ETHIOPIA
Strategy Support Program

ETHIOPIAN DEVELOPMENT RESEARCH INSTITUTE
EDRI

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI
A member of the CGIAR Consortium

WORKING PAPER 75

Cereal productivity and its drivers: The case of Ethiopia

Fantu Nisrane Bachewe, Bethelhem Koru, and Alemayehu Seyoum Taffesse

May 2015

TABLE OF CONTENTS

Abstract 2

1. Introduction 2

2. Theoretical Models 3
   - 2.1. Stochastic Frontier Analysis 4
   - 2.2. Data Envelopment Analysis 4

3. Empirical Models and Data 6
   - 3.1. Empirical models 6
   - 3.2. Data 8

4. Results 9
   - 4.1. Estimates of the Stochastic Production Frontier 9
   - 4.2. Patterns of Efficiency and Productivity in Cereals Production 11
   - 4.3. Factors Affecting Efficiency and Productivity of Cereals Production 12
   - 4.4. Sensitivity Analyses: Patterns in Productivity and Scale of Production 16

5. Key Findings and Policy Implications 17

LIST OF TABLES

Table 3.1—Definition of variables used in production frontier analysis 7

Table 3.2—Definition of variables used in inefficiency/efficiency and TFP equations 8

Table 3.3—Summary of crop level variables used in analyses 9

Table 4.1—Maximum likelihood estimates of stochastic cereals production frontiers 10

Table 4.2—Estimates of technical efficiency, scale efficiency, and relative total factor productivity 11

Table 4.3—Factors explaining cereals production technical efficiency, scale efficiency, and relative total factor productivity 12

Table 4.4—Crop area at which efficiency and productivity indices of small- and large-holders change in sign, ... 17

LIST OF FIGURES

Figure 2.1—Output-oriented measures of efficiency 5

Figure 4.1—Relationship between crop area, technical efficiency, and relative total factor productivity 15

Figure 4.2—Relationship between area and technical efficiency, obtained using only area and area squared in the inefficiency equation of the stochastic frontier analysis (SFA) 16

LIST OF APPENDIX TABLES

Appendix Table A.1—Mean value of household and farmers' associations level variables 22

Appendix Table A.2—Estimates of stochastic cereals production frontier coefficients (aggregate sample - variables in levels) 23

Appendix Table A.3—Factors affecting technical efficiency of cereals production (aggregate sample - variables in levels) 24

Appendix Table A.4—Factors affecting technical inefficiency of crop specific SPFs [in Table 4.3 of text] 25

Appendix Table A.5—Estimates of stochastic cereals production frontiers for smallholders and large holders, respectively 26

Appendix Table A.6—Factors affecting efficiency and relative total factor productivity (TFP) of smallholder and large-holder cereal producers, respectively 27

ABSTRACT

Cereal production has exhibited unprecedented growth in Ethiopia, leading to important welfare improvements in the country. However, it is not well understood what the drivers have been of this growth and how it can be sustained. In particular, there is a lack of evidence on the contribution of improvements in productivity to growth in yields. Moreover, doubts exist on whether it is possible to sustain such growth on declining landholdings.

We study cereal production using a unique large-scale survey of households and analyze productivity issues using stochastic frontier and data envelopment analyses, two conceptually dissimilar methods. Production frontier estimates indicate that modern inputs contribute significantly to improvements in yields. The two analytical methods used indicate that an average cereal producing household is less than half as efficient as optimally producing households, and, consequently, there is considerable opportunity for additional growth in cereal production in Ethiopia.

Factors explaining efficiency differences are robust across analytical methods. Households with sufficient land adopt efficiency-increasing modern inputs, yet adoption of these inputs is low. Productivity also is shown to improve with exposure to information on modern production practices and with local availability of extension services. The productivity of households that specialize in fewer crops and rent-in land is higher. In general, productivity and efficiency improve with the area a household sows to cereals. These findings have important implications for policy.

I. INTRODUCTION

Smallholder agriculture is a source of livelihood for a large proportion of the population and of the poor in sub-Saharan Africa (Henderson 2013, Diao et al. 2010). Development economists in the past have broadly agreed that public sector support to smallholder agriculture is much needed, owing largely to the effectiveness of smallholder agriculture growth in poverty reduction and evidence of its contribution to broader economic growth in a number of Asian countries during the Green Revolution (Diao et al. 2010, Hazell et al. 2010). Smallholder agriculture is a favored target for development investments among those governments and agencies that give priority to poverty reduction and food security (FAO 2010, Gates Foundation 2011, Pandya-Lorch et al. 2005).

However, this focus on smallholders has increasingly been challenged in Africa (e.g. Collier and Dercon 2014). While there is a perceived inverse relationship between farm size and productivity (e.g. Barrett et al. 2010), a number of researchers have shown that medium and large scale farmers perform better in productivity relative to smallholders (Rios and Shively 2005, Padilla-Fernandez and Nuthall 2012, Helfand and Levine 2004) and that the poor might derive greater benefit from improved labor markets generated by more efficient farms than by farming their own smallholdings (Maertens and Swinnen 2009). Even those policy analysts that promote smallholder focused policies as important for economic growth and poverty reduction underline the need for tailoring such policies to specific conditions (Birner and Resnick 2010, Fan et al 2013, Hazell 2013).

In this study, we look at agricultural productivity in the case of Ethiopia. With average annual GDP and GDP-per capita growth rates of 11 percent and 8 percent, respectively, Ethiopia's economic performance has been remarkable over the period 2004 to 2013 (WDI 2014). Agricultural and cereal growth has been substantial over this period, contributing to important improvements in general welfare (Hill and Tsehaye 2014). However, there is still an important debate on what the drivers of this agricultural growth, and, in particular, cereal growth, have been, and, in consequence, what policies should be pursued to sustain this growth in the future (Dercon and Hill 2009).

In particular, doubts exist on whether it is possible to generate continued agricultural growth that is sufficient to contribute to sustained overall economic growth and poverty reduction on landholdings that are declining

in size (Diao 2010, Headey and Jayne 2014). This is an important issue as over 85 percent of the Ethiopian population and 90 percent of Ethiopia's poor lived in rural areas and derived their livelihood from agriculture in 2010 (Diao 2010). Moreover, it is predicted that over 70 percent will continue to reside in rural areas in 2040, when there will be 40 percent more rural residents (UN 2014), placing more and more pressure on the limited cultivable land. Moreover, illustrating the tension between the focus on small and large-scale farms, although government policies have traditionally focused on smallholder farmers, there is now an increasing policy emphasis in Ethiopia on commercial farming as a driver of agricultural growth (e.g. Baumgartner et al. 2013). Despite the importance of the link between farm size and agricultural productivity, there is surprisingly little empirical evidence on that relationship in Ethiopia.

The contribution of our research to the international literature is three-fold. First, we use a unique recent large-scale farm household dataset from Ethiopia that includes information collected from almost 7,000 households producing five important cereals in high-potential areas of the country. Second, we contrast the findings of two methods used to analyze the drivers of cereal productivity, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA), each of which uniquely integrates scale of operation, specialization, and risk mitigation variables. Third, we evaluate measures of total factor productivity and efficiency of cereals by farm size.

Our SFA results indicate that modern inputs contribute significantly to cereal yields and output, although adoption of modern inputs remains low. Moreover, SFA results support the inverse farm-size-productivity hypothesis only partly, whereby technical efficiency declines with area up to medium-size landholdings and then increases with larger farm size. However, our DEA results show the clear superiority of larger farms where relative total factor productivity (TFP) increases across all farm-sizes. In particular, our investigation of medium and large farms, with half a hectare or larger, reveals that productivity and efficiency increase significantly with area.

Both SFA and DEA indicate that an average cereal producer is about 40 percent as efficient as optimal cereal producers operating at the production frontier. Efficiency and TFP improve with education, access to credit, and information on modern production methods. Productivity of households in areas where extension services are provided and producers' associations are active is relatively high, while those that specialize in cereal production partially or fully perform better relative to those that do not specialize. Households endowed with more land, diversify their risk by adopting efficiency-increasing, if more risky, modern inputs only after using less-risky inputs. Off-farm income generation activities that help reduce household income variability, affect scale efficiency adversely and technical efficiency positively.

These findings have important policy implications. First, rural land markets in Ethiopia function under severe constraints (Deininger et al. 2003). Our findings suggest that more flexible land markets would contribute to higher agricultural output by enabling the reallocation of land to more efficient farmers. Second, there is still significant potential for growth in agricultural and cereal productivity in Ethiopia. Realizing this potential could be achieved by stimulating and improving the way that agricultural input markets and advisory services operate and by encouraging diversification and specialization.

The remainder of this paper is organized as follows. In Section 2, we describe the theoretical SFA and DEA models used in the analyses. In Section 3, we provide the empirical specifications and describe the data. The results are presented and discussed in Section 4, with key findings and their policy implications summarized in the last section.

2. THEORETICAL MODELS

Let the optimal output vector, $Y^* \in \Re_+^M$, corresponding to each input vector, $X \in \Re_+^N$, be given by the maximum level of output produced by one or more households using X. Suppose Y^* and X have the following functional relationship:

$$Y^* = F(X, \beta) \quad (1)$$

where $Y^* = [y_1^*, y_2^*, \dots, y_M^*] \in \Re_+^M$ is a 1 x M output vector, $X = [x_1, x_2, \dots, x_N] \in \Re_+^N$ is a 1 x N input vector, and β is an N x 1 vector of production function parameters. The actual output of an arbitrary household j, Y_j, using X may differ from Y^*; where $j \in [1,2, \dots, J]$ indexes farm households. Suppose the input-output relationship of household j is represented by:

$$Y_j = F(X, \beta) \text{ for all } j \in [1,2, \dots, J] \quad (2)$$

The two analytical methods described below differ in how they explain or to what they attribute the deviation of Y_j from Y^*.

2.1. Stochastic Frontier Analysis

The underlying assumption of stochastic frontier analysis (SFA) is that differences in output produced using a given bundle of inputs, result either from efficiency differences or from random shocks. A stochastic production frontier (SPF) is often specified as:

$$Y_j = F(X, \beta) = f(X, \beta) \cdot \exp(V_j - U_j) \text{ for all } j \in [1,2, \dots, J] \quad (3)$$

In equation (3), the term $exp(V_j - U_j)$, often called the *composed error term,* captures the underlying assumption of SFA. The $\exp(V_j)$ part represents producer-specific random shocks. The $exp(-U_j)$ part accounts for deviations in Y_j from Y^* due to differences in efficiency. Hence $U_j = 0$ for technically efficient producers and increases with declines in efficiency. The *deterministic component* of the SPF, $f(X, \beta)$, is uniform across j. Under certain assumptions on V_j and U_j, parameters of equation (3) can be estimated using maximum likelihood methods (Kumbhakar and Lovell. 2000).[1]

Let us define the technical efficiency of agricultural household j, relative to an optimal household operating at the frontier and indexed by k, as a ratio of their output levels as:

$$TE_j = \frac{Y_j}{Y_k} = \frac{f(X,\beta) \cdot \exp(V_j - U_j)}{f(X,\beta) \cdot \exp(V_k - U_k)} \text{ for all } j \in [1,2, \dots, J] \quad (4)$$

Equation (4) can be expressed as:

$$TE_j = \exp(-U_j) \text{ for all } j \in [1,2, \dots, J] \quad (5)$$

$TE_j \leq 1$ and declines with increase in U_j. U_j is assumed to be distributed as: $U_j \sim N(Z_j\delta, \sigma_U^2)$, where Z_j is a 1 x m vector of household and location specific variables that affect technical efficiency, while δ is an m x 1 vector of unknown parameters.

The *inefficiency* equation associated with the SPF given in (3) is then specified as:

$$U_j = Z_j\delta + W_j \quad (6)$$

where W_j is assumed to be distributed as: $W_j \sim N(0, \sigma_W^2)$.

2.2. Data Envelopment Analysis

We use DEA to study the relative total factor productivity (TFP) and efficiency of farm households. DEA employs linear programming (LP) to construct non-parametric piece-wise linear production frontiers. In DEA deviations in output from optimal levels are assumed to result entirely from efficiency differences. As a result, productivity of farmers located away from the frontier is gauged relative to those operating at the frontier using input and output

[1] We assume: i) V_j are identically and independently normally distributed with zero mean and standard deviation of σ_V^2, $V_j \sim N(0, \sigma_V^2)$; ii) U_j is a non-negative truncation of a normally and independently distributed random variable; and iii) V_j and U_j are distributed independently of each other and X_j.

distance functions. Specifically, we use the Fare-Primont index. According to this index, the TFP of household j, $j \in [1, \dots, J]$, is defined as a ratio of aggregate output to aggregate input (O'Donnell 2011c) as:

$$TFP_j = \frac{Q_j}{I_j} \tag{7}$$

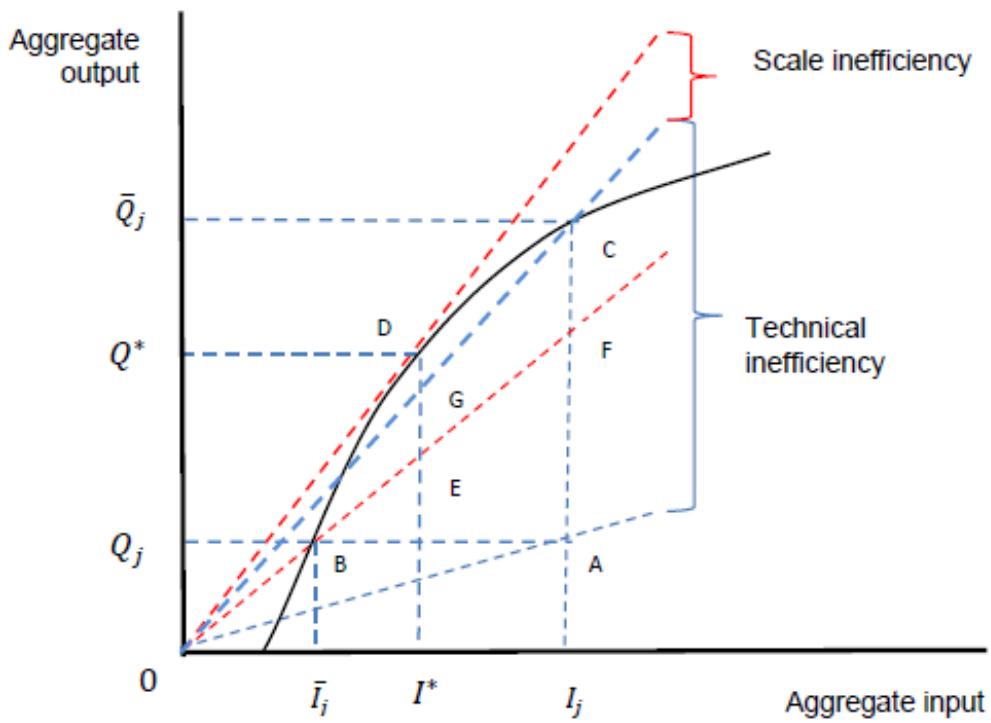
where $Q_j = Q(y_{m,j})$ is the aggregate output of j that produces $y_{m,j}$ of each crop type m, where $y_{m,j} \in Y_j = [y_{1,j}\ y_{2,j} \dots\ y_{M,j}]$. Similarly, $I_j = I(x_{n,j})$ is an aggregate input index of j that uses $x_{n,j}$ of input type n, where $x_{n,j} \in X_j = [x_{1,j}\ x_{2,j}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

Then, the TFP of household j, TFP_j, relative to the TFP of an optimally producing household, TFP^*, is given as:

$$RTFP_{k,j} = \frac{TFP_j}{TFP^*} = \frac{y_j/I_j}{y_k^*/I_k^*} \tag{8}$$

where in equation (8), *k* represents an optimal household and $RTFP_{k,j}$ denotes the TFP of *j* relative to *k*. The index at (8) is *multiplicatively complete*, so can be decomposed into technical and scale efficiency indices that obtain $RTFP_{k,j}$ multiplicatively (O'Donnell 2009 and 2011c).

Figure 2.1—Output-oriented measures of efficiency



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

We use Figure 2.1 to illustrate the technical and scale efficiency components of relative TFP. Suppose household j operates at point A where it produces output Q_j using inputs I_j. The household's production performance is inferior relative to C, which produces $\bar{Q}_j \geq Q_j$ using I_j, where $\bar{Q}_j$ is the maximum output that is a scalar multiple of Q_j possible to produce using I_j. The output-oriented technically efficiency (OTE) of the household at A is given by:

$$OTE_j = \frac{Q_j/I_j}{\bar{Q}_j/I_j} = \frac{TFP_j}{TFP_C} = \frac{Q_j}{\bar{Q}_j} = D_O^j(X_j, Y_j) \leq 1 \tag{9}$$

where $D_O^j(X_j, Y_j)$ is the output distance function of j, which under some regularity and disposability conditions, is defined as: [2]

$$D_O^j(X_j, Y_j) = \inf_{\theta}\{\theta:\ (X_j, Y_j\ /\theta) \in T\} \text{ where } T = \{(X, Y): X\ can\ produce\ Y\} \tag{10}$$

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

$$ITE_j = \frac{Q_j/I_j}{Q_j/\bar{I}_j} = \frac{TFP_j}{TFP_B} = \frac{\bar{I}_j}{I_j} = D_I^j(X_j, Y_j)^{-1} \leq 1 \tag{11}$$

where $D_I^j(X_j, Y_j)$ stands for the input distance function of j.

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^*. D is superior to C in output oriented scale efficiency (OSE) and to B in input oriented scale efficiency (ISE).[3]

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

$$OSE_j = \frac{\bar{Q}_j/I_j}{Q^*/I^*} = \frac{TFP_C}{TFP^*} \leq 1 \text{ and } ISE_j = \frac{Q_j/\bar{I}_j}{Q^*/I^*} = \frac{TFP_B}{TFP^*} \leq 1 \tag{12}$$

3. EMPIRICAL MODELS AND DATA

In the first subsection here we provide empirical versions of the stochastic production frontier equation (3), inefficiency equation (6), and output distance function (10). We then describe the Agricultural Growth Program (AGP) baseline survey dataset used in this study.

3.1. Empirical models

Stochastic Frontier Analysis

We use a Cobb-Douglas production function as a deterministic component of (3) and define the empirical SPF as:

$$\begin{aligned} ln\, y_{m,j} = {} & \beta_0 + \textstyle\sum_{i=1}^{4} \beta_i\, ln\, x_{i,m,j} + \sum_{l=5}^{9} \beta_l D_{l,m,j} + \beta_{10}\, Land\ quality\ index_{m,j} + \ \beta_{11}\, ln\, RF_j + \beta_{12}\, ln\, RF_j^2 + \\ & \beta_{13}\, Coef\ var\ RF_j\ + \beta_{14}\, GDD_j + \beta_{15} GDD_j^2 + \textstyle\sum_{r=A,O,S} \beta_r\ Region\ dummy_{rj} + \beta_{19}\, AGP_j + \\ & \textstyle\sum_{m=BT,B,W,M,S} \beta_m Crop_{m,j} + \ V_{mj} + U_{m,j} \end{aligned} \tag{13}$$

where y_{mj} stands for household *j*'s yield of crop m, with m∈(white teff, black teff, barley, wheat, maize, sorghum) and $j \in [1, \ldots, 6575]$. $x_{i,m,j}$ in the first summation, stands for input type *i* household *j* used in the production of *m*, where *i* ∈ [labor/hectare, oxen/hectare, fertilizer/hectare, improved seeds/hectare] (See Table 3.1 for the definition of variables).[4] D_{mjl} stands for 5 dummy variable type inputs indexed by *l*: pesticides, irrigation, tractors, harvester, and thresher. $Region\ dummy_{rj}$ is a region dummy where r∈[Amhara (A), Oromiya (O), and Southern Nations, Nationalities, and Peoples (SNNP) region (S)]. Similarly, AGP_j takes a value of 1 if the household resided in woredas selected to benefit from the AGP. $Crop_{mj}$ is a dummy for crop m, where *BT*, *B*, *W*, *M*, and *S* stand for

[2] See Fare and Primont (1995) on disposability and regularity conditions.

[3] In this work the relative TFP of households is defined by comparing their performance with technically and scale efficient household/s, operating on the production frontier constructed from the dataset. The comparisons can also be made relative to households operating on the *mix-unrestricted* production frontier lying above the frontier, constructed from the current data (see, for instance, O'Donnell 2008 and 2011c). The objective of comparing households within the frontier constructed from the data, justifies our approach.

[4] Given log of zero is undefined, we use ln(max($x_{i,m,j}$, 0.0001)) for oxen, fertilizer, and improved seeds.

black teff, barley, wheat, maize, and sorghum, respectively, and white teff is omitted. V_{mj} and U_{mj} stand for stochastic and inefficiency components of the composed error term.

The empirical inefficiency equation is specified as:

$$U_{mj} = \delta_0 + \sum_{i=1}^{4} \delta_i \, HH\ demography_{ij} + \delta_5\, TLU_j + \delta_6\, Used\ credit_j + \delta_7\, Area_{mj} + \delta_8\, Area_{mj}^2 + \delta_9\, Land\ owned\ by\ HH_{mj} + \delta_{10}\, Off\text{-}farm\ work_j + \delta_{11}\, Partially\ Spec_j + \delta_{12}\, Fully\ Spec_j + \delta_{13}\, Crop\ seed\ and\ fert\ type_j + \delta_{14}\, HH\ participation_j + \delta_{15}\, Production\ \text{info}_j + \delta_{16}\, Distance\ to\ mkt_j + \delta_{17}\, DA\ center\ in\ FA_j + \delta_{18}\, PAs\ in\ FA_j + \sum_{m=BT,B,W,M,S} \delta_m Crop_{mj} + \sum_{r=A,O,S} \beta_r\ Region\ dummy_{rj} + \delta_{27}\, AGP_j + \sum_{z=WD,D} \delta_z AEZ_{zj} + W_{mj} \quad (14)$$

Technical *inefficiency*, U_{mj} is a function of crop, household, and administrative and agroecologic zone specific factors. This includes four demographic variables: *age, gender,* and *education level* of the household head and *household size*, indexed 1 through 4 in the first summation. We use agroecologic zone (AEZ) dummies, given in the last summation, to account for AEZ effects. The households surveyed lived in AEZs locally known as *Kolla*, which is the omitted category, *Woina dega* (*WD*), and *Dega* (*D*).[5] W_{mj} is the error term, which is assumed to be distributed as: $W_{cj} \sim N(0, \sigma_W^2)$.

The remaining variables are defined in Tables 3.1 and 3.2. We estimate equations (13) and (14) simultaneously aggregating the five crops, as well as for each crop separately.

Table 3.1—Definition of variables used in production frontier analysis

Variables	Definition	Aggregation
y	Yields=output per area cultivated to crop (kilograms/hectare)	Crop
X_1	Labor =sum of family and hired labor days per hectare	Crop
X_2	Oxen =number used to plow land per hectare	Household
X_3	Fertilizer =sum of DAP and Urea fertilizers in kilograms per hectare	Crop
X_4	Improved seeds =fresh bought improved seeds in kilograms per hectare	Crop
D_5	Pesticides dummy=1 if pesticides, herbicides, and/or fungicides used	Crop
D_6	Irrigation dummy=1 if cropland irrigated	Crop
D_7, D_8, and D_9	Tractor, harvester, thresher dummy =1 if respective machinery used	Crop
Land quality index	Land quality index=land fertility index × slope of land; where land fertility index ∈ [1=infertile, 2=semi-fertile, 3=fertile] and slope of land ∈ [1= steep, 2=gentle, 3= flat].	Crop
RF	Total cropping season rainfall=sum of daily rainfall (millimeters) during 1 May-31 October 2010	District
Coef var RF	Variation of rainfall= coefficient of variation of weekly total rainfall during 1 May-31 October 2010	District
GDD	Growing degree days=sum of daily beneficial heat (*see table note*) during 1 May-31 October 2010	District

Source: Authors.

Note: *Daily beneficial heat* is the contribution to yields of any given day's average temperature in excess of the lower bound of a given temperature range, generally 8^0C -32^0C. Growing degree days is the sum over days in the cropping season of daily beneficial heat times the probability of the average temperature to occur on that day in that area (see Roberts, Schlenker, and Eyer 2013).

[5] This classification divides Ethiopia into five altitude, temperature, and rainfall based agroecologic zones (AEZs). In general, the *Wurch* AEZ has the highest altitude and precipitation, followed respectively by *Dega*, *Woina Dega*, *Kolla,* and *Berha* (Ministry of Agriculture 2000). Out of the 6,575 households in this data set, 1.1 percent resided in *Wurch*, as a result we ignore its dummy variable. Out of the remaining households, 59 percent resided in *Woina dega*, 25 percent in *Dega*, and 15 percent in *Kolla* AEZs.

Table 3.2—Definition of variables used in inefficiency/efficiency and TFP equations

Variables	Definition	Aggregation
HH demography$_1$	Head gender; dummy=1 if male	Household
HH demography$_2$	Head age in years	Household
HH demography$_3$	Head education; dummy=1 if educated in grades 4 or higher	Household
HH demography$_4$	Household size; number of members in household	Household
Land owned by HH	Ownership of land cultivated to crop; dummy=1 if allocated to household by authorities, purchased, or inherited; and =0 if rented or sharecropped	Crop
Area	Land area used in the production of the crop	Crop
Partially spec	HH partially specializing=1 if household cultivates two crops	Household
Fully spec	HH specializes=1 if household cultivates only one crop	Household
Crop seed and fert type	Number of crops cultivated×(seed variety per crop × fertilizer type per crop)×number of plots used to grow each crop	Household
Off-farm work	=1 if at least one household member earns income from off-farm/non-farm employment	Household
Used credit	=1 if household used credit to purchase inputs	Household
TLU	Tropical livestock units=number of livestock normalized to cattle units	Household
DA center in FA	Center where development agents (DAs) provide services available in farmers' association (FA); dummy=1 if yes.	FA
HH participation	Household participation; dummy=1 if household members visited DA centers, FTCs, or attended community meetings	Household
Production info	Production information; dummy=1 if household head obtained production information from radio, newspaper, or information board	Household
PAs in FA	One or more producers' association (PA) active in FA; dummy=1 if yes.	FA
Distance to market	Distance in kilometers to closest market out of FA	FA

Source: Authors.

Note: DA, FA, and PAs stand respectively for *development agents, farmers' association,* and *producers' associations.*

Output distance function

Next we define the output distance function of household *j* whose production level of crop *m* is given by $y_{m,j}$. Let also the amount of type *n* input used in the production of $y_{m,j}$ be $x_{n,m,j}$, such that $x_{n,m,j} \in X_{m,j} = [x_{1,m,j}\ x_{2,m,j} \dots\ x_{n,m,j}]$, where *n* ∈ [cultivated area, labor, oxen, fertilizer, improved seeds, pesticides, irrigation, land quality index, rainfall, growing degree days]. In applied DEA studies, often translog input and output distance functions are used, which we will adopt also in this study. Then, the output distance function is given as:

$$D_O^{m,j}(X_{m,j}, y_{m,j}) = \alpha_0 + \alpha_m ln\, y_{m,j} + \frac{1}{2}\alpha_{m,m} ln y_{m,j}^2 + \sum_{n=1}^{10} \beta_{n,n} ln\, x_{n,m,j}\ ln\, x_{n,m,j} + \frac{1}{2}\sum_{n'=1}^{10}\sum_{n=1}^{10} \beta_{n',n} ln\, x_{n',m,j}\ ln\, x_{n,m,j} + \sum_{n=1}^{10} \delta_{n,m} ln\, x_{n,m,j}\ ln\, y_{m,j} \quad (15)$$

Linear programming problems that seek output and input distance functions, compute the latter for all households simultaneously, and thus involve large matrices (see Fare and Primont 1995 and O'Donnell 2010a and 2010b). To reduce the computational burden, we limit our analyses to the 10 factors listed above.

3.2. Data

The data from the Agricultural Growth Program survey on agricultural inputs are summarized in Table 3.3, while the data on households and farmers' associations included in the analyses is summarized in Appendix Table A.1.[6] The AGP dataset includes 12,770 crop level observations from 6,575 households, representing 7.97 million households in the woredas surveyed (Table 3.3). The AGP baseline survey covered 93 moisture reliable districts, out of which 61 were designated to benefit from the program (treated group) and 32 in the control group. The dataset pertains to the 2010/11 main agricultural season.

[6] Farmers' associations are the smallest administrative units in rural Ethiopia. The AGP baseline sample included 304 farmers' associations.

We focus on households producing the five cereals due to the importance of the crops in the country's agriculture. Teff, barley, wheat, maize, and sorghum together accounted for an average of 70 percent of the nationwide cultivated area and output during the decade ending in 2013 (CSA Vol. I 2004-2013). Moreover, in 2010 the crops accounted for 62 percent of average Ethiopians' daily calorie intake and for 45 percent of food expenditure of an average household (Diao 2010).

Table 3.3—Summary of crop level variables used in analyses

Variable	Average by household	Average by crop	White teff	Black teff	Barley	Wheat	Maize	Sorghum
Area (hectare)	0.85	0.44	0.49	0.45	0.34	0.41	0.33	0.73
Labor (working days)	88.6	45.6	54.2	50.4	36.1	42.3	40.6	58.1
Oxen (number)	1.1	1.3	1.4	1.3	1.2	1.3	1.2	1.3
Fertilizer (kilograms)	45.5	23.4	36	22.4	19.2	40.9	20.5	4.2
Improved seeds (kilograms)	2.5	1.3	0.7	0.1	0.4	3.0	2.1	0.1
Pesticides (% applying)	23.4	24.2	33.9	33.5	24.2	45.2	4.1	20.9
Irrigation (% irrigating)	1.6	1.5	2.5	1.4	0.7	1.2	1.8	1.7
Tractors (% irrigating)	2.2	1.9	2.7	1.5	2.2	2.3	1.3	2.1
Harvesters (% irrigating)	5.0	3.3	3.0	2.7	2.1	9.5	1.4	1.7
Threshers (% irrigating)	8.5	5.2	2.7	2.4	2.0	9.5	7.8	3.5
Land quality index	6.7	6.6	6.6	6.4	6.3	6.5	7.2	6.4
Number of observations	*6,575*	*12,770*	*1,417*	*1,804*	*2,006*	*2,177*	*3,518*	*1,848*

Source: Authors' calculations using data from the AGP Baseline Survey (2011).

About 72 percent of the households had male heads and about 41 percent of all heads were literate (Appendix Table A.1). In the econometric analyses, heads with an education level of Grade 4 or higher are assigned a value of 1. This follows Wier's (1999) discovery that 4 years of schooling is the minimum threshold for education to have a meaningful effect on productivity.

4. RESULTS

In the first part of this section we discuss estimated coefficients of the stochastic production frontiers (SPF). This is followed by a brief discussion of relative efficiency and the TFP estimated. Finally, we discuss results of the analyses we conducted to explain efficiency and productivity.

4.1. Estimates of the Stochastic Production Frontier

Estimates of the SPFs obtained using the aggregate sample and the data on the five cereals are provided in Table 4.1. All estimated coefficients have the expected sign and are significant, with the exceptions of the growing degree days, which has the wrong sign, and the tractor and thresher dummies, which are insignificant. Our discussion focuses on estimates of the aggregate data, because crop specific estimates, where significant, have qualitatively similar implication to those of the aggregate data. The two exceptions are the thresher dummy in maize and growing degree days in barley.

Elasticity of yield with respect to labor is 21 percent, and it is 2 percent with respect to oxen. These are similar to the elasticities Bachewe (2012) and Nisrane et al. (2011) find, respectively. Yields increase with quality of cultivated land and rainfall, while excessive and erratic rainfall affect yields adversely. The coefficient of rainfall in this study is higher relative to those in other studies. This could be because households included in this survey reside in the moisture or rainfall reliable districts of the country where the AGP operates (Berhane et al. 2013). The temperature variable, growing degree days (GDD), which accounts for the contribution of beneficial heat, was expected to affect yields positively (see Roberts, Schlenker, and Eyer 2013). The results in Table 4.1 indicate that yields decline quadratically with temperature.

Table 4.1—Maximum likelihood estimates of stochastic cereals production frontiers

	All crops[a]						
Variables	Estimates	Elasticity	Teff[a]	Barley	Wheat	Maize	Sorghum
Constant	-5.30***		-12.5***	-0.58***	-9.71***	-9.42**	-0.79
	(1.64)		(3.66)	(0.04)	(3.28)	(4.11)	(5.28)
Log labor/hectare	0.21***	0.21	0.18***	0.14***	0.21***	0.25***	0.16***
	(0.01)		(0.01)	(0.02)	(0.02)	(0.01)	(0.02)
Log oxen/hectare	0.02***	0.02	0.03***	0.03***	0.03***	0.02***	0.01
	(0.003)		(0.01)	(0.003)	(0.01)	(0.01)	(0.01)
Log fertilizer/hectare	0.01***	0.01	0.01***	0.01***	0.01***	0.02***	-0.00
	(0.001)		(0.002)	(0.002)	(0.003)	(0.002)	(0.004)
Log improved seeds/hectare	0.02***	0.02	0.003	0.002	0.01**	0.02***	-0.01
	(0.002)		(0.006)	(0.010)	(0.004)	(0.003)	(0.013)
Pesticides (chemicals)	0.06***	0.06	-0.03	-0.03	0.20***	0.21***	0.08*
	(0.02)		(0.03)	(0.03)	(0.04)	(0.07)	(0.04)
Irrigation	0.12**	0.13	0.18**	0.22	-0.18	0.16*	0.03
	(0.05)		(0.09)	(0.20)	(0.13)	(0.10)	(0.11)
Used tractor	0.02		0.04	-0.16	0.15	-0.03	0.09
	(0.05)		(0.08)	(0.12)	(0.10)	(0.12)	(0.11)
Used harvester	0.21***	0.24	0.01	0.10*	0.12	0.22**	-0.04
	(0.04)		(0.07)	(0.06)	(0.08)	(0.11)	(0.13)
Used thresher	-0.01		-0.02	0.14***	0.19**	-0.13***	-0.07
	(0.03)		(0.08)	(0.04)	(0.08)	(0.05)	(0.09)
Land quality index	0.03***	0.18	0.02***	0.02***	0.02***	0.03***	0.03***
	(0.003)		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Log total rainfall	3.30***	3.30	5.26***	1.14***	4.97***	4.28***	2.07
	(0.47)		(1.05)	(0.12)	(0.97)	(1.16)	(1.54)
Log total rainfall-squared	-0.23***	-0.23	-0.36***	-0.07***	-0.35***	-0.29***	-0.15
	(0.03)		(0.07)	(0.01)	(0.07)	(0.08)	(0.11)
Variability of RF	-0.002**	-0.12	0.002	0.0001	-0.01***	-0.00001	-0.001
	(0.001)		(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
Growing degree days	-0.13**	-0.001	-0.10	0.41***	-0.09	-0.07	-0.29
	(0.05)		(0.12)	(0.11)	(0.13)	(0.11)	(0.21)
Growing degree days squared	-1.67***	-0.03	-0.70	-0.32	-1.30	-3.60***	-0.46
	(0.29)		(0.62)	(0.88)	(0.86)	(0.64)	(0.64)
Amhara	-0.12		-0.36	0.09	-0.08	0.35**	0.37**
	(0.08)		(0.24)	(0.10)	(0.21)	(0.15)	(0.18)
Oromiya	-0.29***	-0.25	-0.51**	0.21*	-0.48***	0.07	0.40**
	(0.08)		(0.24)	(0.12)	(0.14)	(0.14)	(0.19)
SNNP	-0.40***	-0.33	-0.52*	0.31**	-0.87***	-0.65***	0.55
	(0.14)		(0.28)	(0.14)	(0.20)	(0.14)	(0.41)
AGP woreda	0.21***	0.24	-0.04	-0.15***	0.03	-0.20***	0.63***
	(0.05)		(0.12)	(0.02)	(0.10)	(0.05)	(0.15)
Gamma	0.73		0.71	1.00	0.74	0.35	0.83
Log likelihood function	-14,046		-3,373	-2,069	-2,279	-3,995	-1,906
LR test of the one-sided error	714		370	239	171	191	122

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

Notes: Numbers in parentheses are standard errors. SNNP - Southern Nations, Nationalities, and Peoples region. Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

a) All crop dummies except black teff in the aggregate ("All crops") sample and black teff dummy in the "Teff" equation were positive and significant.

The effect of modern inputs on yields sets this study apart from similar works on smallholder farmers in Ethiopia. Unlike other works, estimated coefficients of fertilizer, improved seeds, irrigation, pesticides, harvesters, and threshers (barley and wheat) are significant or higher in this study. For instance, Ayele et al. (2006) find no effect of fertilizer and improved seeds on productivities of teff, maize, and wheat. Yami et al. (2013) find both quantity of fertilizer and improved seed costs have negative effects on wheat output. Bachewe (2012) finds no effect of fertilizer, improved seeds, and pesticides on total agricultural output, while Nisrane et al. (2011) find no

effect of fertilizer on real value of output. Gebru (2006) finds no effect of modern input adoption on total output of farmers in Tigray, with some exceptions documented by Gebru (2006), Asrat et al. (2010), and Endale (2011).

The higher contribution of modern inputs noted may indicate the positive result of efforts of the Ethiopian government to increase application of modern inputs and production methods. This was also observed in Byerlee et al. (2007). However, as we discuss, average relative productivity and efficiency computed in this study is close to those found in other studies, indicating a persistent gap in productivity.

The statistic "LR [likelihood ratio] test of the one-sided error" in Table 4.1 rejects the null hypothesis of: H_0: U_{mj}=0, the null hypothesis of OLS in favor of SFA. The statistic, computed as -2[log likelihood under H0 - log likelihood under HA], has a mixed chi-square distribution with degrees of freedom of the number restrictions, 1. The estimate of gamma, which is defined as: $\gamma = \sigma_U^2/\sigma^2$, where $\sigma^2 = \sigma_U^2 + \sigma_V^2$, indicates that about three-quarters of the variation in the composed error term, is due to inefficiency. We estimate equations 13 and 14 also using log of output as a dependent variable. Log of cultivated area is included in the analyses where labor, oxen, fertilizer, and improved seeds are in log-levels. Elasticity of output with respect to area is 0.49, which is comparable to estimates in other studies (see Appendix Tables A.2 and A.3). Estimates of the latter specification are qualitatively similar to those in Table 4.1.

4.2. Patterns of Efficiency and Productivity in Cereals Production

We summarize technical efficiency predictions of the aggregate and crop specific stochastic frontier analyses (SFA) in columns 2 and 3 of Table 4.2. The remaining five columns summarize performance indices obtained from data envelopment analyses (DEA).

Table 4.2—Estimates of technical efficiency, scale efficiency, and relative total factor productivity

	Stochastic Frontier Analysis			Data Envelopment Analysis			
				Output-oriented		Input-oriented	
Crop type	Aggregate sample	Crop specific	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency
All crops	0.37	0.46	0.32	0.37	0.90	0.65	0.47
White teff	0.46	0.48	0.36	0.41	0.92	0.69	0.51
Black teff	0.36	0.34	0.34	0.38	0.92	0.64	0.51
Barley	0.36	0.27	0.32	0.39	0.88	0.66	0.47
Wheat	0.42	0.45	0.36	0.42	0.89	0.67	0.51
Maize	0.27	0.69	0.27	0.31	0.89	0.61	0.42
Sorghum	0.45	0.34	0.33	0.37	0.92	0.67	0.48

Source: Authors' analyses using data from the AGP Baseline Survey (2011).

Stochastic Frontier Analysis – The results indicate that technical efficiency averaged 0.37 – that is, cereals yields of an average household were only 37 percent of the yields obtained by technically efficient households using similar production techniques. This is slightly lower than the average found in Nisrane et al. (2011), which was 0.46. Average efficiency from crop-specific analyses was higher because performance is assessed within a relatively smaller groups of households for each crop.

Data Envelopment Analysis – The summary of DEA predicted performance indices indicate that relative TFP averaged 0.32 and output-oriented technical efficiency (OTE) averaged 0.37. OTE is 9 percent lower than the comparable crop-specific average technical efficiency obtained from SFA, because the former attributes differences in output per unit inputs entirely to deviations in efficiency. However, the similarity is remarkable, considering the differences in underlying assumptions and computations involved in the two methods. Variation in performance is low whereby the minimum and maximum coefficients of variation of the entries in Table 4.2 are 0.17 and 0.83, respectively.

4.3. Factors Affecting Efficiency and Productivity of Cereals Production

We use the variables in equation (14) to explain the determinants of efficiency and relative TFP. Results using inefficiency levels predicted in SFA as a dependent variable and estimated simultaneously with (13) are provided in column 2 of Table 4.3.[7] OLS results obtained using DEA predicted relative TFP (RTFP) as dependent variable, are provided in column 3. The last four columns provide results obtained using output-oriented technical and scale efficiency (OTE and OSE) and input-oriented technical and scale efficiency (ITE and ISE) as dependent variables. We use three-stage least squares to estimate the last two pairs of equations.

Household characteristics – The gender of the household head has no effect on the technical inefficiency index predicted by SFA. As expected, DEA, which decomposes relative TFP into output- and input-oriented efficiency indices, provides more nuanced results. Accordingly, although gender did not affect RTFP, technical efficiency was higher and scale efficiency lower among female headed households. Younger heads have higher efficiency and RTFP.[8] Educated heads had higher performance in all indices except OSE. Relative TFP and scale efficiency improve and input technical efficiency declines with household size.

Table 4.3—Factors explaining cereals production technical efficiency, scale efficiency, and relative total factor productivity

	Dependent variable					
			Output oriented		Input oriented	
Variables	Technical inefficiency (SFA)	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency
Household characteristics						
Sex of head of household	-0.02	-0.05	-1.17**	1.15***	-0.75**	0.23
Age of head of household	0.002***	-0.03**	-0.01	-0.03***	0.005	-0.05***
Head education	-0.05**	1.36***	2.12***	-0.52*	0.76**	1.22**
Household size	0.003	0.18*	0.03	0.24***	-0.15**	0.36***
Land management and risk						
Crop area	0.67***	1.87**	-5.08***	9.87***	-13.77***	12.92***
Crop area squared	-0.17***	2.12***	3.89***	-2.41***	4.46***	-0.62**
Proportion of land owned	0.09***	-2.93***	-3.71***	0.62*	-1.48***	-2.93***
Partially specialized	-0.16***	3.96***	3.91***	0.36	2.25***	3.76***
Fully specialized	-0.23***	6.07***	6.32***	0.02	3.76***	5.93***
Crops grown seed and fertilizer use	-0.0003	0.06***	0.08***	-0.02**	0.03***	0.08***
HH member works off-farm	0.01	-0.06	0.30	-0.57***	0.55***	-0.39*
Tropical livestock units	-0.01***	0.42***	0.36***	0.09***	0.11***	0.54***
Access to credit, extension, and services						
Used credit	-0.03	1.36**	1.47**	-0.28	0.83**	2.16***
Production information	-0.13***	2.94***	2.85***	0.47	0.51	3.91***
DA center available in FA	-0.12***	3.27***	2.90***	0.74*	1.88***	2.72***
Household member participation	0.05***	-1.61***	-1.40***	-0.31	-1.08***	-1.59***
PAs available in FA	-0.04*	1.80***	3.44***	-1.52***	1.19***	1.96***
Distance to closest market	-0.001*	0.02	0.09***	-0.08***	0.04***	0.01
Constant	0.90***	18.32***	36.61***	69.57***	86.29***	17.99***

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

Notes: All equations estimated included crop, region, AGP-woreda, and agroecologic zone dummies, which are jointly significant in all equations. DA, FA, and PAs stand respectively for *development agents, farmers' association,* and *producers' associations.*
Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Access to credit, extension, and services – Households that purchased one or more type of input on credit, partly or fully, performed better in all DEA indices except OSE. Households that obtain information from media or information boards were more efficient in all indices except OSE. Moreover, households in areas where

[7] Similar estimates of crop specific inefficiency equations are provided in Appendix Table A.4
[8] The dependent variable in column 2 of Table 4.3 is *inefficiency* level while it is *TFP/efficiency* in columns 3-5.

government extension offices provide services performed superior in all indices. However, households with members that visited development agents' (DAs) offices, farmers' training centers, or attended community meetings had low performance in all but one index.

Households in areas where producers' associations were active had higher performance in all indices except in OSE. Households in areas closer to markets performed superior in OSE and inferior in technical efficiency. One of the possible explanations for the positive relationship between technical efficiency and distance to markets is that villages close to markets have often existed there a long time and their production potential may have diminished from years of cultivation (see also Nisrane et al. 2011). However, the latter makes it hard to explain the negative association of scale efficiency and distance to markets.

Land endowment, specialization, and scale of operation – Lack of specialization characterizes subsistence farmers who produce most of the items they consume. In our dataset only 11.4 percent of households cultivated a single crop or fully specialized, 19.5 percent cultivated two crops or partially specialized, while about 45 percent cultivated four or more crops. Results of the econometric analyses indicate that fully or partially specializing households performed higher relative to those cultivating three or more crops in all indices, except OSE. The results also indicate that households who sharecrop or rent-in land, perform superior in all productivity indices, except OSE.

Although it leads to low specialization and dissection of cropland, cultivating different crops helps farmers avoid price shocks in crops that they would otherwise have to buy (Joshi and Bauer 2006; Barrett et al. 2010). Moreover, agriculture is inherently risky as it is susceptible to weather shocks. Farmers cope with such risks by cultivating the same crop in different plots and by using indigenous seeds before adopting improved varieties (Castelhano 2008). We argue that this also holds in relation to fertilizer – that is, farmers cultivate the first few plots/crops without chemical fertilizer, and only later adopt fertilizer, which is considered risky. We use an index to account for the joint effect on productivity of these risk coping mechanisms, computed by multiplying the number of crops cultivated, seed varieties of a given crop planted on different plots (using 1 if either indigenous or improved variety and 2 if both), fertilizer use on a given crop planted on different plots (using 1 if either fertilized or not and 2 if both), and number of plots on which a given crop is cultivated.

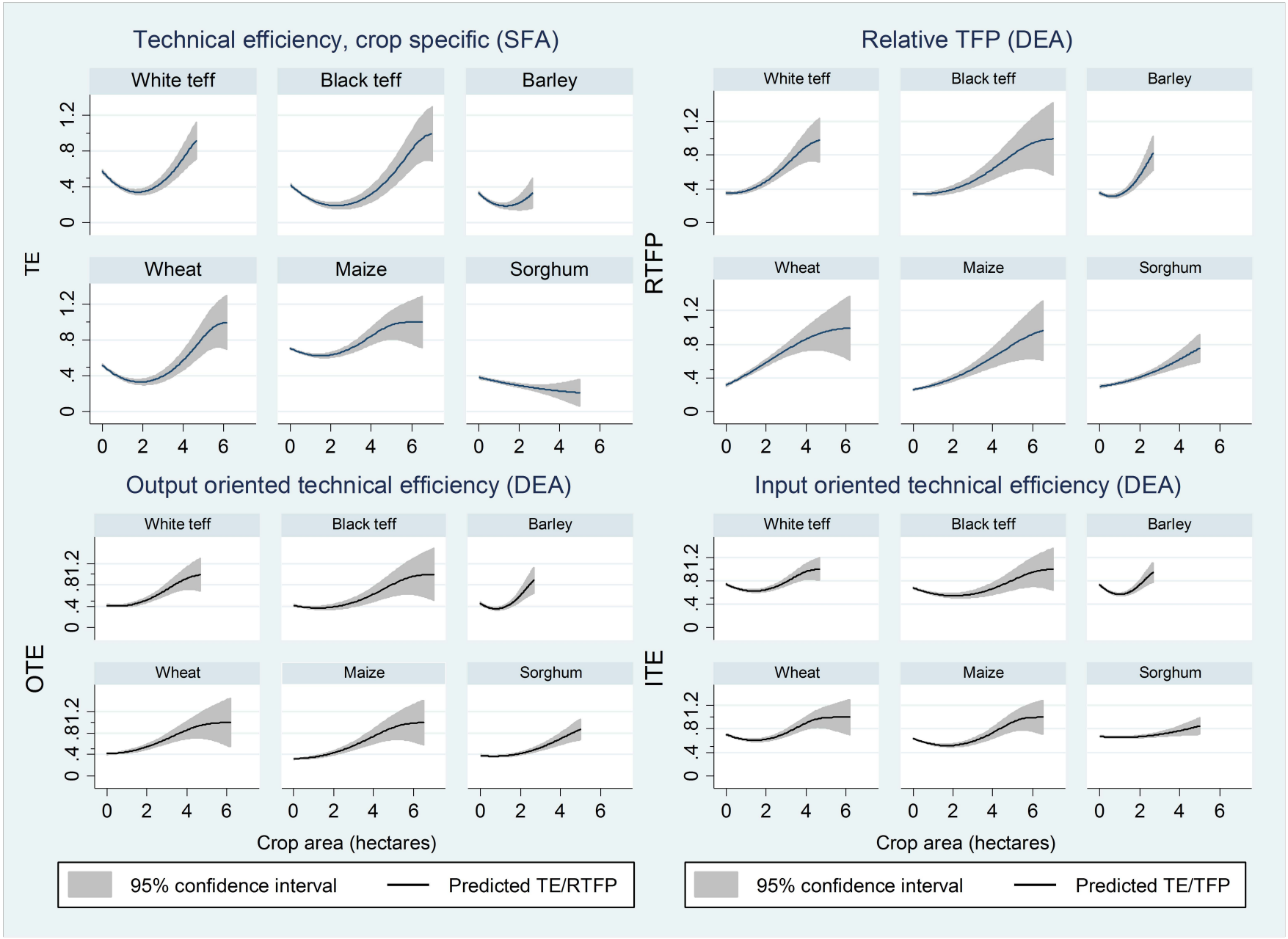
The index is positively correlated with improved seeds or fertilizer adoption, with total and per-hectare application of the inputs, and with cereals and household area. For instance, 7.6 percent of the 6,575 households included in this study have a value of 1 in the index. For 14 percent, 14 percent, 15 percent, and 5.5 percent of households, the index was 2 to 5, respectively. Out of households with a value of 1 in the index, 2.2 percent adopted only improved seeds, 28 percent adopted only fertilizer, and 6.4 percent adopted both, while the remaining 63 percent adopted neither. Out of those with a value of 2 in the index, those that adopted both inputs was 7 percent, while those that adopted either of the inputs was 34 percent, a larger proportion of which adopted fertilizer. About 11 percent of the households with 3 and 4 in the index adopted both inputs, while 40 percent and 41 percent adopted either one of the inputs, respectively. Out of households with a value of 5 in the index, 46 percent adopted either one of the inputs and 13 percent adopted both. This pattern continues in households with higher values in the index. The econometric results indicate that almost all DEA indices improve with the index. This suggests that households adopt modern inputs that they consider risky yet increase their efficiency, although only if they are endowed with sufficient land to also use less-risky, non-modern inputs.

Household members engage in off-farm hired labor or non-farm business activities and livestock production to reduce income variability. The results indicate that households with members engaged in off-farm hired labor or non-farm income generation activities had lower scale efficiency, while their input-technical efficiency was higher. Performance in all indices improves with the number of livestock that the household possesses.

Given fixed landholdings, an increase in the types of crops cultivated leads to a decline in area allocated for each crop, the latter of which we use to gauge scale of production. The results in Table 4.3 indicate that technical efficiency first declines and then increases with cultivated area, while the reverse is true in scale efficiency.

Relative TFP increases non-linearly at all levels of area, resulting from gains in scale efficiency at smaller farm-sizes, and gains in technical efficiency at larger farm-sizes. We use the estimates in Table 4.3 to compute the area at which each performance index alternates in sign (Table 4.4). We also depict the area-efficiency relationship in Figure 4.1, plotting the quadratic function predicted by SFA-technical efficiency, RTFP, OTE, and ITE against crop area. The SFA graphs verify the observation described above in all crops except sorghum, while the DEA graphs verify this in all crops.

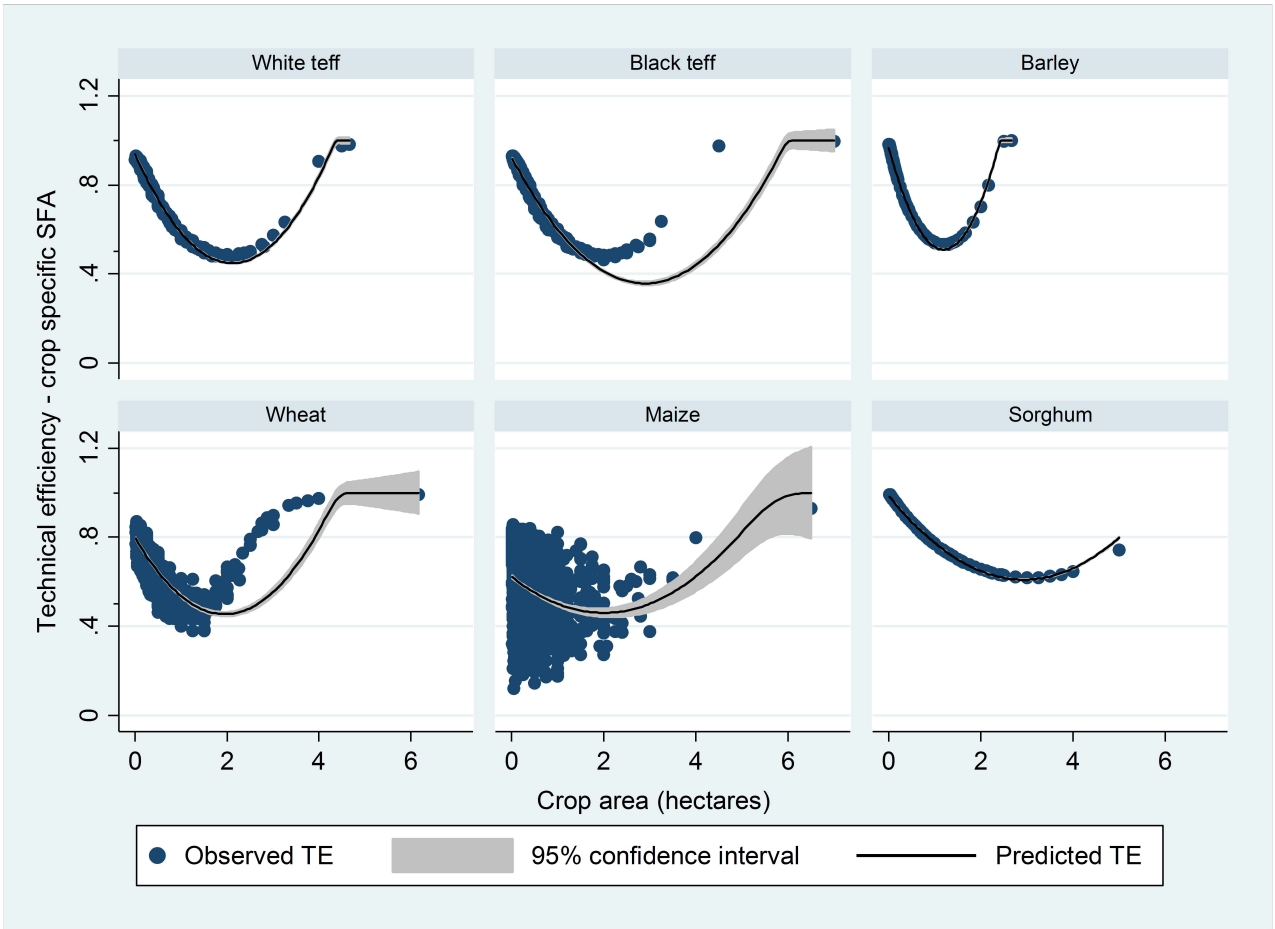
Figure 4.1—Relationship between crop area, technical efficiency, and relative total factor productivity



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

We estimate equations (13) and (14) whereby we use only area and area square as explanatory variables of inefficiency in the latter equation. We depict the area-technical efficiency relationship obtained from this analyses in Figure 4.2. The figure clearly depicts a U-shaped efficiency-area curve for all crops, and the predicted interval is narrow.

Figure 4.2—Relationship between area and technical efficiency, obtained using only area and area squared in the inefficiency equation of the stochastic frontier analysis (SFA)



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

4.4. Sensitivity Analyses: Patterns in Productivity and Scale of Production

Given the distinct relationship between crop area and productivity noted above and depicted in Figures 4.1 and 4.2, we further investigate the relationship by conducting most of the analyses for two groups of observations: smallholdings and medium to large-holdings (henceforth smallholders and large holders, respectively).[9] We use area percentiles to form the groups for each of the five crops. Accordingly, observations in the highest 20 percentile of areas are categorized as large-holders. According to this crop-area based classification, 73 percent of the households were smallholders (operating smallholdings in all crops), 10 percent were large-holders (operating large-holdings in all crops), while 17 percent of the households cultivated crop areas that lay in both categories. Ignoring households with crop area in both categories for the moment, relative to smallholder households, an average large holder produced 87 percent more cereals per household member, cultivated 200 percent larger cereals area, and were endowed with 170 percent larger area per household member.

[9] The results of these analyses are provided in Appendix Tables A.5 and A.6.

Results of the latter analyses reveal interesting distinctions between the two groups. First, the contribution to yields of all inputs, except for oxen and improved seeds, is higher for large holders. Secondly, factors explaining performance in productivity and efficiency are distinct between the two groups. While credit use improves input scale efficiency of smallholders, it affects output and input technical efficiencies of large-holders positively and OSE negatively. Household member participation in events that provide production information adversely affects only smallholders' efficiency. The proportion of large holders that sharecropped or rented-in land is about 70 percent higher than smallholders. However, all productivity indices of large-holders' are not affected by tenure type, while smallholders' productivity increases with sharecropped or rented-in land. The latter and the low per-capita output of smallholders together, imply that they are severely land constrained. Depending on the index considered, productivity of smallholders declines with area up to an area between 1.0 and 1.3 hectares, which is higher than the maximum area that smallholders cultivate (Table 4.4). In contrast, the relative TFP (DEA) and technical efficiency (SFA) of large holders increases with area linearly. Qualitatively similar implications were obtained from analyses conducted considering areas of 0.75 and 1 hectares and larger as large-holdings.

Table 4.4—Crop area at which efficiency and productivity indices of small- and large-holders change in sign,

		Criterion used to categorize observations in large holding category					
		Upper 20 percent area		Area>=0.75 ha		Area>=1 ha	
Variable/statistics	Full sample	Small-holders	Large holders	Small-holders	Large holders	Small-holders	Large holders
SFA-technical efficiency	3.89	1.25	Linear	0.95	Linear	1.16	Linear
DEA - RTFP	Quadratic	1.05	Linear	0.76	Linear	0.88	Linear
DEA - OTE	1.31	1.20	17.68*	0.80	18.14*	0.96	Linear
DEA - OSE	4.10*	1.59*	6.66	0.90*	6.82	1.16*	6.07
DEA - ITE	3.09	1.30	Linear	0.88	-5.18*	1.05	Linear
DEA - ISE	20.74*	0.50	11.56*	0.51	10.41*	0.48	12.49*
Observations (%)	*100.0*	*83.4*	*16.6*	*81.1*	*18.9*	*88.1*	*11.9*

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

Note: Except for the proportion of observations in the first row, the remaining figures represent the area at which the indices obtain minimum, except figures with *, which represent the area at which the indices obtain maximum, and those with "Linear" and "Quadratic", in which the indices increase with area linearly and quadratically, respectively.

5. KEY FINDINGS AND POLICY IMPLICATIONS

We employ stochastic frontier (SFA) and data envelopment (DEA) analyses on input-output data of households producing five important cereals that was collected in the baseline survey of Ethiopia's Agricultural Growth Program (AGP). We study factors contributing to cereals yields, measure relative productivity and efficiency, and investigate factors explaining productivity and efficiency.

The contribution to yields and output of traditional inputs, such as size and quality of cultivated area, labor, and plowing power obtained in this study, are broadly similar to those of other studies on Ethiopia. Unlike other studies, however, this study finds that fertilizer, improved seeds, pesticides, irrigation, and farm machinery contribute significantly to increases in output and yields. The effect of agronomic weather measures on yields is mostly consistent with predictions in the relevant literature. Sensitivity tests imply that the preferred SFA specification performs superior.

Despite being dissimilar in their underlying assumptions, the SFA and the DEA predicted output-oriented technical efficiencies are comparable and indicate that an average cereal-producing household is less than half as efficient as optimal households.

The analyses explaining productivity and efficiency and their implications are mostly similar across the methods used in analysis and indices derived. Accordingly, productivity improves with education and exposure to

information on modern production practices. Local availability of extension service providers and producers' associations improve productivity. Fully and partially specializing households have higher productivity relative to households growing more crops, while households that sharecrop or rent-in land perform better. Households endowed with larger area and numerous plots adopt efficiency-increasing risky modern inputs only after using less-risky ones. Off-farm income generation activities that help reduce income variability adversely affect scale efficiency, but positively affect input-technical efficiency. Unlike the inverse farm size-productivity hypotheses, results in this study indicate large holders are as more productive. The results also indicate that the productivity of large holders increases linearly with cultivated area, while smallholders' productivity first declines and then increases with crop area. The results obtained using datasets of different subsamples and all observations consistently indicate that land size and productivity are positively related after a specific threshold of cultivated area is reached.

Many factors that influence efficiency and productivity are amenable to being targeted by policy changes. This includes increasing access to education, possibly through off-season programs. Moreover, improving access to information on better production methods, such as through extension services and strengthening producers' associations, are likely to lead to higher performance in cereal production. In Ethiopia renting out and sharecropping land is restricted. With a large proportion of households cultivating small croplands and efficiency increasing with rented-in land, the sector will miss out on efficiency gains that result from unrestricted land rentals. The results of this study indicate that helping farmers specialize in fewer crops increases their performance, which is a finding also implied by well-established theories in international trade.

REFERENCES

Asrat, S., G. Getachew, and A.S. Taffesse. 2010. *Trends and determinants of cereal productivity: Econometric analysis of nationally representative data*. Mimeo. International Food Policy Research Institute, Addis Ababa.

Ayele, G., M. Bekele, and S. Zekeria. 2006. *Productivity and Efficiency of Agricultural Extension Package in Ethiopia*. EDRI Research Report 5. Ethiopian Development Research Institute, Addis Ababa.

Bachewe, F., A. Nin-Pratt, and A.S. Taffesse. Forthcoming. *Productivity and Technical Change in Ethiopia's Agriculture: Why not a Revolution Yet?* IFPRI-ESSP Research Monograph. International Food Policy Research Institute, Addis Ababa.

Bachewe, F. 2012. *Growth in Total Factor Productivity in the Ethiopian Agriculture Sector: Growth Accounting and Econometric Assessments of Sources of Growth*. ESSP II Working Paper 37. International Food Policy Research Institute, Addis Ababa.

Barrett, C. B., M.F. Bellemare, and J.Y. Hou, 2010. "Reconsidering conventional explanations of the inverse productivity–size relationship". *World Development* 38: 88-97.

Baumgartner, P., J. von Braun, D. Abebaw, and M. Müller. 2013. *Impacts of Large-Scale land Investments on Income, prices, and Employment: Empirical Analyses in Ethiopia*. Paper presented at the World Bank Annual Conference on Land and Poverty, April 8-11.

Berhane, G., M. Dereje, J. Hoddinott, B. Koru, F. Nisrane, F. Tadesse, A.S. Taffesse, I. Worku, and Y. Yohannes. 2013. *Agricultural Growth Program (AGP) of Ethiopia-Baseline Report 2011*. ESSP-EDRI Report. International Food Policy Research Institute, Addis Ababa.

Birner, R., and D. Resnick. 2010. "The Political Economy of Policies for Smallholder Agriculture". *World Development* 38: 1442-1452.

Byerlee, D., D.J. Spielman, D. Alemu, and M. Gautam. 2007. *Policies to Promote Cereal Intensification in Ethiopia: A Review of Evidence and Experience*. IFPRI Discussion Paper 00707. International Food Policy Research Institute, Washington DC.

Castelhano, M.J. 2008. *Staple Crop Diversity and Risk Mitigation-Potatoes in Bolivia*. M.Sc. Thesis, Virginia Polytechnic Institute and State University, Virginia.

Central Statistical Agency of the Federal Democratic Republic of Ethiopia. 2014. *Agricultural Sample Survey: Volume I-Report on Area and Production of Crops (Private Peasant Holdings, Meher Season)*. Central Statistical Agency, Addis Ababa, 2004, 2005,…, 2014.

_____. 2014. *Agricultural Sample Survey: Volume IV-Report on Land Utilization (Private Peasant Holdings, Meher Season)*. Central Statistical Agency, Addis Ababa, 2004, 2005,…, 2014.

Collier, P. and S. Dercon. 2014. "African Agriculture in 50 Years: Smallholders in a Rapidly Changing World?" *World Development* 63: 92-101.

Deininger, K., E. Zegarra, and I. Lavadenz. 2003. "Determinants and Impacts of Rural Land Market Activity: Evidence from Nicaragua." *World Development* 31: 1385–1404.

Dercon, S. and R.V. Hill. 2009. *Growth from Agriculture in Ethiopia: Identifying Key Constraints*. Paper prepared as part of a study on Agriculture and Growth in Ethiopia. Department for International Development, London.

Diao, X., P. Hazell, and J. Thurlow. 2010. "The Role of Agriculture in African Development". *World Development* 38: 1375-1383.

Diao, X. 2010. *Economic Importance of Agriculture for Sustainable Development and Poverty Reduction: The Case Study of Ethiopia*. Paper presented at Global Forum on Agriculture, Paris, November 29-30.

Endale, K. 2011. *Fertilizer Consumption and Agricultural Productivity in Ethiopia*. EDRI Research Report 3, Ethiopian Development Research Institute, Addis Ababa.

Fan, S., J. Brzeska, M. Keyzer, and A. Halsema. 2013. *From Subsistence to Profit: Transforming Smallholder Farms*, Food Policy Report. International Food Policy Research Institute, Washington DC.

Fare, R., and D. Primont 1995. *Multi-output Production and Duality: Theory and Applications*. Boston: Kluwer Academic Publishers.

Gebru, A. 2006. *The Determinants of Modern Agricultural Inputs Adoption and their Productivity in Ethiopia*. MSc Thesis. Addis Ababa University, Addis Ababa.

Hazell, P. 2013. *Is Small Farm Led Development Still A Relevant Strategy for Africa and Asia?*. Unpublished work downloaded from: http://www.fondation-farm.org/zoe/doc/peterhazell_original_english_paper.pdf.

Headey, D.D., and T.S. Jayne. 2014. "Adaptation to land constraints: Is Africa different?" *Food Policy* 48: 18-33.

Henderson, H. 2014. "Structural transformation and smallholder agriculture: an information-theoretic analysis of the Nicaraguan case." *Agricultural Economics* 45: 443-458.

Hill, R.V., and E. Tsehaye. 2014. *Growth, safety nets and poverty: Assessing progress in Ethiopia from 1996 to 2011*. Background paper for the Ethiopia Poverty Assessment, Addis Ababa.

Joshi, G.R., and S. Bauer. 2006. *Determinants of Rice Variety Diversity on Household Farms in the Terai Region of Nepal*. Paper presented at the International Association of Agricultural Economists Conference, Gold Coast, Australia.

Kumbhakar, S.C. and A.K. Lovell. 2000. *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press.

Maertens, M., and J.F. Swinnen. 2009. "Trade, standards, and poverty: Evidence from Senegal." *World Development* 37: 161-178.

Ministry of Agriculture of the Federal Democratic Republic of Ethiopia. 2009. *Agroecological Zonations of Ethiopia*. Ministry of Agriculture, Addis Ababa.

National Aeronautics and Space Administration of the United States. *NASA Prediction of Worldwide Energy Resource: Climatology Resource for Agroclimatology*. Available at: http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi. Accessed 15 July 2014.

Nisrane, F., G. Berhane, S. Asrat, G. Getachew, A.S. Taffesse, and J. Hoddinott. 2011. *Sources of Inefficiency and Growth in Agricultural Output in Subsistence Agriculture: A Stochastic Frontier Analysis*. ESSP II Working Paper 19. International Food Policy Research Institute, Addis Ababa.

O'Donnell, C.J. 2008. *An Aggregate Quantity-Price Framework for Measuring and Decomposing Productivity and Profitability Change*. CEPA Working Papers WP07/2008. University of Queensland, Centre for Efficiency and Productivity Analysis, Brisbane.

O'Donnell, C.J. 2010a. "Measuring and Decomposing Agricultural Productivity and Profitability Change." *Australian Journal of Agricultural and Resource Economics*. 54: 527-560.

O'Donnell, C.J. 2010b. *Nonparametric Estimates of the Components of Productivity and Profitability Change in U.S. Agriculture*. CEPA Working Papers WP02/2010. University of Queensland, Centre for Efficiency and Productivity Analysis, Brisbane.

O'Donnell, C.J. 2011a. *Econometric Estimation of Distance Functions and Associated Measures of Productivity and Efficiency Change*. CEPA Working Papers WP01/2011. University of Queensland, Centre for Efficiency and Productivity Analysis, Brisbane.

O'Donnell, C.J. 2011b. *The Sources of Productivity Change in the Manufacturing Sectors of the U.S. Economy*. CEPA Working Papers WP07/2011. University of Queensland, Centre for Efficiency and Productivity Analysis, Brisbane.

O'Donnell, C.J. 2011c. DPIN 3.0: *A Program for Decomposing Productivity Index Numbers*. Mimeo. University of Queensland, Centre for Efficiency and Productivity Analysis, Brisbane.

Pandya-Lorch, R., P. Hazell, S. Wiggins, C. Poulton, and A. Dorward. 2005. "Foreword" In *The Future of Small Farms: Proceedings of a Research Workshop*. International Food Policy Research Institute, Washington DC.

Roberts, M., W. Schlenker, and J. Eyer. 2013. “Agronomic Weather Measures in Econometric Models of Crop Yield with Implications for Climate Change.” *American Journal of Agricultural Economics* 95: 236-243.

United Nations. 2014. *World Urbanization Prospects: The 2014 Revision*. UN Department of Economic and Social Affairs, Population Division, Washington DC.

Weir, S. 1999. *The Effects of Education on Farmer Productivity in Rural Ethiopia*. CSAE Working Paper WPS99-7. University of Oxford, Centre for the Study of African Economies.

Wiggins, S., J. Kirsten, and L. Llamb. 2010. “The Future of Small Farms.” *World Development* 38: 1341–1348.

Yami, M., T. Solomon, B. Begna, F. Fufa, T. Alemu, and D. Alemu. 2013. “Source of technical inefficiency of smallholder wheat farmers in selected waterlogged areas of Ethiopia: A translog production function approach.” *International Journal of Agrochemicals and Plant Protection* 1: 25-34.

APPENDICES

Appendix Table A.1—Mean value of household and farmers' associations level variables

Variable	Mean	Standard deviation
Household head gender (1 if male)	0.72	0.4
Household head age	43	15
Household head education	0.27	0.45
Household size	4.8	2.2
Land owned by household	0.82	0.39
Number of crops household cultivated	3.6	1.8
Proportion partially specializing	0.20	0.40
Proportion fully specializing	0.11	0.32
Number of crops×(seed variety × fertilizer type per crop)×number of plots	8.2	10.4
Proportion with members engaged in off/non-farm activities	0.40	0.49
Proportion that used credit	0.21	0.41
Tropical livestock units	3.6	4.1
Household participation	0.50	0.50
Household obtains production information	0.28	0.45
Extension (development agents'0 center in farmers' association	0.85	0.36
Producers' associations in Farmers Association	0.24	0.43
Distance to market	12.5	11.7
Total cropping season rainfall	1,465	596.2

Source: Authors' calculations using data from the AGP Baseline Survey (2011) except *Total cropping season rainfall*, which is obtained from NASA (2014)

Appendix Table A.2—Estimates of stochastic cereals production frontier coefficients (aggregate sample - variables in levels)

Variables	Estimates	Elasticity	Dummy variable	Estimates
Log of cultivated area (hectares)	0.49***	0.49	Amhara	-0.25***
	(0.01)			(0.06)
Log of labor (working days)	0.15***	0.15	Oromiya	-0.15**
	(0.01)			(0.07)
Log of oxen (number)	0.02***	0.02	SNNP	-0.70***
	(0.00)			(0.08)
Log of fertilizer (kg)	0.03***	0.03	AGP woreda	0.10***
	(0.00)			(0.03)
Log of improved seeds (kg)	0.02***	0.02	Black teff	-0.01
	(0.002)			(0.05)
Pesticide and others (1 if applied)	0.07***	0.07	Barley	0.39***
	(0.02)			(0.05)
Field irrigated	0.11**	0.12	Wheat	0.33***
	(0.05)			(0.05)
Used tractor	0.03		Maize	0.72***
	(0.04)			(0.06)
Used harvester	0.23***	0.25	Sorghum	0.69***
	(0.04)			(0.05)
Used thresher	-0.01		Constant	-4.99***
	(0.03)			(1.65)
Land quality index (1 poor; 9 best)	0.03***	0.21	Sigma-squared	0.57
	(0.003)		Gamma	0.77
Log of total cropping season rainfall	3.21***	3.21	Log likelihood function	-13,756
	(0.48)			
Log of total cropping season rainfall-squared	-0.22***	-0.22		
	(0.03)			
Variability of rainfall (CV weekly total rainfall)	-0.003***	-0.18		
	(0.001)			
Growing degree days	-0.09			
	(0.05)			
Growing degree days squared	-1.52***	-0.03		
	(0.29)			

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

Notes: Numbers in parentheses are standard errors. Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Appendix Table A.3—Factors affecting technical efficiency of cereals production (aggregate sample - variables in levels)

Variables	Estimates	Dummy variable	Estimates
Household characteristics		Black teff	0.33***
Sex of head of household	-0.03		(0.10)
	(0.03)	Barley	0.16
Age of head of household	0.002***		(0.10)
	(0.001)	Wheat	0.16
Head education	-0.04		(0.10)
	(0.02)	Maize	0.57***
Household size	-0.01		(0.10)
	(0.01)	Sorghum	0.31***
Land management and risk mitigation			(0.10)
Crop area	-0.58***	Amhara	-0.20***
	(0.08)		(0.08)
Crop area squared	0.06**	Oromiya	-0.01
	(0.02)		(0.09)
Proportion of land owned	0.14***	SNNP	-0.20*
	(0.03)		(0.10)
Partially specialized	-0.19***	AGP woreda	0.02
	(0.03)		(0.06)
Fully specialized	-0.26***	*Woina dega*	-0.61***
	(0.05)		(0.04)
Crops grown seed and fertilizer use	-0.003	*Dega*	-0.45***
	(0.001)		(0.05)
Household member works off-farm	0.01	Constant	1.38***
	(0.01)		(0.14)
Tropical livestock units	-0.02***		
	(0.003)		
Access to credit, extension, & services			
Used credit	-0.03		
	(0.03)		
Production information	-0.16***		
	(0.03)		
DA center available in FA	-0.15***		
	(0.03)		
Household member participation	0.06**		
	(0.02)		
PAs available in FA	-0.05**		
	(0.03)		
Distance to closest market	-0.002*		
	(0.001)		

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

Notes: Numbers in parentheses are standard errors. DA, FA, and PAs stand respectively for *development agents, farmers' association,* and *producers' associations.* SNNP - Southern Nations, Nationalities, and Peoples region. Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Appendix Table A.4—Factors affecting technical inefficiency of crop specific SPFs [in Table 4.3 of text]

Variables	Dependent variable: relative technical inefficiency				
	Teff	Barley	Wheat	Maize	Sorghum
Household characteristics					
Sex of head of household	-0.04	0.005	0.03	0.001	-0.11**
	(0.04)	(0.05)	(0.06)	(0.07)	(0.05)
Age of head of household	0.002	0.000	0.001	0.001	0.002
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
Head education	-0.14***	-0.05	-0.07	-0.06	-0.01
	(0.04)	(0.04)	(0.05)	(0.07)	(0.05)
Household size	-0.002	-0.01	0.02	0.01	0.0002
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land management and risk mitigation					
Crop area	1.11***	1.34***	1.12***	1.69***	0.41***
	(0.16)	(0.16)	(0.17)	(0.28)	(0.09)
Crop area squared	-0.32***	-0.48***	-0.36***	-0.66***	-0.07***
	(0.08)	(0.09)	(0.09)	(0.18)	(0.02)
Proportion of land owned	0.03	0.09	0.23***	0.44***	-0.01
	(0.04)	(0.06)	(0.07)	(0.11)	(0.05)
Partially specialized	-0.21***	-0.15***	-0.15*	0.05	0.02
	(0.06)	(0.05)	(0.08)	(0.08)	(0.06)
Fully specialized	-0.25**	-0.43***	-0.06	-0.22*	0.00
	(0.10)	(0.07)	(0.12)	(0.13)	(0.09)
Crops grown seed and fertilizer use	-0.005***	0.001	0.001	-0.003	-0.001
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
HH member works off-farm	0.04**	-0.02	-0.01	-0.07**	0.06***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)
Tropical livestock units	-0.01	-0.02***	-0.03***	-0.02**	-0.01**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Access to credit, extension, and services					
Used credit	-0.02	-0.06	-0.31***	-0.01	-0.04
	(0.05)	(0.05)	(0.08)	(0.08)	(0.07)
Production information	-0.09**	-0.17***	-0.05	-0.38***	-0.05
	(0.04)	(0.04)	(0.06)	(0.09)	(0.05)
Development Agent center available in Farmers Association	-0.14**	-0.20***	-0.30***	-0.08	-0.08
	(0.06)	(0.06)	(0.09)	(0.12)	(0.07)
Household member participation	0.06	0.10**	-0.02	0.12*	0.02
	(0.04)	(0.04)	(0.05)	(0.06)	(0.05)
PAs available in FA	0.07*	-0.14***	0.02	-0.23***	-0.07
	(0.04)	(0.05)	(0.07)	(0.07)	(0.05)
Distance to closest market	0.002	-0.010***	0.003	-0.004	-0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Region, woreda, or agro-ecology dummy					
Amhara	-0.38	0.15**	0.64***	0.62***	0.79***
	(0.25)	(0.07)	(0.22)	(0.22)	(0.22)
Oromiya	-0.37	0.06	0.18	-0.34	0.97***
	(0.26)	(0.07)	(0.17)	(0.26)	(0.18)
Southern Nations, Nationalities, and Peoples (SNNP) region	0.01	0.86***	0.30	-1.96***	1.49***
	(0.31)	(0.10)	(0.23)	(0.58)	(0.40)
AGP woreda	-0.30**	-0.31***	0.01	-0.61***	0.60***
	(0.15)	(0.04)	(0.15)	(0.11)	(0.17)
Woina dega	-0.61***	-0.34***	-0.13**	-0.67***	-0.50***
	(0.07)	(0.08)	(0.06)	(0.11)	(0.09)
Dega	-0.29***	-0.32***	0.95***	-0.22*	-0.43***
	(0.08)	(0.08)	(0.17)	(0.13)	(0.14)
Constant	1.40***	1.88***	0.34	0.57*	0.44*
	(0.41)	(0.16)	(0.28)	(0.32)	(0.25)

Source: Analyses using the AGP Baseline Survey data (2011).

Notes: Numbers in parentheses are standard errors. Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Appendix Table A.5—Estimates of stochastic cereals production frontiers for smallholders and large holders, respectively

Variables	Smallholders	Large holders
Log of labor per hectare	0.16***	0.20***
	(0.01)	(0.02)
Log of oxen per hectare	0.02***	0.01**
	(0.003)	(0.01)
Log of fertilizer per hectare	0.01***	0.01***
	(0.001)	(0.003)
Log of improved seeds per hectare	0.02***	0.01***
	(0.002)	(0.005)
Pesticide/chemicals	0.06***	0.09**
	(0.02)	(0.04)
Irrigation	0.06	0.31**
	(0.05)	(0.13)
Used tractor	0.04	-0.15*
	(0.05)	(0.08)
Used harvester	0.19***	0.24***
	(0.05)	(0.08)
Used thresher	-0.02	0.02
	(0.04)	(0.07)
Land quality index	0.03***	0.03***
	(0.003)	(0.01)
Log of total rainfall	3.78***	-1.56
	(0.51)	(1.65)
Log of total rainfall-squared	-0.26***	0.10
	(0.04)	(0.12)
Variability of RF	-0.003***	-0.00005
	(0.001)	(0.002)
Growing degree days	-0.07	-0.24*
	(0.06)	(0.15)
Growing degree days squared	-1.82***	0.32
	(0.31)	(0.76)
Amhara	-0.17**	0.10
	(0.09)	(0.16)
Oromiya	-0.31***	2.94
	(0.09)	(11.00)
SNNP	-0.16	0.90***
	(0.18)	(0.26)
AGP woreda	0.22***	1.08***
	(0.05)	(0.25)
Black teff	0.11	-0.27
	(0.09)	(0.29)
Barley	0.55***	0.10
	(0.09)	(0.23)
Wheat	0.45***	-0.15
	(0.08)	(0.23)
Maize	1.07***	-0.47*
	(0.11)	(0.28)
Sorghum	0.43***	0.14
	(0.08)	(0.27)
Constant	-6.42***	11.54**
	(1.75)	(5.68)
Log likelihood function	-11,729	-2,073

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

Notes: Numbers in parentheses are standard errors. Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

Appendix Table A.6—Factors affecting efficiency and relative total factor productivity (TFP) of smallholder and large-holder cereal producers, respectively

	Smallholders						Large-holders					
			Output oriented		Input oriented				Output oriented		Input oriented	
Variables	Technical ineffi-ciency (SFA)	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency	Technical ineffi-ciency (SFA)	Relative TFP	Technical efficiency	Scale efficiency	Technical efficiency	Scale efficiency
Household characteristics												
Sex of head of household	-0.02	-0.20	-1.52**	1.34***	-0.88**	0.08	-0.06	1.40	1.86	-0.68	0.84	1.55
Age of head of household	0.002**	-0.03*	-0.001	-0.03***	0.01	-0.04**	0.002**	-0.06*	-0.06	0.01	-0.03	-0.06*
Head education	-0.04*	1.25**	1.84***	-0.28	0.57*	1.06*	-0.05	1.52	1.66	0.34	0.49	1.77
Household size	-0.003	0.24**	0.16	0.15**	-0.11	0.43***	-0.004	0.09	-0.19	0.36***	-0.02	0.15
Land management and risk mitigation												
Crop area	2.63***	-42.16***	-70.67***	36.46***	-72.61***	-8.60**	0.16**	14.04***	16.40***	-4.59***	6.06***	15.28***
Crop area squared	-2.11***	40.11***	59.03***	-22.96***	55.90***	17.32***	-0.02	-0.66	-0.93*	0.69***	0.08	-1.32**
Proportion of land owned	0.10***	-3.42***	-4.65***	1.16***	-2.05***	-3.23***	0.05	-1.39	-1.39	-0.20	-0.33	-1.77
Partially specialized	-0.15***	4.13***	4.38***	-0.01	2.31***	3.99***	-0.09*	2.84*	1.59	1.60***	1.69*	2.50
Fully specialized	-0.19***	5.61***	6.16***	-0.58	3.47***	5.54***	-0.26***	6.80***	5.42***	2.71***	3.29**	7.03***
Crops grown seed and fertilizer use	-0.00004	0.05**	0.07***	-0.03**	0.03*	0.06***	-0.002	0.08**	0.08**	0.02	0.03	0.10**
HH member works off-farm	0.01	-0.15	0.27	-0.67***	0.55***	-0.49**	-0.02	0.28	0.65	-0.56***	0.54	0.24
Tropical livestock units	-0.01***	0.36***	0.27***	0.14***	0.03	0.52***	-0.02***	0.59***	0.60***	-0.01	0.30***	0.62***
Access to credit, extension, and services												
Used credit	-0.02	0.73	0.47	0.24	-0.14	2.01***	-0.03	2.32	3.13**	-1.65***	3.12***	1.44
Production information	-0.13***	3.08***	3.13***	0.29	0.56*	4.17***	-0.04	2.36**	1.85	0.89*	0.51	2.69**
DA center available in FA	-0.11***	2.95***	2.39***	0.97**	1.17**	2.85***	-0.03	3.12*	2.68	0.82	2.99***	1.26
Household member participation	0.05**	-1.40***	-1.03*	-0.48	-0.71**	-1.60***	0.05	-1.70	-1.91	0.22	-2.07***	-0.86
PAs available in FA	-0.07***	2.09***	3.93***	-1.65***	1.31***	2.35***	0.08*	-0.36	0.06	-0.56	-0.36	-0.21
Distance to closest market	-0.002**	0.04**	0.11***	-0.08***	0.05***	0.03	0.003*	-0.10*	-0.07	-0.05**	-0.05	-0.12**
Constant	0.99***	26.06***	49.48***	62.86***	99.09***	20.49***	0.24	21.71***	31.53***	84.26***	72.53***	30.72***

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

Note: Coefficients with ***, **, and * are significant at 1%, 5%, and 10% levels, respectively

About the Authors

Fantu Nisrane Bachewe is an Associate Research Fellow in the Development Strategy and Governance Division of the International Food Policy Research Institute, based in Addis Ababa, Ethiopia. **Bethelhem Koru** is a Research Officer in the Ethiopia Strategy Support Program of the International Food Policy Research Institute and the Ethiopian Development Research Institute, based in Addis Ababa. **Alemayehu Seyoum Taffesse** is a Senior Research Fellow in the Development Strategy and Governance Division of the International Food Policy Research Institute, based in Addis Ababa.

About ESSP

The Ethiopia Strategy Support Program is an initiative to strengthen evidence-based policymaking in Ethiopia in the areas of rural and agricultural development. Facilitated by the International Food Policy Research Institute (IFPRI), ESSP works closely with the government of Ethiopia, the Ethiopian Development Research Institute (EDRI), and other development partners to provide information relevant for the design and implementation of Ethiopia's agricultural and rural development strategies. For more information, see http://www.ifpri.org/book-757/ourwork/program/ethiopia-strategy-support-program or http://essp.ifpri.info/ or http://www.edri-eth.org/.

About these working papers

The ESSP Working Papers contain preliminary material and research results from IFPRI and/or its partners in Ethiopia. The papers are not subject to a formal peer review. They are circulated in order to stimulate discussion and critical comment. The opinions are those of the authors and do not necessarily reflect those of their home institutions or supporting organizations.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
2033 K Street, NW | Washington, DC 20006-1002 USA
T: +1.202.862.5600 | F: +1.202.457.4439
Skype: ifprihomeoffice | ifpri@cgiar.org | www.ifpri.org

IFPRI–ESSP ADDIS ABABA
P.O. Box 5689, Addis Ababa, Ethiopia
T: +251.11.617.2000 | F: +251.11.646.2318
mahlet.mekuria@cgiar.org | http://essp.ifpri.info

ETHIOPIAN DEVELOPMENT RESEARCH INSTITUTE
P.O. Box 2479, Addis Ababa, Ethiopia
T: +251.11.550.6066; +251.11.553.8633 | F: +251.11.550.5588
info@edri-eth.org | www.edri-eth.org

The Ethiopia Strategy Support Program (ESSP) is financially supported by the United States Agency for International Development (USAID) and the Department for International Development (DFID) of the government of the United Kingdom and is undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI). This publication has been prepared as an output of ESSP and has not been independently peer reviewed. Any opinions expressed here belong to the author(s) and do not necessarily reflect those of IFPRI, the Ethiopian Development Research Institute, USAID, DFID, PIM, or CGIAR.

Copyright © 2015 International Food Policy Research Institute. All rights reserved. To obtain permission to republish, contact ifpri-copyright@cgiar.org.