriented			Output oriented		Input oriented	
Variables	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency
Household characteristics										
Gender of household head	-1.24	-3.40*	1.37	-1.95*	-0.92	1.28	1.29	0.15	0.42	2.68
Age of household head	0.003	0.02	-0.05*	0.03	-0.001	0.003	0.01	0.01	-0.01	0.02
Head education	2.88**	5.04***	-0.98	1.48	3.37**	-0.35	0.02	-0.65	-1.00	1.21
Household size	0.39	0.33	0.03	-0.22	0.66*	-0.04	-0.07	0.12	-0.10	-0.19
Land management and risk										
Crop area	-191.7***	-318.8***	90.1***	-197.7***	-127.0***	16.0***	16.3***	-2.00	1.15	21.2***
Crop area squared	298.6***	511.5***	-136.3***	265.2***	225.1***	-0.17	0.03	0.72	1.70**	-1.36*
Proportion of land owned	-1.24	-2.08	2.30**	-1.85	-1.27	0.63	0.004	0.14	-0.37	1.89
Percent of crop damaged	-15.4***	-13.9***	-4.68**	-2.34	-20.5***	-9.27***	-9.24***	-1.19	2.52	-18.2***
Partially specialised	6.07***	7.06***	-0.48	4.26***	5.12***	4.13**	1.83	3.46***	1.01	5.17**
Fully specialised	6.50	8.89*	0.15	5.91*	5.54	7.22**	7.00**	2.42	3.32	7.95**
Household member works off-farm	-1.02*	-0.89	-1.10***	0.42	-1.45**	-0.27	0.18	-0.33	0.28	-0.58
Tropical livestock units	0.05	-0.06	0.30*	-0.10	-0.02	0.02	-0.03	0.12	-0.18	0.24
Access to information and services										
Production information	1.08	1.24	-0.08	0.77	1.00	4.32***	4.59***	-0.20	1.78*	4.95***
Fertilizer users in zone (lagged)	0.11**	0.14***	-0.01	0.08**	0.15***	-0.03	-0.05	-0.04	-0.05	0.06
Improved seed users in zone (lagged)	-0.01	0.37*	-0.38***	0.37***	-0.14	0.70***	0.68***	0.11	0.37***	0.75***
Extension users in zone (lagged)	0.04	-0.16**	0.24***	-0.22***	0.10*	0.09	0.03	0.10***	0.11**	0.01
DA centre available in FA	4.83**	5.94**	-0.46	4.42***	2.95	5.14**	3.14	2.67**	0.51	7.19***
PAs available in FA	0.38	0.15	1.12	-0.68	0.02	-5.23***	-5.06***	0.19	-2.22**	-5.71***
Creditor institutions available FA	1.30	3.07*	-1.94*	1.38	2.09	2.86**	2.84**	1.05	2.74***	3.41**
Travel time to closest market (Hrs)	0.73	2.06*	-1.21*	0.99	0.44	-1.74*	-2.85***	0.77	-2.64***	0.61
Constant	44.5***	82.1***	57.1***	113.2***	41.8***	10.0*	24.4***	76.9***	81.1***	7.80
Log-Likelihood	-6,806	-6,649	-5,893	-5,683	-6,870	-6,272	-6,302	-5,137	-5,553	-6,356

Source: Authors' analyses using the AGP Baseline Survey data (2011), NASA(2014), and CSA(2010c).
Coefficients with ***, **, and * are significant at 1, 5, and 10 percent level of significance, respectively
Notes: a) Equations estimated including region and agroecologic zone dummies specified in equation (13).