An analysis of the productivity and technical efficiency of smallholder irrigation in Ethiopia

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ABSTRACT

Agriculture is the mainstay of Ethiopia's economy, contributing more than 40% to GDP and providing a livelihood to about 80% of the population. Agriculture is dominated by smallholders growing predominantly rainfed cereals, making economic performance dependent on rainfall availability. This study used the stochastic frontier production function to analyse the productivity and technical efficiency of 4 different agricultural production systems in Ethiopia; namely, irrigated seasonal farms on traditional irrigation systems, irrigated seasonal farms on modern communal irrigation systems, rainfed seasonal farms for farmers who have access to irrigation and rainfed seasonal farms for farmers who do not have access to irrigation. Simple random samples of farmers were selected from lists of farmers. The sample of farmers constituted 122 from the traditional irrigated sites, 281 from the modern communal irrigated sites and 350 from the control rainfed sites of farmers without access to irrigation. For those farmers, from both traditional and modern communal irrigation, who also had access to rainfed farms, their rainfed farms were included in the sample of rainfed with access to irrigation. This sample constituted 434 farmers. The marginal productivity of land on modern communal irrigation systems shows that this is the smallholder irrigation option that should be developed by the Government of Ethiopia. However, the marginal productivity of land in the 'rainfed without access to irrigation' category is higher than that of the traditional irrigated system. Thus additional developed land should be put under 'rainfed without access to irrigation' before it is put under traditional irrigation; otherwise it should be developed into modern communal irrigation. The average technical efficiency for the modern irrigated system was estimated to be about 71%, whereas this was estimated to be 78% for the 'rainfed without access to irrigation' system. There are potential gains to be realised in improving efficiency in these two systems.

Keywords: Ethiopia, irrigation, productivity, technical efficiency

INTRODUCTION

Agriculture is the most significant contributor to Ethiopia's national economy (World Bank, 2006). Over the period 1996 to 2006, agriculture contributed more than 44% to GDP with crop production contributing 26% (Government of Ethiopia, 2006). Agricultural production is dominated by smallholders who predominantly grow rainfed cereals on an area of approximately 10 million ha (World Bank, 2006). Agriculture employs 80% of the labour force. In rural areas, 85% of the population, which is estimated to be about 88 million (CSA, 2008), depends on agriculture for a living (Awulachew, 2006; UNDP, 2006). The Ethiopian economy's heavy reliance on rainfed subsistence agriculture leaves its economic performance '…virtually hostage to its hydrology' (World Bank 2006 p. xi).

Ethiopia has abundant water resources that could be developed for, among other things, irrigation, in order to de-link the performance of the economy from rainfall variability (Government of Ethiopia, 2001; World Bank, 2006). Given the importance of agriculture to the Ethiopian national economy, the Government of Ethiopia has embarked on an agriculture-led development programme with irrigation development a central component. It is estimated that only 5% of 3.5 million ha of land that could be irrigated is currently developed (Awulachew et al. 2005, Hagos et al. 2010). Makombe et al. (2007) highlight the Ethiopian paradox, where, given the combination of the potentially irrigable land and abundant surface runoff, 52% of the population is considered food insecure (Kassahun, 2007).

Given the aspirations regarding irrigation development, it is important to understand how irrigation is currently performing. One measure that can be used to evaluate irrigation performance is technical efficiency. In this study, we estimated and compared the levels of production and technical efficiency of different small-scale irrigation farmers in Ethiopia.

BACKGROUND

Irrigation in Ethiopia is classified by management system, namely, traditional, modern communal, modern private and public systems (Werfring, 2004). The management of the smallholder traditional irrigated systems is communal, the diversion weirs are constructed with local materials and are usually washed away every year so that they have to be reconstructed annually. Typically earth canals are used. Modern communal irrigation schemes are also smallholder systems managed locally but with concrete diversion weirs and sometimes concrete primary canals. Sometimes, secondary canals are also lined. Land on the modern private scheme is privately owned and managed. Most of this land is used to grow high-value crops such as horticulture

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(floriculture and beans) and cotton. Public schemes are large scale, managed by the government, growing different export and food crops like sugar, cotton and a variety of fruits. An estimated 60 000 ha are developed under traditional, 30 000 ha under modern-communal, 6 000 ha under modern-private and 60 000 ha under public irrigation systems. (Werfring, 2004; Makombe et al., 2007).

The objective of this study was to determine the productivity and technical efficiency of the traditional and modern communal irrigation systems and to compare them with the rainfed control system. Four production systems are compared, namely, the traditional and modern communal irrigation systems and the two rainfed systems comprising the rainfed system of farmers who have access to irrigation, and the rainfed systems of farmers who do not have access to irrigation (control). The cropping practices for the two rainfed systems are based on cereals – maize, teff, sorghum, wheat and barley – but a variety of oil seeds like rape seed and niger seed are also grown. Both irrigated systems are based on similar crops to the rainfed systems during the rainy season, but during the dry season a variety of leafy green vegetables, onions, tomatoes and carrots are grown. Farmers in all of the systems also grow a variety of perennial crops including, among others, banana, guava, chat, mango and hops. Hagos et al. (2010) and Makombe et al. (2011) provide a detailed description of the cropping patterns observed.

There is substantial variation in the results of earlier studies of technical efficiency of agricultural production in Ethiopia. Using data envelopment analysis, Suleiman (1995) found that technical efficiencies varied between 39 and 57% across the regions Turufe Kechema, Sirbana Godeti and Aze Deboa. These results are similar to the technical efficiencies ranging between 34 and 50% reported by Nisrane et al. (2011) from their study which used the stochastic frontier approach. Admassie and Heidhues (1996), in a study carried out on rainfed agricultural production for farmers who used fertilizer and those who did not, found high levels of technical efficiency in Baso-Worana District. The technical efficiency for fertilizer and non-fertilizer users averaged 92 and 87%, respectively. The differences were not statistically significantly different. This is in agreement with the findings of Makombe et al. (2007) who also found low levels of inefficiency in both rainfed and irrigated production. Admassie and Heidhues (1996) conclude that improving technical efficiency cannot be a solid basis for long-term, sustainable growth in agricultural production. Bogale and Bogale (2005) estimated the technical efficiency of modern and traditional smallholder irrigating potato farmers to be 71 and 97%, respectively.

This study used the stochastic frontier approach to estimate technical efficiency for both rainfed and irrigated systems. We hypothesized that, given the different irrigation infrastructure, the traditional irrigation production systems perform worse than the modern communal irrigated system. We also hypothesized that, given the potential for interaction between rainfed and irrigated production for those farmers with access to irrigation, the production system of the purely rainfed farmers also performs differently from the rainfed production system of farmers with access to irrigation. In Ethiopia, there are no studies that compare the technical efficiency of irrigated systems while separating the two rainfed system.

METHODOLOGY

The stochastic frontier production function as proposed by Aigner et al. (1977) to estimate technical inefficiency across a cross-section of firms or farms was used in this study. The stochastic frontier production function is given as:

$$Y_i = f(X_i, b) + e_i,\ i = 1,\ldots,N \qquad (1)$$

Where Y_i is the output of the i^{th} firm X_i is vector of inputs, and b is a vector of production function parameters. e_i is an error term made up of 2 components such that:

$$e_i = v_i - u_i \qquad (2)$$

The error term v_i in Eq. 2 is assumed to be a symmetric disturbance that is independently distributed as $N(0, \sigma^2_v)$. This error term is thought to exist due to two sources, namely, favourable and unfavourable external shocks out of the firm's control, and errors of measurement. This part of the error term makes the frontier stochastic as firms can temporarily be above the frontier if the value of v_i is large enough (Aigner et al. 1977).

The error term u_i is assumed to be independent of v_i and meets the condition that $u_i > 0$, which means that it is truncated above zero. It is this error term that provides deviations from the frontier or technical inefficiency. The negative sign in Eq. 2, along with positive values of u_i, results in negative deviations from the frontier for each of the observations. Aigner at al. (1977) modelled this error term as a half–normal and also as an exponential distribution in the original paper. A detailed literature survey of the application of the frontier production to both cross-sectional and panel data is provided by Battese (1992), Bravo-Ureta and Pinheiro (1993) and Makombe et al. (2001). Thiam et al. (2001) provided a meta-analysis from the application of the approach to estimating technical inefficiency in developing country agriculture.

Following the specification of the frontier production function for cross-sectional data by Jondrow et al. (1982) the production function was specified as:

$$GV = (A, L, F, I, Ox) \qquad (3)$$

where:

GV = estimate of gross value of output at farm gate prices in Ethiopian Birr (ETB) (1 USD = 8.65 ETB at the time of survey, currently I USD=16.7 ETB)
A = total area planted (ha)
L = labour used in man-days
F = fertilizer applied in kg
I = total number of times a plot is irrigated during the grow ing season/s (for rainfed producers I and its interaction terms are excluded)
Ox = oxen days needed to for land preparation

In the specification, gross value of output (GV) is used instead of yield and the number of irrigation applications was used instead of volume of water applied. Smallholder farmers do not keep records; as a result most of the time they remember the value of the output from a plot and not yield. Furthermore, during the dry season, when irrigation is used to increase cropping intensity, the types of crops grown during that time (mostly leafy greens) are harvested several times and sold in small quantities such that farmers cannot remember yield but remember the value derived from a plot. As a result of this, the gross value of output, the sum total of all outputs from all the plots grown by the farmer during the summer and winter (or wet and dry seasons), is used. Makombe et al. (2001) and Nisrane et al. (2011) use a similar approach to address similar data issues with smallholder irrigated production data in Zimbabwe and rainfed production data in Ethiopia, respectively. Due to the nature of land ownership and the low investment in irrigation infrastructure, in all of the irrigation systems studied water is supplied by a combination of concrete-lined canals (primary and sometimes secondary canals) and in-field earthen channels. This makes it difficult and very expensive to measure the exact amount of water applied to a crop throughout the growing season. Makadho (1994; 1996) reports attempts at measuring the amount of water applied to irrigated crops using partial flumes but, at best, estimated the amount of water applied to a block of plots. Further, the method used in the studies by Makadho works better where canals are lined, a rare case at plot level in smallholder irrigation systems. Given these limitations, the number of times a crop is irrigated during the season is used as a rough proxy for the amount of water applied to crops. Makombe et al. (2001) also used number of irrigations as a rough proxy for water applied when they estimated the technical efficiency of irrigated production in Zimbabwe.

Kumbhakar and Knox Lovell (2000) argue that where the stochastic frontier production function approach is used to estimate the technical efficiency of a multiple output production system, separate distance functions should be estimated for each output or crop in this case. However, the nature of the data of smallholder producers discussed above precludes this approach.

Of importance in using the stochastic frontier production function approach is the choice of functional form. After initially specifying the model as the general form of the translog, we test whether each of the four equations, namely traditional and modern irrigation, rainfed with access to irrigation and rainfed without access to irrigation, can be reduced to the Cobb Douglas specification by restricting the coefficients of the square and the interaction terms to be jointly equal to zero. The result is $F[15, 108] = 3.25$ ($p = 0.000$) and $F[15, 259] = 3.66$ ($p = 0.000$) for the traditional and modern scheme equations, respectively, and so we conclude that both equations do not reduce to a Cobb Douglas specification. We then test whether we can pool the two irrigated seasonal crop samples into one sample by restricting the traditional scheme equation by the coefficients of the modern scheme equation $F[21,108] = 5.04$ ($p = 0.000$) and vice versa $F[21,259] = 21.28$ ($p = 0.000$). We conclude that the two cannot be pooled.

Further, we also test whether the two rainfed samples, the sample from farmers with access to irrigation and that from farmers without access to irrigation, can be reduced to the Cobb Douglas specification by following the same procedure as above. The result is $F[10, 415] = 6.25$ ($p = 0.000$) and $F[10, 342] = 6.98$ ($p = 0.000$) for the rainfed equation of farmers with access to irrigation and for those without access to irrigation, respectively. We conclude that both equations do not reduce to a Cobb Douglas specification. We then test whether the two samples could be pooled by restricting the equation of the farmers who do not have access to irrigation by the coefficients of that of the farmers who have access to irrigation $F[15,336] = 3.70$ ($p = 0.000$) and vice versa $F[15,419] = 81.07$ ($p = 0.000$). We conclude that the samples come from different populations and cannot be pooled.

Compared to the seasonal crops, the area under perennial crops was not easy to estimate, because sometimes a farmer can earn significant income from a few perennial tree crops that are standing in isolation or only take up an insignificant portion of the area under seasonal crops. The equation for the perennial crops is therefore specified as a simple Cobb Douglas functional form and is estimated for irrigated and rainfed without the distinctions made for the seasonal crops. The results for the perennial crops are therefore, at best, indicative. However, because of the potential of the perennial crops, we do feel that it is essential to report these indicative results.

The estimation of the stochastic frontier production function can be done as a one- or two-step procedure. In the two-step procedure the output, for example, yield *(y)*, is regressed against the inputs *(x's)*, and in the second step the estimated inefficiencies are regressed against a set of exogenous variables that affect inefficiency, the *z's*. Wang and Schmidt (2002) observe that it has been recognized that the two-step procedure gives biased estimates due to misspecification bias in the first step, a bias substantial enough to strongly argue against the two-step estimation procedure.

The model for the one-step estimation can be specified as:

$$Y = f(x)\ TE(x;z) \quad (4)$$

where:

x = the vector of inputs to produce output Y

$TE(x;z)$ = the output-oriented measure of technical inefficiency, and

z = the vector of explanatory variables associated with the technical inefficiency (Batesse and Coelli, 1988, 1995)

In this study the vector of *z's* constituted the age of the farmer, the gender of the farmer, the farmer's education (a dummy variable for the categories less than or equal to 5 years of education = 0; more than 5 years of education = 1) and whether the farmer had extension contact (farmer had no extension contact = 0; farmer had extension contact = 1). There is considerable debate about what should constitute the *z's*. Nisrane et al. (2011), in addition to similar variables that we use, also include variables like distance to market and distance to health facility as part of the *z's*. We argue that, given the structure of our data and the aggregation to farm level, the *z's* should constitute those variables that directly affect farmer access to resources and decision making.

We can also test whether the variance of u_i in Eq. 2 is equal to zero. If the variance of u_i is equal to zero this means that $u_i = 0$ and thus production lies on the frontier. This means that production is technically efficient and deviations from the frontier are a result of a combination of favourable and unfavourable external shocks out of the farms' control, and errors of measurement.

Maximum likelihood is used to estimate the parameters for Eq. 1 and to estimate the variance parameter given by:

$$\sigma^2 = \sigma^2_v + \sigma^2_u \quad (5)$$

and

$$\gamma = \sigma^2_u / \sigma^2 \quad (6)$$

The likelihood ratio (LR) test, with a mixed chi-square distribution as described by Kodde and Palm (1986), is used to test the null hypothesis that $\gamma = 0$ and hence $e_i = v_i$. Kodde and Palm (1986) provide the critical limits of the mixed chi-squared test for testing this hypothesis. If the computed LR statistic is above the critical limit, given the degrees of freedom and the significance level *(α),* then we reject the null; otherwise we fail to reject it. From this test, if we fail to reject the null hypothesis that $\gamma = 0$, this implies that there are no inefficiency effects ($u_i = 0$) which means that the model can be efficiently estimated using OLS (Battesse and Coelli, 1995). Lokina (2008) used the one-step estimation approach to estimate the technical efficiency of fisheries in Lake Victoria, Tanzania.

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Data collection and descriptive statistics

Simple random samples of farmers were selected from lists of farmers from 4 traditional and 7 modern smallholder irrigation schemes. From each irrigation site the target sample was 50 farmers. Additionally, simple random samples of 50 rainfed farmers were selected from lists of farmers from villages in close proximity to the irrigation schemes as a control. In cases where the modern and traditional sites were close to each other, only one control sample was selected. This resulted in an effective sample of 122 from the traditional irrigated sites, 281 from the modern communal irrigated sites and 350 from the control rainfed sites of farmers without access to irrigation. As mentioned earlier, for those sampled farmers from both traditional and modern communal irrigated sites who had rainfed farms, data were also collected from their rainfed farms, resulting in a sample of 434 farms, which we called 'rainfed with access to irrigation'. For the irrigated and rainfed samples, data were collected for both perennial and seasonal crops. The resultant sample size for farms with perennial crops was 105 for irrigated perennial and 65 for rainfed perennial. Figure 1 shows the location of the sample sites.

Plot-level data were collected during the growing season from May 2005 to March 2006. Data were collected on cropping patterns, area planted, number of irrigations, labour, oxen days (number of days oxen were used for land preparation), fertilizer use and the use of other inputs like herbicides, insecticides and fungicides.

The gross value of output was estimated in the local Ethiopian currency (the ETB) using farm gate prices and production estimated in quintals. The quintal is a measure that is commonly used by smallholder farmers in Ethiopia with a conversion factor of 1 quintal = 100 kg (Seyoum et al., 1998).

Table 1 summarizes the descriptive statistics for the systems under study. The average cropped area for the traditional scheme is 0.5 ha while that of the modern schemes is slightly higher at 0.63 ha. Cropped area for the rainfed systems averaged 0.94 ha and 1.2 ha for farmers with access to irrigation and those without access, respectively. The small areas cropped by farmers suggest that land is a limiting factor in the production system. Nisrane et al. (2011) also observed that land is a limiting factor in Ethiopia. The average productivity of land, assuming constant returns to scale, is 4 076, 3 857, 1 964 and 1 673 ETB/ha for the traditional irrigated, modern irrigated, rainfed crops for farmers with access to irrigation and rainfed crops for farmers without access to irrigation, respectively. Labour use per ha is slightly lower for the modern than for the traditional schemes while the modern schemes appear to irrigate their crops more than the traditional schemes. The use of oxen days is quite comparable across all the systems but is slightly lower for the rainfed systems compared to the irrigated systems on a per ha basis. Farmers believe that good land preparation is essential for a good crop and invest considerable time in the process of land preparation.

The areas for the perennial crops are also comparable for farmers with access to irrigation and for those without. It is not clear why the irrigated perennial crops require more labour, but this may be associated with labour for irrigation. The average productivities of land are 4 660 and 3 712 ETB per ha for the irrigated and rainfed perennial crops, respectively. Although indicative, these results show the perennial crops could play a

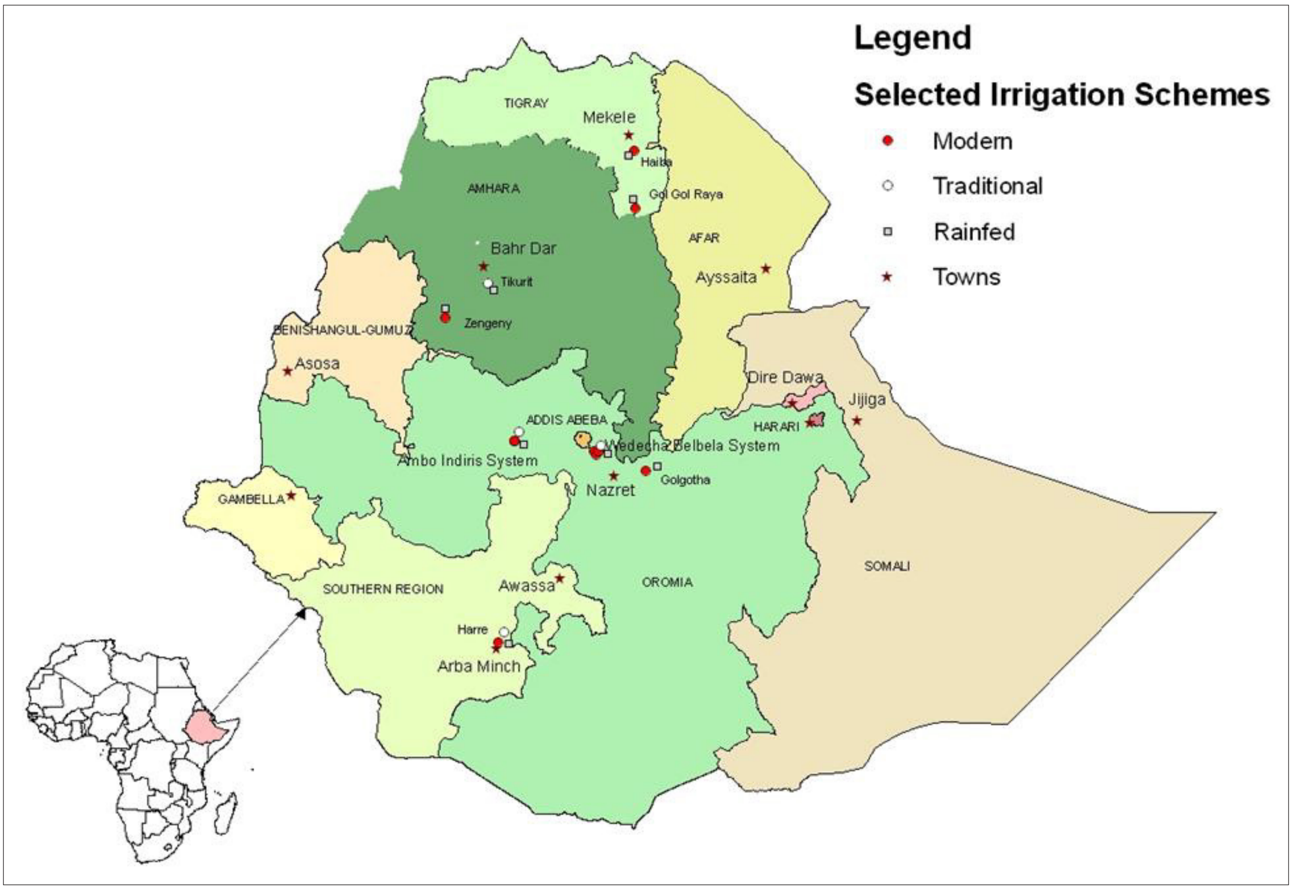

Figure 1

Location of 'traditional irrigated, 'modern irrigated' and 'rainfed' sample sites

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significant role in increasing farm incomes together with the rainfed seasonal crops.

Compost was applied to 12% of irrigated plots and 5% of rainfed plots. Compost is important because it restores organic matter in the soil especially in the Ethiopian farming system where 'traditional cereal farming is not only low-yielding but also results in the mining of plant nutrients from the soil. After harvest, traditional farmers remove the stalks and the leaves, and sometimes even the maize stumps and roots, for feed, fuel and building materials. These practices leave no crop residue to restore soil nutrients and organic matter' (Seyoum et al., 1998 p. 342).

Less than 11% of the irrigated plots, and less than 3% of rainfed plots, received herbicide, fungicide or any form of insecticide. Makombe et al. (2007) report slightly higher use of pesticides. However, this may have been a site-specific result linked to presence or absence of support service for inputs. The current study covers more sites with different characteristics than that of the Makombe et al. (2007) study, which looked at 3 modern small-scale irrigation systems. Based on these statistics, in the model we used a dummy variable for the use of compost.

Frontier Version 4.1 was used to estimate the stochastic frontier production functions (Coelli, 1996). In this study, for the estimation of the equations to estimate technical efficiency, 8 outliers were omitted. The residuals of these observations were outside 2 standard deviations and resulted in an incorrect skewness, giving an indication of a cost rather than a production relationship. The program Frontier also requires that there be no missing values in the data matrix so after meeting this condition the effective samples for the estimation of the stochastic production functions were reduced to 109 for the irrigated traditional sample, 248 for the modern irrigated sample and 319 for the rainfed control. The rainfed sample which has access to irrigation was reduced to 390. The rainfed perennial sample reduced to 60 while the irrigated perennial sample reduced to 99. This was mainly a result of missing values in the *z*'s, especially farmer's age, where some farmers simply could not remember their age, and in some cases where farmers were reluctant to give their level of education.

RESULTS AND DISCUSSION

We tested the null hypothesis that $\gamma = 0$, meaning the equation can be estimated a OLS, for each of the estimated stochastic frontier production functions. The results of this test are presented in Table 2. Table 2 shows that for the traditional irrigated sample, the rainfed sample which has access to irrigation and the rainfed perennial, we fail to reject the null hypothesis (H_0) that $\gamma = 0$. Hence we conclude that these farmers are technically efficient and are producing on the frontier, and that deviations from the frontier are a result of a combination of favourable and unfavourable external shocks out of the farms' control, and errors of measurement. Bogale and Bogale (2005) reached a similar conclusion when they estimated the technical efficiency of traditional irrigated smallholder potato farmers in the Awi zone of Ethiopia to be 97%.

However, as shown in Table 2, we reject the null hypothesis that $\gamma = 0$ for irrigated communal modern, rainfed without access to irrigation, and irrigated perennial. For these equations, the stochastic frontier production functions, including the inefficiency effects, are estimated in a one-step model. We also observe that, since for the traditional irrigation sample we fail to reject the null hypothesis that $\gamma = 0$, yet we reject it for the communal modern irrigation sample, this is further evidence supporting the conclusion reached in the test for pooling that these two samples come from different populations. The same observation also applies to the two rainfed samples.

The estimated stochastic frontier production functions are summarized in Table 3. Accordingly, as a result of the conclusions from functional form tests, the coefficients reported in Table 3 for the traditional irrigated, rainfed which has access to irrigation, and rainfed perennial equations are based on OLS estimates whereas the rest are based on stochastic frontier estimates.

In order to compare the frontiers for the different production systems, we evaluate them at the means of the estimated regression equations. These are evaluated from the log likelihood functions in the log form and then the exponent is taken to get the input levels. Based on this evaluation, Table 4 shows that the

TABLE 1
Descriptive statistics for the different production systems (x's)

Variable	Mean values by system type*					
	Irrigated		**Rainfed**		**Perennial**	
	Traditional $N = 122$	Communal modern $N = 281$	Has access to irrigation $N = 434$	No access to irrigation $N = 351$	Irrigated $N = 105$	Rainfed $N = 65$
Gross value of output (ETB)	2 038 (2 820) [4 076]	2 430 (2 820) [3 857]	1 846 (1 683) [1 964]	2 008 (2 218) [1 673]	1 771 (2 487) [4 660]	928 (1 228) [3 712]
Area (ha)	0.5 (0.4)	0.63 (0.56)	0.94 (0.74)	1.2 (0.94)	0.38 (0.34)	0.25 (0.22)
Fertilizer (kg)	65 (70)	57 (83)	77 (97)	39 (81)	N/A	N/A
Irrigations (No)	3 (3)	6 (7)	N/A	N/A	N/A	N/A
Labour (man-days)	25 (24) [50]	26 (23) [41]	28 (23) [30]	32 (23) [27]	31 (25) [66]	10 (13) [40]
Oxen (days)	4 (4) [8]	5 (5) [8]	6 (5) [6]	7 (6) [7]	N/A	N/A

**( ) = sdev, [ ] = per ha*

traditional irrigated system requires 0.4 ha, 16 days of labour, 2 irrigations and 2 oxen days to produce a gross value of output of 1 254 ETB. This compares to 0.53 ha, 23 labour days, 3 irrigations and 3 oxen days needed to produce 2 857 ETB of gross output for the communal modern irrigation schemes. Because of the limited use of fertilizer in the production systems, the frontier production function does not include fertilizer.

In Table 4 the figures in bold are the average productivities for the respective inputs, assuming constant returns to scale. For the seasonal crops, the highest average productivity for land is on the communal modern irrigation systems with 5 361 ETB, followed by the traditional irrigation system at 3 129 ETB, and then rainfed crops from farmers without access to irrigation and those who have access to irrigation at 2 748 and 1 849 ETB, respectively.

An inspection of input productivities for the seasonal crop (Table 4) shows that the communal modern irrigated system is a higher frontier than the other three seasonal cropping systems. Using the first derivatives of the equations in Table 3 we compute the marginal productivities of the inputs. The marginal productivity of land is highest for the communal modern irrigation system at 2 137 ETB followed by the rainfed without access to irrigation at 1 056 ETB, the traditional irrigated system at 660 ETB and then the rainfed system with access to irrigation at 625 ETB. The marginal productivity of land in the 'rainfed with access to irrigation' system is lower than that of 'rainfed without access to irrigation'. It is possible farmers with access to irrigation pay more attention to the irrigated plot than the rainfed plot. The marginal productivity of land on the traditional irrigated plot is lower than that of 'rainfed without access to irrigation' but higher than that of 'rainfed with access to irrigation'. This means that if an additional unit of land were to be introduced, it should be put under communal modern irrigation, followed by rainfed production without access to irrigation, before it is put under traditional irrigation. This shows that there are significant gains to shifting the frontier of the traditional irrigated system towards that of the modern irrigated system.

In order to shift the frontier of the traditional irrigated system, there is a need for technological change in the production system. An example of this could be the effective introduction of the use of chemical fertilizer which is hardly used in all the seasonal cropping systems. Based on average productivity of land the gain of shifting the traditional irrigated frontier to that of the communal modern irrigated system is potentially 2 232 ETB per hectare.

For the perennial crops the productivities of both inputs are higher for the irrigated than the rainfed. It is not clear why the irrigated systems requires so much more labour but this may be related to labour associated with irrigation and the possibility of more labour that may be required for harvesting. The average and marginal productivities for the perennials show that the irrigated perennials have a higher frontier. The high marginal productivities for labour may be a reflection of the fact that more labour could be invested in the perennials, or a reflection of potential missing variables or both. As mentioned earlier these results of perennial crops are, at best, indicative, but show the potential, especially of irrigated perennials, to contribute towards improving input productivities and therefore income to farmers.

The average technical efficiency for the communal modern irrigation schemes is 71%. This is similar to that of 77% found by Bogale and Bogale for modern smallholder irrigating potato farmers in the Awi zone of Ethiopia. This technical efficiency level shows that there is room for improving the technical efficiency of the communal modern irrigation systems. The high technical efficiency of the traditional schemes is consistent with the results reported by Seyoum et al. (1998). The technical efficiency results of the traditional irrigated system remind us of the Schultz (1964) 'efficient but poor' farmer hypothesis.

TABLE 2
Test of functional form for stochastic frontier production functions

Equation	Log likelihood	LR statistic	Decision[†]
Irrigated traditional	−94.48 (−95.00)[‡]	1.03	Fail to reject H_0
Irrigated communal modern	−298.91	18.48	Reject H_0
Rainfed access to irrigation	−403.74 (−408.63)	9.78	Fail to reject H_0
Rainfed no access to irrigation	−295.43	24.9	Reject H_0
Irrigated perennial	−144.60	27.26	Reject H_0
Rainfed perennial	−70.18 (−70.45)	0.87	Fail to reject H_0

[†]*The critical value for the mixed chi -square distribution for 6 degrees of freedom and α = 0.5 = 11.91 (Kodde and Palm, 1986).*
[‡]*Parentheses show log likelihood for OLS estimate in the cases where we fail to reject the null hypothesis.*

The technical efficiency of the rainfed systems with no access to irrigation is estimated at 78%, also showing that there is still room to improve its technical efficiency. The estimated level of technical efficiency for the rainfed system without access to irrigation, coupled with the high marginal return to land in this system, which is second to the communal modern irrigated system, suggests that, although in Ethiopia it is essential to develop the modern irrigation system in order to delink the economy from the vagaries of nature which result from variations in rainfall, the rainfed production system should not be ignored in the agricultural development strategy. It is therefore essential for the Government to take a two-pronged approach in which both irrigated and rainfed production systems are developed simultaneously. The technical efficiency of the irrigated perennial system is estimated at 13%, showing great potential for improvement, but once again this estimate has to be taken as indicative but provides the argument for conducting a more accurate study, possibly focusing entirely on estimating the potential for perennial crops to contribute towards farmer's incomes.

Makombe et al. (2011) report the results of inefficiency estimates from the same dataset as the one used in this paper but using the two-step procedure. Consistent with the results reported in this paper, they conclude that the modern irrigation system has the highest frontier and that the traditional irrigated system has a very low inefficiency. However, the rest of the results are not consistent with those reported in this paper, thus possibly providing evidence in support of the use of the one-step procedure.

Kalirajan and Shand (1986) argue that, in addition to the average estimates of technical efficiency, from a policy perspective it is essential to analyse the technical efficiency of individual farmers. Following their example, we report the technical efficiency of farmers from the communal modern irrigated and rainfed farmers without access to irrigation in the form of a frequency distribution. Table 5 summarizes these results.

Slightly more that 40% of the farmers in the communal modern irrigation scheme are in the technical inefficiency range

TABLE 3
Stochastic frontier production function estimates for seasonal and perennial crops

Frontier production function equation coefficients by system type

Variable	Irrigated seasonal		Rainfed seasonal		Perennial	
	Traditional *N* = 109	Communal Modern *N* = 248	With access to irrigation *N* = 390	Without access to irrigation *N* = 319	Irrigated *N* = 99	Rainfed *N* = 60
Constant	5.1570*** 6.224	7.2757*** 12.893	4.9808*** 16.093	6.2610*** 15.114	9.0068** 2.753	6.2881*** 19.182
LnA	0.3294 0.694	0.8447*** 2.855	0.4334** 2.398	0.1601 0.803	0.4292*** 3.681	0.2764* 1.846
LnF	0.2455*** 3.540	0.1433*** 3.772	0.2172*** 8.696	0.1693*** 6.765	N/A	N/A
LnI	0.0025 0.021	0.0753 0.810	N/A	N/A	N/A	N/A
LnL	0.5274 1.125	−0.3508 −1.110	0.5627*** 2.956	0.2130 0.828	0.3228*** 3.325	0.3206*** 3.461
LnOx	−0.2271 −0.961	0.0806 0.459	−0.3237*** −3.318	−0.0492 −0.461	N/A	N/A
LnA_SQ	0.1880* 1.983	0.0327 0.680	0.0127*** 0.339	−0.1397*** 2.700	N/A	N/A
LnF_SQ	0.0249** 2.071	0.0348*** 5.035	0.0373*** 6.573	0.0294*** 5.100	N/A	N/A
LnI_SQ	−0.0136* 1.670	−0.0053 −0.755	N/A	N/A	N/A	N/A
LnL_SQ	−0.0278 −0.374	0.0734 1.519	−0.0634** 2.038	−0.0089 −0.223	N/A	N/A
LnOx_SQ	−0.0261* 1.866	−0.0076 −0.702	−0.0195** −2.220	−0.0054 −0.604	N/A	N/A
Ln(AxF)	−0.0187 −0.849	−0.0177 −1.155	−0.0137 −1.457	−0.0166* −1.741	N/A	N/A
Ln(AxI)	−0.0039 −0.106	0.0537** 2.132	N/A	N/A	N/A	N/A
Ln(AxL)	0.1389 1.045	−0.1679** −2.014	−0.0155 −0.265	0.1081* 1.669	N/A	N/A
Ln(AxOx)	−0.2183** 2.183	0.0747* 1.959	−0.0238 −0.631	−0.0044 −0.121	N/A	N/A
Ln(FxI)	−0.0194 −1.432	−0.0071 −1.366	N/A	N/A	N/A	N/A
Ln(FxL)	−0.0386* −1.925	−0.0029 −0.275	−0.0334*** −4.281	−0.0208 −2.250**	N/A	N/A
Ln(FxOx)	0.0156 0.932	−0.0035 −0.480	0.1425** 2.286	0.3531 0.418	N/A	N/A
Ln(IxL)	0.0222 0.547	−0.0104 −0.327	N/A	N/A	N/A	N/A
Ln(IxOx)	−0.0264 −1.033	0.0230** 2.070	N/A	N/A	N/A	N/A
Ln(LxOx)	−0.0558 1.027	−0.0208 −0.463	0.1006*** 3.668	0.0162 0.550	N/A	N/A
Compost Dummy	1.0384 3.418***	0.2204 1.212	3.668*** 2.788	0.2194 1.828*	N/A	N/A
Z's						
Constant	N/A	−0.2047 −0.940	N/A	0.8453 1.518	0.0216*** 4.712	N/A
Age	N/A	0.1541 1.084	N/A	−0.1216** −2.183	0.0196** 2.132	N/A
Sex	N/A	6.0422 0.921	N/A	0.0138** 2.560	1.6356** 2.598	N/A
Education	N/A	2.1334 0.908	N/A	−0.0324** −2.009	−0.4208 −1.240	N/A
Extension	N/A	3.2985 1.033	N/A	0.2592 0.741	−0.744** −2.940	N/A
σ^2	0.4192	0.5.1246 1.108	0.4964	1.7148*** 3.164	1.2184*** 5.447	0.6452
Γ	N/A	0.9070*** 9.744	N/A	0.8356*** 14.615	0.1000*** 4.747	N/A

**significant at α = 0.1*
***significant at α = 0.05*
****significant at α = 0.01*

TABLE 4
Frontier production function input levels, average and marginal productivities (ETB)

Input	Level by scheme type					
	Irrigated seasonal		Rainfed seasonal		Perennial	
	Traditional seasonal	Communal modern seasonal	Has access to irrigation	No access to irrigation	Irrigated perennial	Rainfed perennial
Gross value of output (ETB)	1 254	2 857	1 600	2 743	11 606	592
Area (ha)	0.40 **3 129** [660]	0.53 **5 361** [2137]	0.87 **1 849** [625]	1.11 **2 748** [1056]	0.22 **53 627** [4011]	0.20 **2 895** [80]
Fertilizer (kg)	3 N/A N/A	1 N/A N/A	1 N/A N/A	0 N/A N/A	N/A	N/A
Irrigation (number)	2 **627** [18]	3 **952** [24]	N/A	N/A	N/A	N/A
Labour (man-days)	16 **78** [19]	23 **122** [23]	28 **58** [17]	40 **69** [16]	23 **509** [11348]	5 **115** [341]
Oxen (days)	2 **660** [116]	3 **1102** [-28]	5 **334** [-15]	5 **557** [11]	N/A	N/A

Bold = average productivity
[ ] = marginal productivity

TABLE 5
Frequency distribution (%) of technical efficiency for 'rainfed with no access to irrigation' and 'modern communal irrigation' farmers. The distributions are statistically significantly different.

Technical efficiency interval	System type	
	Rainfed without access to irrigation	Irrigated modern communal
≥ 10 < 20	0	0.8
≥ 20 < 30	0	0
≥ 30 < 40	0.3	1.6
≥ 40 < 50	0.3	3.6
≥ 50 < 60	3.8	9.3
≥ 60 < 70	9.4	21.0
≥ 70 < 80	29.5	40.3
≥ 80 < 90	53.0	23.0
≥ 90 < 100	3.1	0.4
Total	**100**	**100**
N	**319**	**248**

of 70 to 80%, whereas 53% of the farmers from the 'rainfed without access to irrigation' system are in the range of 80 to 90%. From the two technical efficiency distributions we can conclude that, although their frontiers are different, more farmers from the 'rainfed without access to irrigation' systems are closer to their frontier than the farmers from the modern communal irrigation system. In a study from Malaysia, Kalirajan and Shand (1986) reached a similar conclusion when they compared rice farmers in the Kemubu irrigation scheme and the rainfed farmers outside the scheme. This maybe a result of the fact that the frontier of the irrigated system is higher than that of the rainfed system. However, it is possible to improve the distribution of the irrigated farmers to be closer to their frontier, for example, through effective extension messages pertinent to irrigation and especially regarding water management. On the irrigation schemes there is no attempt to measure the amount of water applied so as to make efficient use of this scarce resource.

Although based on the LR test we conclude that for the communal modern irrigated seasonal cropping system the variance of the technical efficiency effects is not zero; all the coefficients are not significant. However, all the efficiency effects have the expected signs, namely, higher efficiency for the older farmers who have more experience with irrigation, higher efficiency for the male farmers who have more resources than females, higher efficiency for the more educated farmers, and higher efficiency for the farmers with extension contact. From the equation for the rainfed system without access to irrigation (the control sample), age and sex are significant and have the expected signs. Extension is significant but has an unexpected sign. It is possible that even if the rainfed farmers have extension contact, they may be failing to translate this to actual production. Although not significant, the sign for education is also unexpected. Again it is possible that the more educated farmers, who have greater ability to understand and therefore translate extension messages to production, may not entirely depend on rainfed production. Although these are possible explanations for the unexpected signs, it is essential to clearly establish the relationships between extension contact, farmer education and extension.

CONCLUSION

This study analyses the productivity and technical efficiency of two irrigated systems in Ethiopia, namely, communal modern irrigated and traditional irrigated systems, and compares the irrigated systems with rainfed systems, namely, rainfed farmers with access to irrigation and rainfed farmers without access to irrigation. We use the stochastic frontier production for the analysis.

The average productivity of land is highest on the communal modern irrigated system, followed by the traditional system, and rainfed systems without access to irrigation, while rainfed systems with access to irrigation come last. The benefit of raising the production function of the traditional to that of the communal modern irrigated systems is very high. Given the differences

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in the productivities of inputs between the communal modern and traditional systems, we recommend that the existing traditional irrigation systems be upgraded to communal modern schemes, before or concurrently with new small-scale irrigation development. The gains from both upgrading traditional systems to communal modern systems and that of new irrigation development can be better achieved if extension recommendations directly pertinent to irrigated production are made easily available to farmers.

The marginal productivity of land is highest in the communal modern irrigated system. However, the marginal productivity of land in the 'rainfed without access to irrigation' system is higher than that of the traditional irrigation system. Since the costs of developing an additional hectare of rainfed production are expected to be much lower than the costs of developing an additional hectare of traditional irrigated production, given the investment necessary to develop traditional irrigated production, an additional unit of land should be put under 'rainfed without access to irrigation' before it is put under the traditional irrigated system. This indicates that it is essential not to ignore the development of rainfed production in the agricultural development strategy.

The average technical efficiency for the communal modern irrigated system was estimated to be about 71%. The technical efficiency of the rainfed system without access to irrigation was estimated to be 78%. This shows that there are potential gains to be had from improving efficiency in these two systems. There are no gains to be had in improving the efficiency of the traditional irrigated system and the rainfed system with access to irrigation, as these farmers are efficient and producing on their respective frontiers. Although the communal modern irrigated system and the 'rainfed without access to irrigation' systems can also benefit from technical change, only technical change can shift the production frontiers for the two systems estimated to be efficient.

Although the production frontier for the traditional irrigated system is lower than that of the communal modern irrigated system, it is essential to study what makes the technical efficiency of the traditional irrigation systems higher compared to that of communal modern systems and to establish whether it is possible to apply the practices that achieve this high technical efficiency so that the communal modern irrigation systems can achieve the same. The same argument applies to the differences in technical efficiency between 'rainfed with access to irrigation' and 'rainfed without access to irrigation'. Finally we conclude that the agricultural development strategy should take a two-pronged approach: namely, to develop irrigation systems, especially the modern irrigated system, to take advantage of the high average and marginal returns to land, while also developing the rainfed system to take advantage of the high marginal returns to land evident in this system. An increase in the technical efficiency in the communal modern irrigated and purely rainfed system could also bring significant gains.

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