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WORKING PAPER 143

A Comparative Analysis of the Technical Efficiency of Rain-fed and Smallholder Irrigation in Ethiopia

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Collaborators

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Contents

Summary

Agriculture is the most significant contributor to Ethiopia's national economy. The Government of Ethiopia uses agriculture-led industrial development to spearhead the country's development program. Irrigation development is seen as one of the major contributors to the development process. It is, therefore, essential to study the performance of existing irrigation systems in order to become informed about this development process.

We used the stochastic frontier production function approach to estimate the production frontiers and technical inefficiency of four different production systems; namely rain-fed production for purely rain-fed farmers (n = 351), rain-fed production for farmers with access to irrigation (n = 434), traditional (n = 122) and modern (n = 281) irrigation systems. The data used for the estimations were collected from random samples of farmers from each of the systems for the 2005/2006 production season. The results showed that the traditional irrigation farmers are producing on a lower production frontier than the modern irrigation scheme farmers. It was also seen that the traditional scheme farmers have lower technical inefficiencies than the modern scheme farmers.

The stochastic frontier production function shows that the production frontier for the rain-fed system of farmers with access to irrigation is higher than that of rain-fed farmers without access to irrigation. We hypothesize that there may be some resource transfers by using the cash generated from irrigated farms to intensify rain-fed production through the acquisition of fertilizer, herbicides and other inputs. The gains from such a shift in intensification may be more cost-effective than the gains that may accrue from irrigation since such a shift most likely will not involve the initial capital outlay as is usually required by irrigation and since such gains have the capacity to affect many of the rain-fed farmers. The only disadvantage is that this approach does not 'de-link' the performance of the economy from rainfall variability.

We explored some socioeconomic factors that are associated with technical inefficiency for the different systems. We found that the age of the household head was significantly associated with the level of technical inefficiency in the purely rain-fed and modern irrigation systems. We also found that gender and extension were significantly associated with the levels of technical inefficiency. The analysis of constraints showed that soil fertility, weed control, pest and diseases control, soil erosion, input access and moisture deficiency are significantly associated with levels of technical inefficiency for rain-fed farmers. This analysis showed that identifying the socioeconomic variables that impact technical inefficiency, (e.g., extension) and alleviating the constraints associated with them can improve rain-fed production. This result is consistent with the conclusion from the stochastic frontier production function analysis.

Based on these findings, we conclude that the Government of Ethiopia should take a two-pronged approach, i.e., developing irrigation while not ignoring the potential gains to be made from improving rain-fed production.

We computed the gross margins for the different systems. We observed that the higher frontier for the rain-fed farmers with access to irrigation did not result in higher gross margins when compared to the lower production frontier for the purely rain-fed farmers, since the statistics of the average gross margins were not significantly different between the two samples. We also observed that the same applied to the irrigation systems, because the higher frontier for the modern irrigation systems did not also translate into higher gross margins than the lower frontier for the traditional irrigation farmers. We conclude that it is important to investigate what constraints cause the higher

frontiers not to translate into higher gross margins. The results suggest that the farmers on the higher frontier may be making poor allocative decisions and thus achieving the same gross margins as farmers on a lower frontier. Identifying and addressing such constraints can lead to more viable rain-fed and irrigated production.

Finally, we note that most of the findings from this paper suggest that irrigation could be used as a viable development strategy. However, the results in this paper are based on one year's data. In order to improve the robustness of the results it is important to collect exactly the same data from exactly the same sample for two or three seasons.

BACKGROUND

Agriculture is the most significant contributor to Ethiopia's national economy (World Bank 2006). National Accounts Statistics of Ethiopia show that over the period 1996 to 2006, agriculture contributed more than 44% to gross domestic product (GDP) while crop production alone contributed 26% over the same period (Government of the Republic of Ethiopia 2006). The World Bank (2006) notes that: "The dominant agricultural system in Ethiopia is smallholder production of cereals under rain-fed conditions, with a total area of approximately 10 million hectares." The same report shows that Ethiopia's GDP growth is highly correlated to rainfall variations. In Figure 1, the strong positive correlation between growth in GDP as well as per capita GDP and in agriculture and crop production further demonstrates the importance of agriculture to the Ethiopian national economy. When agriculture, in general, and crop production, in particular, perform well, GDP and, hence, the economy also tend to perform well and vice versa as shown in Figure 1. When crop production, which is largely based on rain-fed production, performs well, the quality of the rainfall season is good and vice versa. Figure 1, therefore, clearly demonstrates that the performance of the economy, as estimated by the GDP growth, depends on the quality of the rainfall season because of the GDP's dependence on agriculture, in general, and specifically on crop production.

Agriculture employs 80% of the labor force while 85% of the population, which currently is approaching nearly 80 million, depends on agriculture for a living and live in rural areas (Awulachew 2006; UNDP 2006). As noted by the World Bank (2006) report: "The very structure of the Ethiopian economy with its heavy reliance on rain-fed subsistence agriculture makes it particularly vulnerable to hydrological variability. Its current extremely low levels of hydraulic infrastructure and limited water resources management capacity undermine attempts to manage variability. These circumstances leave Ethiopia's economic performance virtually hostage to its hydrology." UNDP (2006) notes that failed rains will send shock waves beyond the household to the entire economy. It is estimated that in Ethiopia, one drought event in 12 years lowers GDP by 7 to 10% and increases poverty by 12 to 14%. The World Bank estimates that the inability of Ethiopia to reduce the impact of rainfall variability results in a one-third reduction in Ethiopia's potential for economic growth (UNDP 2006). This situation makes it imperative for development efforts in Ethiopia to 'de-link' the performance of the economy from rainfall variations.

World Bank (2006) recommends major investments in water resources infrastructure as one possible mechanism to 'de-link' Ethiopia's economic performance from rainfall, and thus enable

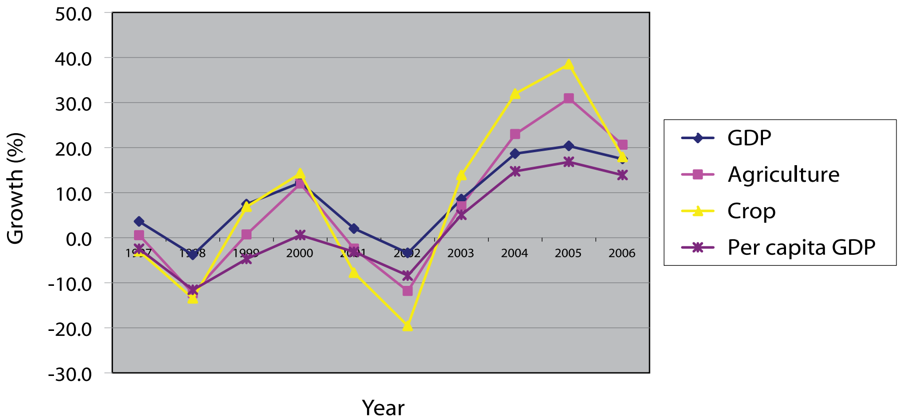

FIGURE 1. GDP, agriculture, crop production and per capita GDP growth 1997–2006. *Source*: Based on data from Government of the Republic of Ethiopia (2006).

sustained growth. Ethiopia has ample water resources that could be developed, for example, by developing storage facilities. Even though it has uneven spatial and temporal distribution, resulting in droughts in some parts of the country, it is estimated that Ethiopia has more than 122 billion cubic meters (BCM) of surface runoff from 12 river basins, not considering groundwater (Government of the Republic of Ethiopia 1999). This amounts to a per capita water availability of about 1,644 cubic meters (m^3), which makes Ethiopia a water-abundant country (UNDP 2006). The United States stores 6,000 m^3 of water per person, Australia 5,000 m^3, while Ethiopia stores only 43 m^3 per person. While water use in Ethiopia is estimated to be about 30 liters per person per day (l/person/day), it is more than 150 l/per person/per day in the UK and Brazil and stands at more than 550 l/per person/per day in the USA (UNDP 2006). This means that in Ethiopia there is potential for developing water facilities, for instance, storage, that could be used for multiple purposes, including irrigation. Estimates of irrigable land in Ethiopia vary between 1.5 and 4.3 million hectares (Mha), depending on the assessment criteria used, with about 3.5 Mha generally agreed as the accurate estimate (Werfring 2004; Awulachew et al. 2005; Government of the Republic of Ethiopia 2001a; World Bank 2006; Makombe et al. 2007). Makombe et al. (2007) highlight the Ethiopian paradox, where in spite of the combination of having potentially irrigable land and an abundance of surface runoff that has earned the country the nickname 'The water tower of Africa', 52% of the population is considered food insecure (Kassahun 2007) and the country annually received about 750,000 metric tonnes (Mt) of food aid to feed about 5.5 million people (or 10% of its population) between 1998 and 2004 (Government of the Republic of Ethiopia 1998-2004). The Government of Ethiopia believes that irrigation development, as a component of an agriculture-led development program, can contribute to solving this paradox by playing a major role in the country's economic development program (Government of the Republic of Ethiopia 2003). Given the high dependence of Ethiopia's economy on agriculture, and the availability of both water resources and irrigable land, it is surprising that less than 5% of the country's irrigable land has been developed for irrigation (World Bank 2006; Makombe et al. 2007).

The anticipated role that irrigation could play in the economic development strategy is stated in the water sector strategy as follows, "Irrigation development is key to the sustainable and reliable agricultural development, and thus for the overall development of the country. In order to ensure food security at the household level for Ethiopia's fast growing population, more small-, medium- and large-scale irrigation infrastructure needs to be developed. Such development could also generate an externally marketable surplus that would earn the much needed foreign exchange and provide the required raw material to the local industries." (Government of the Republic of Ethiopia 2001b).

Irrigation development in Ethiopia is classified in two ways. The first classification uses the size of the command area as follows:

1. Small-scale irrigation systems (<200 hectares (ha))
2. Medium-scale irrigation systems (200-3,000 ha)
3. Large-scale irrigation systems (>3,000 ha)

According to this classification, 46% of proposed irrigation development is in the small-scale irrigation category (Table 1).

The second classification uses a mix of the history of establishment, time of establishment, management system and nature of the structures as follows:

1. Traditional schemes: These are small-scale irrigation systems which usually use diversion weirs made from local material and need annual reconstruction. The canals are usually earthen and the schemes are managed by the community. Many were constructed by

TABLE 1. Current and planned irrigation development in Ethiopia. *Source*: Government of the Republic of Ethiopia 2001a.

Time frame	Classification of irrigation		
	Small-scale	Medium- and large-scale	Total
Current estimate (ha)	98,625	98,625	197,250
Planned development 2002-2016 (ha)	127,138	147,474	274,612
Total	225,763	246,099	471,862

local communities and have been functional for very long periods of time, while some were recently constructed with the aid of nongovernmental organizations (NGOs) and the government.

2. Modern schemes: These are small-scale irrigation systems with more permanent diversion weirs made from concrete and, therefore, do not require annual reconstruction. The primary and sometimes secondary canals are made of concrete. They are community-managed and have recently been constructed by the government.
3. Public: These are large-scale operations constructed and managed by the government. Sometimes these schemes support out-growers (smallholder farmers who have farms in the vicinity of the large–scale schemes).
4. Private: These are privately owned systems that are usually highly intensive operations.

Given our interest in small-scale irrigation, which is distinguished from large-scale irrigation by the farm-level scale of operation, we prefer to identify the small-scale irrigation systems using the second classification system and we studied the first and second categories of this classification. Werfring (2004) describes the typology of Smallholder Scale Irrigation (SSI) in Ethiopia in detail. Table 2 presents the estimated areas developed under each management system. According to this classification, it is estimated that 156,000 ha of irrigation are developed.

The figures of the proposed irrigation development presented in Table 1 are based on a plan spanning the period 2002-2016. A more recent planning document, the ‘Plan for Accelerated and Sustained Development to End Poverty (PASDEP),’ which spans the years 2005 to 2010 was aimed at developing about 430,061 ha within this planning period – 2005 to 2010 (Government of the Republic of Ethiopia 2006). This planning document was focused on strongly developing and

TABLE 2. Types of irrigation schemes and estimated areas in relation to different management system. *Source*: Werfring (2004).

Scheme management type	Estimated area (‘000 ha)	Percentage of total (%)	Management system
Traditional	60	38.5	Communal management. Weirs made from local material and reconstructed annually. Earth canals.
Modern communal	30	19.2	Communal management. Concrete Weirs. Lined primary (and sometimes secondary) canals.
Modern private	6	3.8	Private management (usually investors in floriculture).
Public	60	38.5	Government-managed.
Total	156	100	

supporting small-scale irrigation but it does not give an indication of how much of the proposed 430,061 ha of irrigation development will be small-scale irrigation, hence the need for presenting the figures in Table 1.

The above discussion highlights the importance of agriculture to the Ethiopian economy. It also shows why it is important for Ethiopia to develop its water resources. One way in which Ethiopia can exploit the country's water resources is to use water for the development of small-scale irrigation. The Government of Ethiopia, in its agriculture-led development strategy, places a lot of importance on the development of small-scale irrigation. Given this importance, it is essential to evaluate the performance of existing small-scale irrigation systems. In this study we evaluate the technical inefficiency of existing small-scale irrigation in Ethiopia.

There are some studies that have estimated the technical efficiency of agricultural production in Ethiopia. The studies, which have mainly estimated the technical efficiency of rain-fed production, have generated variable results. Suleiman (1995), using a sub-sample of data from the 'Ethiopian Rural Household Survey', conducted by the Department of Economics of Addis Ababa University in conjunction with the Centre for the Study of African Economies (CSAE) of Oxford University, found technical efficiencies ranging between 39 and 57% from three areas, Turufe Kechema, Sirbana Godeti and Aze Deboa. This study used Data Envelopment Analysis (DEA) to estimate technical efficiency. In a study carried out on rain-fed agricultural production for farmers who used fertilizer and those who did not, Admassie and Heidhues (1996) found high levels of technical efficiency in the Baso-Worana District. The technical efficiency for fertilizer and non-fertilizer users averaged at 92 and 87%, respectively. This is in agreement with the findings of Makombe et al. (2007). Admassie and Heidhues (1996) conclude that even though "…there are opportunities to increase output by increasing technical efficiency of farmers… the magnitude of technical inefficiency prevailing in these areas is, however, small. Hence, improving technical efficiency cannot be a solid basis for long-term, sustainable growth in agricultural production." This study provides insights into the technical efficiency of small-scale irrigation in Ethiopia as one measure of performance that can be used to assist decisions about future investment in irrigation.

OBJECTIVES

This study is guided by four objectives. First, we describe the cropping patterns of the four production systems. Second, the production and technical inefficiency of different small-scale production systems are estimated and compared. Third, we analyze the socioeconomic variables that may explain the differences in the estimated levels of technical inefficiency. Fourth, we assess whether technical inefficiency performance affects financial performance as measured by gross margins.

The Concept of Technical Efficiency

Since technical inefficiency forms the basis of this paper, it is important to present and explain the concept. The economic efficiency of a production system is made up of two components, technical and allocative efficiency. Crudely defined, technical efficiency is the physical component of the production system which deals with the maximization of output from the physical combination of inputs, and allocative efficiency is the optimization of the production process which takes into consideration input-output price relationships. It is possible to estimate technical efficiency alone, which is the focus of this study. A technically efficient producer avoids as much waste by producing as much output as input use will allow or by using as little inputs as output production will allow. Thus, comparing two producers, one producer is more efficient than the other if the producer can produce the same output using less of at least one input or can produce more of at least one output using the same inputs. Kebede (2001) discusses the definitions in detail. Tables 3 and 4 illustrate the concept of technical efficiency.

TABLE 3. Technically efficient by using less of at least one input (in this case, land). *Source*: Authors' estimates.

	Farmer 1	Farmer 2
Land (ha)	1	0.8
Water (m^3)	5,000	5,000
Maize (kg)	4,000	4,000
Beans (kg)	1,000	1,000

TABLE 4. Technically efficient by producing more of at least one output (in this case, beans). *Source*: Authors' estimates.

	Farmer 1	Farmer 2
Land (ha)	1	1
Water (m^3)	5,000	5,000
Maize (kg)	4,000	4,000
Beans (kg)	1,000	1,500

In Table 3, Farmer 1 uses 1 ha of land and 5,000 m^3 of water to produce 4,000 kilograms (kg) of maize and 1,000 kg of beans. Farmer 2 uses 0.8 ha of land (0.2 ha less than Farmer 1) and 5,000 m^3 of water to produce the same output. Farmer 2 is technically more efficient than Farmer 1 because the same output is produced by using less of at least one input: land. Alternatively, we can say that Farmer 1 is more technically inefficient than Farmer 2, i.e., the level of technical inefficiency for Farmer 1 is higher than that of Farmer 2.

In Table 4, Farmer 1 uses 1 ha of land and 5,000 m3 of water to produce 4,000 kg of maize and 1,000 kg of beans. Farmer 2 uses the same quantities of the same inputs to produce 4,000 kg of maize and 1,500 kg of beans. Farmer 2 is technically more efficient than Farmer 1 because at least more of one output, beans, is produced using the same levels of inputs as Farmer 1. Likewise, we can say that Farmer 1 is more technically inefficient than Farmer 2, i.e., the level of technical inefficiency for Farmer 1 is higher than that of Farmer 2.

Graphically, we can illustrate technical efficiency as shown in Figure 2. In Figure 2, land and water are inputs that can be used to produce output, say maize. Curve A is a production possibility frontier. This frontier is a plot of the maximum amount of maize that can be produced from all the possible combinations of the inputs land and water given a certain technology. Assume that a farmer uses these inputs but only manages to produce at F in Figure 2. This particular farmer's technical efficiency is given by the distance OF expressed as a percentage of the distance OA. This is a measure of how close to the frontier the farmer manages to get. The farmer's technical inefficiency is measured by the distance FA expressed as a percentage of the distance OA. This is a measure of how much the farmer falls short of getting onto the frontier. From Figure 2 we can observe that the relationship between technical efficiency and technical inefficiency is as shown in Equation (1).

$$\text{Technical inefficiency} = 1 - \text{technical efficiency} \tag{1}$$

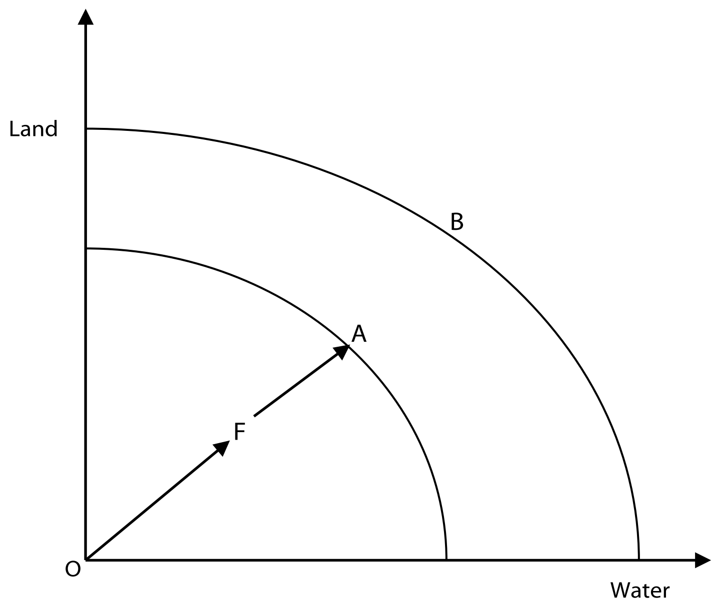

FIGURE 2. Basic illustration of technical efficiency. *Source*: Authors' creation.

Different methods can be used to estimate technical efficiency or technical inefficiency. If one collects farm-level data that can be used in linear programming, then one can use DEA to estimate technical efficiency. If one collects data that can be used for regression analysis, then one can use the stochastic frontier production function and use the residuals to estimate technical inefficiency as explained later in the methodology. Usually, the choice of method is made before data is collected.

Continuing with the example, different farmers will have different levels of efficiency or inefficiency in the land-water space bounded by curve A in Figure 2. If a farmer is 100% efficient, that farmer is producing on the frontier. Given the technology available to the farmer, that farmer has achieved the maximum possible efficiency or has an inefficiency of zero. Most farmers produce with some degree of technical inefficiency.

Assume that those farmers with the frontier defined by curve A are using land and saline groundwater for irrigation. However, the extension agent advises them that if they use the groundwater conjunctively with better quality surface water, they can produce more maize from the same quantities of land and water. The new plot of the maximum possible maize output from all possible combinations of land and water might be represented by frontier B in Figure 2. Frontier B is said to be higher than frontier A. The change in irrigation water quality shifted the production possibility frontier from curve A to curve B for the same farmers. If we assume that the farmers with the production possibility frontier curve A (call them farmer population A) are different from those farmers with the production possibility frontier curve B (call them farmer population B), then farmer population B is producing maize on a higher production possibility frontier than farmer population A. If the knowledge about better quality water that helped farmer population B to achieve a higher frontier is shared with farmer population A, either by contact with population B or through extension advice, then it is possible that farmer population A could shift its production possibility frontier towards the production possibility frontier achieved by farmer population B.

The presentation above simplifies the concept of technical efficiency. In reality farmers use more than two inputs, for instance, they use land, labor, fertilizer, irrigation water, oxen and a host of other inputs to produce one output, for example, maize. This makes the production possibility frontier a multidimensional surface instead of a two dimensional one, as represented in Figure 2. We can usually estimate only portions of the production possibility frontier from a sample of farmers. Fortunately, we have statistical tools that enable us to test whether one portion of a frontier that we have estimated is higher or lower than another.

In Figure 3, assume that curve A is a part of farmer population A's production possibility frontier that we have estimated from a sample of five farmers, and curve B is the frontier estimated from five farmers for farmer population B. In Figure 3 farmer population A is represented by the black dots and farmer population B by the circles. It is still the case that curve B represents a higher production possibility frontier for maize than curve A. Figure 3 shows the distributions for both populations of farmers.

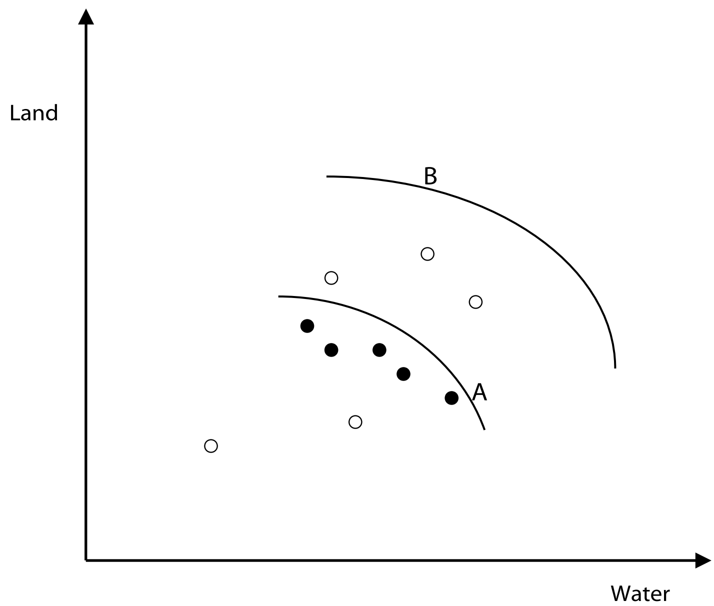

FIGURE 3. Basic illustration of the technical efficiency of two populations of farmers. *Source*: Authors' creation.

If we assume that our two samples of five farmers are representative of their respective populations, then this distribution of the five farmers closely represents the distribution of their populations. We can observe that population A is very close to the frontier A. This means population A has a low level of inefficiency or a high level of efficiency, given the technology they are using. We can also observe that population B, although on a higher frontier, has a low level of efficiency, or has a high level of inefficiency, given the technology they are using. A desirable transformation for population A would be to shift to frontier B while still maintaining the high level of efficiency, while a desirable transformation for population B would be to try and have the same level of efficiency as population A while still maintaining frontier B. The relevance of this discussion becomes obvious as we explain the methodology and interpret the results of the technical efficiency analysis. For a comprehensive treatment of the concept of efficiency, see Coelli et al. (2005).

METHODOLOGY

In this study we use the stochastic frontier production function as proposed by Aigner et al. (1977) to estimate technical inefficiency across a cross section of firms or farms. The stochastic frontier production function is given as shown in Equation (2).

$$Y_i = f\,(X_{i,}\ b) + e_{i,}\ i = 1, \ldots, N \tag{2}$$

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 two components as shown in Equation (3).

$$e_i = v_i - u_i \tag{3}$$

The error term, v_i in Equation (3) is assumed to be a symmetric disturbance that is independently distributed as $N\,(0,\ s^2_v)$. This error term is thought to exist due to two sources, favorable and unfavorable external shocks out of the firms 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 Equation (3) along with positive values of u_i result in negative deviations from the frontier for each of the observations. Aigner et al. (1977) modeled 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 functions 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 efficiency of agriculture in developing countries.

The frontier production function for cross-sectional data as described by Jondrow et al. (1982) to estimate farm-level technical inefficiency is applied in this study. The production function was specified as shown in Equation (4).

$$\text{Gross value of output (ETB)} = (A,\ L,\ F,\ I,\ Ox) \tag{4}$$

where: ETB = Ethiopian Birr; A = Total area planted (ha); L = Labor used (man-days); F = Fertilizer applied (kg); I = Total number of irrigations during the year (for rain-fed producers I and its interaction terms are excluded); and Ox = Oxen-days needed for land preparation.

We use the statistical package LIMDEP, which uses the maximum likelihood method to estimate the frontier production function.

In order to analyze the impact of socioeconomic variables that are associated with the technical inefficiencies, we use the chi-square test for association. We determine the chi-square for association between technical inefficiency and the variables age, education and gender of household head, cropped area and a dummy for whether the farmer visited the extension agent to seek advice, and another dummy for whether the extension agent visited the farmer to give advice. We understand that the multivariate analysis would be ideal for this type of analysis because we could estimate both direction and magnitude of causality. However, by these variables alone, that model would be underspecified. We, therefore, settle for a nonparametric test to assess whether there is any association between these variables and technical inefficiency. We also use the chi-square test to analyze the association between technical inefficiency and production constraints experienced by farmers.

We also try to establish whether technical inefficiency translates into financial performance as measured by gross margin. We define three types of gross margins as follows:

GMNL = Gross margin without accounting for labor = Gross value of output less all cash inputs
GML = Gross margin accounting for labor = GMNL less the opportunity cost of labor
GMLOx = Gross margin accounting for labor and oxen use = GML less opportunity cost of oxen labor

For GMNL, the cash costs included fertilizer, pesticides, herbicides and any other purchased inputs. In computing GML, the opportunity cost of labor was valued at ETB 6 per day (USD 1 = ETB 8.65) based on the wage rate for food for work programs (Government of the Republic of Ethiopia 2004). Most of the labor used for production is supplied by the family, except during labor-bottleneck periods like weeding, when labor is sometimes hired. While conducting the survey, we found out that the most common arrangement when a farmer hires oxen to work on the land is that, the farmer who hired the oxen works on the land of the farmer who supplied the oxen for 2 days. Based on the food for work wage rate we, therefore, valued oxen labor at ETB 12 per day.

Following Makombe and Sampath (2003), we then classify the gross margins into high, medium and low as follows: the lower bound of the high category is the mean plus one-third of the mean while the upper bound of the low category is the mean less one- third of the mean. Everything in between is classified as medium. We then compare the gross margins of rain-fed and irrigated production to establish if the irrigated production results in higher gross margins and to assess whether the differences in technical frontiers and the different levels of technical inefficiency by system translate into gross margin or economic performance.

DATA AND ANALYSIS

Sampling

Simple random samples of farmers were selected from four traditional and seven modern smallholder irrigation schemes. From each irrigation site the target sample was 50 farmers. Additionally, a sample of 50 rain-fed farmers, in close proximity to the irrigation scheme but with no access to irrigation, was selected as a control sample. In cases where the modern and traditional sites were close to each other, only one control sample was selected (see Figure 4). This resulted in an effective sample of 122 from the traditional sites, 281 from the modern sites and 350 from the control rain-fed sites.

Plot level data were collected during the growing season May 2005 to March 2006. Data were collected on cropping patterns, area planted, number of irrigations, labor, oxen-days (number of days oxen were used for land preparation), fertilizer used and the use of other inputs like herbicides, insecticides and fungicides. The gross value of output was estimated in quintals which were converted to kilograms at a rate of 1 quintal = 100 kg. The quintal is a measure that is commonly used by smallholder farmers in Ethiopia (Seyoum et al. 1998).

Data were collected for both irrigated and rain-fed production, for those farmers who had access to both rain-fed plots and irrigated plots. This resulted in four categories of farmland: purely rain-fed farmers who do not have access to irrigation (control), rain-fed farmland for farmers with access to irrigation (rain-fed with access to irrigation), and traditional and modern irrigation farmland. The data were collected with funding provided by IWMI and support from the Government of Austria under the "Impact of Irrigation on Poverty and Environment (IIPE)" project.

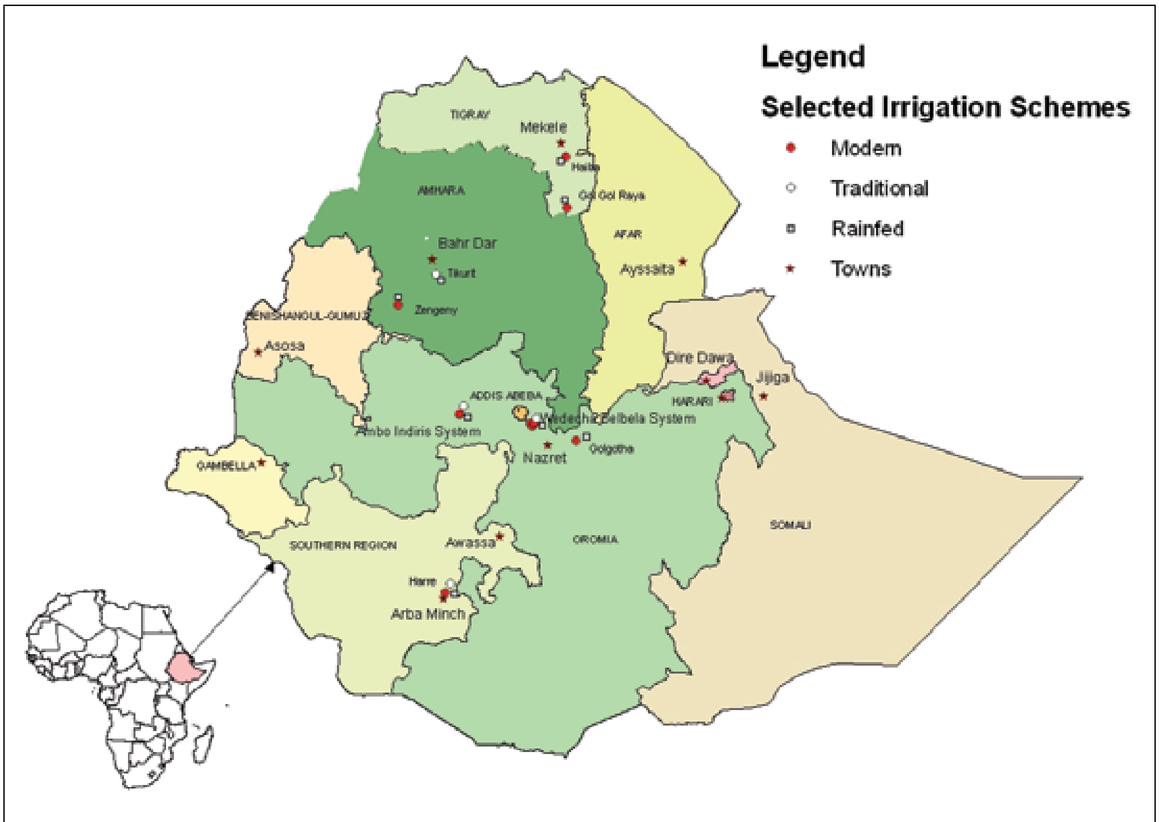

FIGURE 4. Location of traditional irrigated, modern irrigated and rain-fed sample sites. *Source*: A creation by Aster Denekew Yilma; Seleshi Bekele Awulachew; Godswill Makombe; Fitsum Hagos; and Regassa Namara to be used in this publication. *Note*: Treatment samples are the (traditional and modern) irrigated samples. The rain-fed samples shown on the map are the control samples (this is the rain-fed sample without access to irrigation, i.e., the control). The second rain-fed sample (that is with access to irrigation) is based on the sample from the irrigation scheme, because data for the treatment sample was also collected from the rain-fed farms, if they had rain-fed farms.

Cropping Pattern

In most of the analysis there is an aggregation of crops at farm and scheme level. Farmers mostly use irrigated plots for rain-fed production during the rainy season and then they irrigate mostly one and sometimes two seasons during the dry season. For purposes of this analysis, data were aggregated across seasons, plots and crops. Given the aggregation, it is important to thoroughly describe the cropping pattern so as to understand what is being aggregated. Tables 5 and 6 describe, in detail, the cropping patterns for seasonal and perennial rain-fed and irrigated production.

Table 5 shows that the 2,762 rain-fed plots sampled constituted an area of 1,055 ha across the sample schemes. Table 5 also shows the frequency of a crop on the sample plots and the proportion of the cropped area under that crop. For instance, teff was grown on 32% of the 2,762 rain-fed plots and it constituted 33% of the 1,055 ha cropped on the sample irrigation schemes. This makes teff the single most important crop under rain-fed production. Table 5 also shows that, besides teff, rain-fed production is dominated by the cereals wheat, maize, sorghum and barley which have frequencies of 20, 14, 7 and 7 on the sample plots each accounting for 18, 14, 12, and 5% of the cropped area, respectively. The three cereals teff, maize and wheat have a cumulative frequency of 66%, accounting for 65% of the cropped area while the five cereals have a cumulative frequency of 79% and account for 82% of the cropped area. The crops that have a frequency of 1% or more have a cumulative frequency of 88% and account for 88% of the area. The rest is accounted for

TABLE 5. Cropping pattern for seasonal crops in rain-fed and irrigated smallholder agricultural production in Ethiopia. *Source*: IIPE survey.

Crop name	Crop type	System					
		Rain-fed		Traditional irrigation		Modern irrigation	
		Frequency[1] (n = 2,762)	Area[2] (1,055 ha)	Frequency (n = 371)	Area (94 ha)	Frequency (n = 995)	Area (260 ha)
Teff *(Eragrostis Teff)*	Cereal	32	33	9	10	11	13
Wheat	Cereal	20	18	11	13	4	3
Maize	Cereal	14	14	15	19	14	19
Sorghum	Cereal	7	12	-	-	-	-
Barley	Cereal	7	5	2	3	7	5
Nuge *(Guizotia Abyssinica)*	Oilseed	3	3	-	-	-	-
Chickpea	Legume	3	2	5	4	1	1
Bean	Legume	2	1	-	-	-	-
Potato	Tuber/root crop	1	1	14	13	9	5
Tomato	Vegetable	-	-	12	9	14	16
Pepper	Spice	-	-	9	5	3	2
Shallot	Vegetable	-	-	8	7	2	2
Lentil	Legume	-	-	6	6	-	-
Cabbage	Vegetable	-	-	3	2	7	3
Cotton	Lint	-	-	2	3	1	2
Onion	Vegetable	-	-	2	1	16	17
Cumulative frequency (%)		88	-	95	-	90	-
Percentage of total area (%)		-	88	-	94	-	91
List of crops grown with frequencies less than 1 and small areas		Lentil, finger millet, flax, cotton, tomato, onion, hay, green pepper, sugar beet, cabbage, haricot bean, rough pea, gesho, sweet potato, watermelon, garlic, carrot, enguya, sigem, pea, sunflower and some intercrops, e.g., barley-maize, maize-wheat-teff-bean, onion-maize (there are more intercrops)		Flax, sweet potato, bean, chat, sorghum, rough pea, hay, beetroot and intercrops, e.g., bean-cabbage, maize-tomato, flax-teff		Garlic, carrot, bean, haricot bean, sugar beet, Lentil, sunflower, sorghum, coffee, rice, green pepper, besana, soya bean, and intercrops, e.g., tomato-cabbage, teff-chickpea, onion-pepper, potato-barley-teff	

Notes:[1] Percentage frequency with which the crop is planted on n plots; [2] Percentage of total area (in brackets) covered by crop

TABLE 6. Cropping pattern for perennial crops in rain-fed and irrigated smallholder agricultural production in Ethiopia. *Source*: IIPE survey.

Crop name	Crop type	System					
		Rain-fed		Traditional irrigation		Modern irrigation	
		Frequency[1] (n = 258)	Area[2] (46 ha)	Frequency (n = 180)	Area (48 ha)	Frequency (n = 98)	Area (18 ha)
Enset	False Banana-food	21	25	-	-	-	-
Gesho (hops)	For brewing tella (a local alcoholic beverage)	13	11	-	-	12	1
Mango	Fruit	8	6	23	17	10	10
Banana	Fruit	7	20	29	53	28	58
Chat *(Catus Adulis)*	Mild stimulant	4	2	6	3	3	0.5
Cactus	Fruit	3	0.1	-	-	2	Missing
Sugarcane	Sugarcane	3	4	26	18	11	11
Arthelibanose	Tree	3	5	-	-	-	-
Guava	Fruit	2	1	8	4	1	1
Orange	Fruit	2	Missing	-	-	2	0.3
Coffee	Coffee	2	0.2	3	3	11	6
Papaya	Fruit	-	-	-	-	8	1
Avocado	Fruit	-	-	1	Missing	1	1
Apple	Fruit	-	-	-	-	2	Missing
Gesho-eucalyptus	Above	-	-	-	-	1	0.25
Mango-avocado	Above	-	-	-	-	1	1
Banana-citrus	Above	-	-	-	-	1	4
Banana-mango-avocado	Above	-	-	-	-	1	3
Cumulative frequency (%)		68[2]	-	97	-	95	-
Percentage of total area (%)		-	74[2]	-	98	-	98
List of other crops grown		Avocado and intercrops, e.g., papaya-mango, coffee-citrus, citrus-chat, papaya-lemon		Papaya, besana and intercrops mango-coffee-guava, banana-mango		No additional crops	

Notes: [1] Percentage frequency with which the crop is planted on n plots; [2] Percentage of total area (in brackets) covered by crop; Eucalyptus was grown with a frequency of 23% and was found on 21% of the area. It is not included here because it is a tree

by other crops that have a frequency of less than 1% and are listed under the rain-fed section at the bottom of Table 5.

Table 5 also highlights the differences between rain-fed production and irrigated production. The five cereals mentioned above (for rain-fed production) have a cumulative frequency of 37 and 36%, and account for 45 and 40% of the cropped area in the traditional and modern irrigation schemes, respectively, which is much less than their contribution to rain-fed production. High-value and low-bulk crops like vegetables, spices and legumes have a cumulative frequency of 47 and 44%, and account for 37 and 43% of cropped area in the traditional and modern irrigated systems, respectively. The modern schemes grow more onions with a cumulative frequency of 16% and account for 17% of the cropped area. It would be interesting to find out why modern systems grow more onions than traditional irrigated systems. The cropped areas on the traditional and modern irrigated systems are 94 and 260 ha, respectively.

Farmers also grow perennial crops and Table 6 shows the cropping pattern for the perennial crops. The total area under perennial crops was 46, 48 and 18 ha for the rain-fed, traditional and modern irrigated systems, respectively. We have to note that compared to the seasonal crops, the area under perennial crops was not easy to estimate because sometimes a farmer can have a few perennial tree crops that are standing in isolation or only take up an insignificant portion of the area under seasonal crops. The area estimates for seasonal crops are, therefore, more reliable than those of perennial crops. Irrigation for some of the perennial crops is not as consistent and systematic as that of seasonal crops but there are differences between the perennial crops grown on rain-fed and irrigated systems. Enset and gesho dominate the rain-fed systems with a cumulative frequency of 34% and account for 36% of the area. In contrast, none of these crops were grown in the traditional irrigation systems while gesho was grown with a cumulative frequency of 12% in the modern irrigation systems but only accounted for 1% of the cropped area. Given the complexities introduced by perennial crops, it is possible that lone-standing trees of gesho may have been missed in the traditional irrigation systems, so we cannot completely rule out gesho as a possible crop in the traditional irrigation systems but eucalyptus and enset would be easy to notice. Mango, banana and sugarcane are the dominant perennial crops in the irrigated systems. As shown in Table 6, perennial crops are also grown in various intercrops like banana-mango-avocado. Perennial crops grown with a frequency of 1% or more in the rain-fed system have a cumulative frequency of 68%, and account for 74.3% of the cropped area. Other crops with a frequency lower than 1% are listed under the rain-fed system at the bottom of Table 6. Correspondingly, those crops grown in the irrigated systems with a frequency of 1% or more have a cumulative frequency of 96 and 95% and also account for 98 and 98.05% of the cropped area in both the traditional and modern irrigation systems, respectively.

Technical Efficiency Analysis

One of the important factors in estimating technical inefficiency using the frontier production function is the choice of functional form. For all the seasonal crops, irrigated and rain-fed, the model is specified as the general form of the translog functional form. There are four categories of seasonal crops, rain-fed seasonal crops from farmers who do not have access to irrigation, rain-fed seasonal crops for rain-fed farmers who have access to irrigation, and seasonal crops for the two irrigated traditional and modern systems. After initially specifying the model as the general form of the translog, by using the F statistic, we test whether each of the four equations can be reduced to the Cobb-Douglas Specification by restricting the square and interaction terms to be jointly equal to zero. The result is F [15, 108] = 3.25 (p-value = 0.000) and F [15, 259] = 3.66 (p-value = 0.000) for the traditional and modern irrigation scheme equations, respectively. We, therefore, conclude that both equations do not reduce to a Cobb-Douglas Specification. It is possible that the two irrigated samples could be pooled into one sample. We test for pooling 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-value = 0.000) and by restricting the modern scheme equation by the coefficients of the traditional scheme equation, F [21,259] = 21.28 (p-value = 0.000). Given the significance of these F values, we conclude that the two cannot be pooled and, therefore, belong to different populations.

Furthermore, we also test whether the two rain-fed 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-value = 0.000) and F [10, 342] = 6.98 (p-value = 0.000) for the seasonal rain-fed crops of farmers with access to irrigation and for those without access to irrigation, respectively, So we conclude that both equations do not reduce to a Cobb-Douglas Specification. We then test whether the two samples could be pooled. We restrict 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-value = 0.000), and vice versa, F [15,419] = 81.07 (p-value = 0.000). We conclude that the samples come from different populations and cannot be pooled.

Earlier, we mentioned that it was difficult to estimate areas under perennial crops. Furthermore, farmers did not use much fertilizer on the perennial crops and it was quite difficult for farmers to estimate how many times some perennial crops were irrigated since this was sometimes not a regular exercise. Given these observations, the equation for the perennial crops is, therefore, specified as a simple Cobb-Douglas functional form with area and labor as the inputs for both the irrigated and rain-fed perennial crops. The equations for irrigated perennial crops and rain-fed perennial crops for farmers with access to irrigation are estimated for those perennial crops where the area could be estimated with reasonable accuracy. The sample was not large enough to differentiate between irrigated perennial crops from farmers in traditional and modern schemes, although this maybe a possible distinction. Thus, only one equation is estimated for the irrigated perennial crops. The sample from the perennial crops for the rain-fed farmers without access to irrigation was also too small given the difficulty of estimating the areas under the crops. The equation for the rain-fed perennial crops is, therefore, estimated for the rain-fed perennial crops for farmers with access to irrigation where the areas could be estimated with reasonable accuracy. Given the constraints mentioned above, we note that the plot sample of perennial crops is, therefore, less representative when compared with seasonal crops. The results for the perennial crops are, therefore, at best indicative; however, we do feel that it is essential to report these indicative results.

Table 7 shows 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 rain-fed averages at 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. The average productivity of land, assuming constant returns to scale, is ETB 4,076, 3,857, 1,964 and 1,673 per hectare for the traditional irrigated, modern irrigated, rain-fed crops for farmers with access to irrigation and rain-fed crops for farmers without access to irrigation, respectively. Labor use on a per hectare basis is slightly lower for the modern schemes than for the traditional schemes while the modern schemes appear to water 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 rain-fed systems compared to the irrigated systems on a per hectare basis. Farmers believe that good land preparation is essential for a good crop and invest considerable time in the process of land preparation. The time invested in land preparation also depends on the type of crop.

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 labor, but this may be associated with labor for irrigation. The average productivities of land are ETB 4,660 and ETB 3,712 per hectare for the irrigated and rain-fed perennial crops, respectively. Although indicative, these results show the perennial crops could play a significant role in increasing farm

TABLE 7. Descriptive statistics for the different production systems. *Source*: IIPE survey.

Variable	Mean values by system type[1]					
	Traditional irrigated plots (n = 122)	Modern irrigated plots (n = 281)	Rain-fed plots for farmers who have access to irrigation (n = 434)	Rain-fed plots for farmers without access to irrigation (control) (n = 351)	Irrigated perennial crops (n = 105)	Rain-fed perennial crops (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 (number)	3 (3)	6 (7)	N/A	N/A	N/A	N/A
Labor (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

Note: [1] ( ) = Standard deviations, [ ] = per hectare; [2] N/A = not applicable

incomes together with the rain-fed seasonal crops. However, the rain-fed seasonal crops are usually cereals that form the staple diet of the farmers compared with the perennial crops which, though they can also be food crops, could play a more significant role as cash crops and thus contribute to household food security by enhancing purchasing power.

Compost was applied to 12% of irrigated plots and 5% of rain-fed 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).

Less than 11% of the irrigated plots and less than 3% of rain-fed 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. The current study covers more sites with different characteristics than that of the Makombe et al. (2007) study, which looked at three modern small-scale irrigation systems. Improved seed was used on about 21% of irrigated plots and on less than 11% of rain-fed plots.

In the model, we used a dummy variable for the use of compost. We intended to use a dummy variable for the use of improved seed in all the production systems, but this was not possible because within the same farm, some plots were planted with it (improved seed) while other plots were not. When the data were aggregated to farm level for each system, it was, therefore, not possible to use the dummy for improved seed.

In this study, for the estimation of the equations to estimate technical inefficiency, eight outliers were omitted. The residuals of these observations were outside two standard deviations and resulted in an incorrect skewness, giving an indication of a cost rather than a production relationship. The estimated stochastic frontier production functions are summarized in Table 8, and Table 9 shows the estimated input productivities.

TABLE 8. Stochastic frontier production function estimates for seasonal and perennial crops. *Source*: IIPE survey.

Variable	Frontier production function equation coefficients by system type[1]					
	Irrigated seasonal		Rain-fed seasonal		Perennial	
	Traditional (n = 122)	Modern (n = 281)	For farmers with access to irrigation (n = 434)	For farmers without access to irrigation (n = 351)	Irrigated (n = 105)	Rain-fed (n = 65)
Constant	5.0984 (0.215)	7.2076 (0.000)	5.6961 (0.000)	6.6216 (0.000)	6.6756 (0.000)	6.9028 (0.000)
LnA	0.4704 (0.386)	0.7672 (0.006.)	0.4842 (0.006)	0.03686 (0.201)	0.2891 (0.006)	0.1816 (0.264)
LnF	0.2786 (0.000)	0.1375 (0.000)	0.2123 (0.000)	0.1921 (0.000)	0.4852 (0.000)	0.3279 (0.000)
LnI	-0.0474 (0.690)	0.1462 (0.061)	N/A	N/A	N/A	N/A
LnL	0.5882 (0.328)	-0.0304 (0.917)	0.5101 (0.015)	0.0936 (0.775)	N/A	N/A
LnOx	-0.3347 (0.378)	-0.0998 (0.596)	-0.3375 (0.028)	-0.0924 (0.472)	N/A	N/A
LnA_SQ	0.1771 (0.095)	0.0371 (0.517)	0.0074 (0.840)	-0.1003 (0.0712)	N/A	N/A
LnF_SQ	0.0325 (0.021)	0.0285 (0.000)	0.0371 (0.000)	0.0316 (0.005)	N/A	N/A
LnI_SQ	-0.0179 (0.042)	-0.0031 (0.633)	N/A	N/A	N/A	N/A
LnL_SQ	-0.0843 (0.638)	0.0446 (0.343)	-0.0541 (0.172)	0.0068 (0.892)	N/A	N/A
LnOx_SQ	0.0229 (0.591)	-0.0208 (0.044)	-0.0239 (0.014)	-0.0124 (0.134)	N/A	N/A
Ln(AxF)	-0.0245 (0.200)	-0.0224 (0.174)	-0.0085 (0.421)	-0.0160 (0.227)	N/A	N/A
Ln(AxI)	0.0085 (0.864)	0.0543 (0.048)	N/A	N/A	N/A	N/A
Ln(AxL)	0.0708 (0.676)	-0.1194 (0.110)	-0.0396 (0.488)	0.0600 (0.497)	N/A	N/A
Ln(AxOx)	-0.2316 (0.137)	0.0585 (0.158)	-0.0137 (0.760)	-0.0106 (0.789)	N/A	N/A
Ln(FxI)	-0.0232 (0.063)	-0.0073 (0.110)	N/A	N/A	N/A	N/A
Ln(FxL)	-0.0442 (0.046)	-0.0070 (0.500)	-0.0359 (0.000)	-0.0289 (0.012)	N/A	N/A

(Continued)

TABLE 8. Stochastic frontier production function estimates for seasonal and perennial crops. *Source*: IIPE survey. *(Continued)*

Variable	Frontier production function equation coefficients by system type[1]					
	Irrigated seasonal		Rain-fed seasonal		Perennial	
	Traditional (n = 122)	Modern (n = 281)	For farmers with access to irrigation (n = 434)	For farmers without access to irrigation (n = 351)	Irrigated (n = 105)	Rain-fed (n = 65)
Ln(FxOx)	0.0208 (0.364)	-0.0047 (0.550)	0.0172 (0.054)	0.0093 (0.397)	N/A	N/A
Ln(IxL)	0.0475 (0.284)	-0.0350 (0.186)	N/A	N/A	N/A	N/A
Ln(IxOx)	-0.0343 (0.483)	0.0257 (0.027)	N/A	N/A	N/A	N/A
Ln(LxOx)	0.0715 (0.528)	0.0079 (0.862)	0.01049 (0.022)	0.0296 (0.350)	N/A	N/A
Compost dummy	1.0427 (0.000)	0.2716 (0.170)	0.2384 (0.072)	0.1777 (0.174)	N/A	N/A
Variance parameters						
Sigma squared (v)	0.3637	0.4782	0.3005	0.2615	0.7200	0.3429
Sigma squared (u)	0.0310	0.6665	0.6255	0.4401	1.8222	1.1367
Log likelihood	-113.27	-351.54	-474.09	-344.23	-164.84	-82.18

Notes: [1] Significance in parentheses; [2] N/A = not applicable

In order to compare the stochastic frontier production functions for the different production systems, we evaluated them at the means of the estimated regression equations. These are evaluated from the log likelihood functions in the log form and then antilogged to get the input levels. Because the evaluations are based on the means of the estimated equations, the points that were evaluated obviously lie on the respective frontiers. Based on this evaluation, Table 9 shows that for the traditional irrigated system, it takes 0.41 ha, 16 days of labor, 2 irrigations and 2 oxen-days to produce a gross value of output of ETB 1,462. This compares to 0.53 ha, 22 days of labor, 3 irrigations and 3 oxen-days needed to produce a gross value of output of ETB 4,645 for the modern irrigation schemes. Because of the limited use of fertilizer in the production systems, the frontier production function does not include fertilizer.

In Table 9 the figures in bold are the average productivities for the respective inputs. The highest average productivity for land is ETB 8,764 for modern irrigation systems followed by ETB 3,566 for traditional irrigation systems, and then ETB 3,385 for rain-fed crops from farmers with access to irrigation and ETB 2,818 for those who do not have access to irrigation. It is important to note that the difference in the marginal productivity of land between the traditional irrigation system and the rain-fed system for farmers with access to irrigation is very small.

An inspection of both the average and marginal productivities of all inputs in Table 9 shows that the modern irrigated system has the highest productivities for almost all inputs compared to the other systems. However, the labor productivity of the rain-fed system for farmers with access to irrigation appears comparable if not higher than that of the traditional irrigated system. The results show that the modern irrigation system is definitely a higher frontier than the rest of

TABLE 9. Frontier production function input levels, average and marginal productivities (ETB). *Source*: IIPE survey.

Input	Level by scheme type[1]					
	Irrigated traditional seasonal	Irrigated modern seasonal	Rain-fed seasonal for farmers with access to irrigation	Rain-fed seasonal for farmers without access to irrigation	Irrigated perennial	Rain-fed perennial
Gross value of output (ETB)	1,462	4,645	2,877	3,072	2,345	1,308
Area (ha)	0.41 **3,566** [641]	0.53 **8,764** [4,025]	0.85 **3,385** [1,120]	1.09 **2,818** [654]	0.23 **10,195** [363]	0.21 **6,229** [89]
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
Irrigations (number)	2 **731** [16]	3 **1,548** [377]	N/A	N/A	N/A	N/A
Labor (man-days)	16 **91** [24]	22 **211** [76]	26 **111** [36]	37 **83** [21]	23 **102** [1,248]	5 **262** [768]
Oxen-days)	2 **731** [85]	3 **1,548** [-198]	5 **575** [-38]	5 **614** [-27]	N/A	N/A

Notes: [1] Bold = Average productivity, [ ] = marginavl productivity; [2] N/A = not applicable

the systems, that the traditional irrigated system is a higher frontier than the rain-fed system for farmers without access to irrigation, but that the frontier for the rain-fed system for farmers with access to irrigation is quite comparable to that of the traditional irrigated system, although that of the traditional irrigated system appears slightly higher. As would be expected, the lowest frontier from the analysis of seasonal crops is that of the rain-fed farmers without access to irrigation. In some of the frontiers, the marginal productivity of oxen labor is negative suggesting overuse of this resource.

For the perennial crops, the average productivity of land is higher for the irrigated crops. It is not clear why the irrigated systems require so much more labor but this may be related to the labor associated with irrigation and the possibility that labor may be required for harvesting. Alternatively, since the cropping patterns are different and since different crops require different management levels, this may possibly lead to differences in labor requirements. The average and marginal productivities for the perennial crops show that the irrigated perennial crops have a higher frontier. The high marginal productivities for labor may be a reflection of the fact that more labor could be invested in the perennial crops, or be a reflection of potential missing variables or both.

Table 10 summarizes the results of the inefficiency analysis. The average inefficiency for the modern irrigation schemes is 12% while it is 4% for the traditional irrigation schemes. The inefficiency for the modern irrigation schemes varies between 7 and 21%, showing its site-specific nature. The inefficiency of the traditional schemes varies between 1 and 7%. The low technical inefficiency results

TABLE 10. Inefficiency results for irrigated seasonal crops by region, scheme type, and scheme. *Source*: IIPE survey.

Region	Inefficiencies (%)		
	Irrigation scheme name	Irrigation scheme type	
		Modern	Traditional
Oromia	Endris (Ambo)	21	7
	Wedecha Belbela system (Debre Zeit)	9	1
	Golgota	7	N/A
Amhara	Tikurit	N/A	1
	Zengeny	12	N/A
Tigray	Haiba	19	N/A
	Golgol Raya	9	N/A
SNNPR	Hare (Arba Minch)	12	1
Mean		12	4

Notes: SNNPR = Southern Nations, Nationalities, and People's Region; N/A = not applicable

are consistent with those reported by Seyoum et al. (1998) and Makombe et al. (2007), although it should be noted that the low inefficiency reported in Makombe et al. (2007) was observed in modern irrigation systems providing evidence that modern irrigation schemes are capable of achieving low inefficiencies too.

These results show that the traditional scheme farmers have low inefficiencies, reminding us of the Schultz hypothesis of the efficient but poor farmers. The traditional scheme farmers produce on a lower production frontier than the modern scheme farmers, but the traditional scheme farmers also have lower inefficiencies than the modern scheme farmers. This is exactly as we depicted earlier in Figure 3. The question becomes, can the modern scheme farmers maintain their higher frontier and also have the low inefficiency levels of the traditional system farmers, and can the traditional system farmers shift to the higher frontier achieved by the modern farmers while still maintaining their low inefficiencies. The gain of raising the traditional irrigation system frontier production function to that of the modern irrigation system is estimated at ETB 5,208 per hectare. If it is possible to eliminate the 12% inefficiency of the modern schemes, this gain increases to ETB 5,833 per hectare.

The average inefficiencies are 13 and 11% for the seasonal crops of rain-fed farmers without access to irrigation and their rain-fed counterparts who have access to irrigation, respectively. The two means are not statistically different (t-value = 0.678, p-value = 0.498). Thus, although the production functions are different, they have comparable inefficiencies. The benefit of raising the production function for farmers without access to irrigation, to that of the rain-fed farmers with access to irrigation, is ETB 567 per hectare. Eliminating the 11% inefficiency of the rain-fed farmers with access to irrigation would increase this gain to ETB 635 per hectare. The reason that the production function for farmers with access to irrigation is higher than that of farmers without access to irrigation may be the capital transfer between irrigated and rain-fed production, with farmers who have access to irrigation having the ability to use more inputs on their rain-fed plots. Even though the production functions do not include fertilizer due to the low level of use, Table 7 suggests that irrigators tend to use more fertilizer on their rain-fed plots than farmers without access to irrigation.

The gain of raising the production frontier of rain-fed farmers without access to irrigation to that of rain-fed farmers with access to irrigation can be realized, although smaller in magnitude than the gains from irrigation, is an attractive prospect which, if realized, has the potential to affect the estimated 10 Mha planted under the rain-fed system. The gain from a slight improvement of rain-fed production can have a huge impact on levels of rain-fed production. If this gain can be achieved by better extension, it is potentially more cost-effective than irrigation development which would require both initial capital outlay and extension. Zalla (1987) makes this observation about irrigation development in Africa, "….the economic aspects of African irrigation become central to the decision of whether to proceed with further irrigation projects. The overriding policy question becomes whether returns to rain-fed agricultural projects or to alternative approaches to irrigation might be higher." Our analysis provides some support to the observation about rain-fed agricultural projects. However, in the case of Ethiopia, the gain from improving rain-fed production cannot 'de-link' the performance of the economy from rainfall variations as can be accomplished by irrigation. Therefore, it is important for the Government of Ethiopia to focus its efforts on improving rain-fed production while at the same time developing irrigation.

For the perennial crops, the means for the irrigated and rain-fed crops were 19 and 25, respectively. Given that the irrigation of perennial crops is, at times, not as regular as the irrigation of seasonal crops, we tested for the difference of means between the irrigated and rain-fed perennial crops. The result shows that the means are not statistically different [t-value = 0.895, p-value = 0.372]. It is also possible to develop the production of perennial crops so that they can contribute to both food security and income for rural farmers.

Relationship between Technical Efficiency and Socioeconomic Variables

After estimating technical efficiency for each farm, we try to see whether there is any relationship between technical efficiency and the following socioeconomic variables: age of household head, years of education of household head, gender of household head, extension and size of cropped area. We divided the variable 'extension' into two: whether the farmer visited the extension agent for advice or whether the extension agent visited the farmer to give extension advice. Table 11 shows the distribution of these variables in the study sample. Rain-fed production with access to irrigation is constituted by the sample of farmers from the traditional and modern irrigated sample who also have access to irrigation. This sample, therefore, excludes the sample of farmers from Golgota, where the farmers only have access to irrigation and do not have any rain-fed plots. Thus, even if the farmers may be the same in terms of having rain-fed plots and irrigated plots, the inefficiencies used for the analysis of the rain-fed farmers with access to irrigation are from the rain-fed stochastic frontier, and the inefficiencies used under irrigation are from the irrigated frontier. For the farmers with both access to irrigation and rain-fed plots, we, therefore, have two estimates of inefficiency, one from rain-fed and another from irrigated plots.

From Table 11 we observe that the age of the household head is almost similar across the systems. Years of education of the household head is also almost similar, although slightly lower for the rain-fed systems. There are very few female-headed households in all systems with the highest being 12% for the purely rain-fed system. Extension was divided into the percentage of farmers who visited the extension agent and percentage of farmers who were visited by the extension agent. Slightly under 40% of farmers visited the extension agent and a similar proportion were visited by the extension agent. Cropped areas for each system are given in Table 7.

Table 11 also summarizes the results of the Chi-square test for association. We find that most of the variables are nonsignificant, indicating the absence of association between the variables used and the estimated technical inefficiencies. The age of the household head is significant for the rain-fed sample with no access to irrigation. We further defined a young household as those with

TABLE 11. Descriptive statistics for the socioeconomic variables. *Source*: IIPE survey.

Socioeconomic variable	System[1]			
	Rain-fed		Irrigation	
	For farmers without access to irrigation (n=319)	For farmers with access to irrigation (n=390)	Traditional (n = 111)	Modern (n = 248)
Age (years)[2]	45 (16) *[5]	46 (15) NS	43 (16) NS	46 (15) **
Education (years)	1.7 (2.9) NS	2.2 (3.2) NS	2.8 (3.4) NS	2.3 (3.3) NS
Gender (% female)	12 NS	7 NS	5 NS	7 *
Visit agent (%)[3]	36 NS	31 NS	27 NS	29 NS
Agent visit (%)[4]	40 NS	39 NS	33 NS	35 ***
Cropped area (ha)	1.44 (1.12) NS	1.14 (0.90) NS	0.58 (0.59) NS	0.78 (0.71) NS

Notes: [1] ( ) = Standard deviation; [2] Age and education of household head in years; [3] Percentage of farmers who visited the extension agent; [4] Percentage of farmers who were visited by the extension agent; [5] Level of significance; *** Significant at 5%; ** Significant at 10%; * Significant at 20%; NS = Nonsignificant

a household head aged below 40 years, thereby yielding a young household head sample of 154, and 196 for the older. The mean inefficiency for the young households is 20% and is 8% for that of the older. From the one-way ANOVA F [1,348] =3.671 (p-value=0.056), shows that the older households had lower inefficiencies than the younger ones. Obviously, the younger households in the purely rain-fed production system still have some things to learn from the older ones.

Age is also significant for the modern irrigation schemes. By the same categories as defined above, the sample for young households was 119 and was 161 for that of older ones. The inefficiency for the younger households averages 10%, while it is 14% for the older ones. The ANOVA F [1,278] = 01.278 (p-value = 0.083) shows that there is significant difference between the inefficiencies of the older and younger households, with the younger achieving lower inefficiency. This is the opposite result from the rain-fed production system. It is possible that the reason for these results is that under the rain-fed production, older households have lower inefficiencies because they are using age-old practices, whereas the modern irrigation schemes may require more innovation (managerial skills) than rain-fed production to which the younger households may be more open to than the older ones.

Gender is significant for the modern schemes too. The female-headed sample is 17 while there are 231 male-headed households. Mean inefficiency for the male-headed households is 12% while it is 20% for the female-headed households. The ANOVA F [1,278] = 2.235 (p-value = 0.136), shows that there is no significant difference between the inefficiencies of the female- and male-headed households. However, the F is significant at 20%. This result may be due to the underrepresentation of the female-headed households.

In the modern schemes, farmers who were visited by the extension agent had inefficiencies averaging 16% while those who were not visited by the extension agent had inefficiencies of 10%. The ANOVA F [1,278] = 5.228 (p-value = 0.023), suggests a counterintuitive result, where farmers being visited by the extension agent had higher inefficiency than those not visited. It is difficult to explain this result; however, it is possible that the extension agent may be targeting the visit, i.e., targeting the neediest farmers or those farmers who need the most assistance to improve their performance. Another possible explanation may be that the extension agent may not have more relevant knowledge pertaining to irrigated agriculture than the farmers themselves. Some of the development agents are general agriculturalists with limited knowledge or skills in irrigated agriculture.

Relationship between Technical Efficiency and Production Constraints

During the survey, farmers were asked what production constraints they face during the surveyed production season. The figures reported in Table 12 are the percentages of those farmers who reported facing the specific problems. The system that reported the lowest percentage of farmers facing land preparation problems was the traditional irrigation system, recording only 26%. The traditional schemes reported the highest percentages of farmers with problems of soil fertility, weed control, pests and diseases and soil erosion with percentages of 74, 66, 75 and 66%, respectively. However, traditional irrigating farmers also reported the lowest percentage of farmers facing input access and moisture deficiency problems.

All of the abovementioned constraints, except for land preparation, were significantly associated with levels of inefficiency in the rain-fed production system of farmers without access to irrigation, as shown in Table 12.

TABLE 12. Distribution of production constraints by system. *Source*: IIPE survey.

Production constraints	System (%)			
	Rain-fed		Irrigation	
	For farmers without access to irrigation	For farmers with access to irrigation	Traditional	Modern
Land preparation	45[1] NS[2]	31 NS	26 NS	34 NS
Soil fertility	63 **	56 NS	74 NS	48 NS
Weed control	61 **	57 NS	66 NS	52 NS
Pests and diseases	57 **	66 NS	75 NS	66 NS
Soil erosion	56 **	46 NS	66 NS	28 NS
Input access	53 *	44 NS	37 **	48 NS
Moisture deficiency	48 *	34 NS	20 NS	38 **

Notes: [1] Percentage of farmers reporting constraints; [2] Level of significance; *** significant at 5%; ** significant at 10%; * significant at 20%; NS = Nonsignificant

None of the production constraints were significantly associated with technical inefficiency for the rain-fed producers with access to irrigation. This is further evidence to suggest that the two production systems are from different populations, as suggested by the stochastic frontier production function analysis.

Table 13 summarizes the results of the analysis of the variance for those constraints that were significantly associated with technical inefficiency from Table 12.

The results in Table 13 show that for the rain-fed system, except for moisture deficiency, those farmers who did not report experiencing a constraint had consistently higher levels of inefficiency than those farmers who reported experiencing the constraint. In the traditional schemes from Table 12, only input access is significantly associated with technical inefficiency. Once again, those farmers who reported experiencing the constraint had lower technical inefficiency. On the modern schemes, only moisture deficiency is associated with technical inefficiency, and once again it has the expected direction of impact.

TABLE 13. Association between technical inefficiency and production constraints. *Source*: IIPE survey.

System	Production constraints	Mean inefficiency (%)		*F* test	
		Did not report experiencing constraint	Reported experiencing constraint	Value	Significance
Rain-fed with no access to irrigation	Soil fertility	21	9	F [1,334] = 3.187	**
	Weed control	21	9	F [1,328] = 3.613	**
	Pests and diseases	21	8	F [1,329] = 3.804	**
	Soil erosion	20	8	F [1,328] = 3.506	**
	Input access	18	8	F [1,334] = 2.369	*
	Moisture deficiency	8	17	F [1,339] = 2.118	*
Traditional	Input access	5	1	F [1,119] = 4.305	***
Modern	Moisture deficiency	11	17	F [1,234] = 4.114	***

Notes: *** significant at 5%; ** significant at 10%; * significant at 20%; NS = Nonsignificant

For most of the constraints, except for moisture deficiency, the results appear to be counterintuitive, where farmers who reported experiencing a constraint actually had consistently lower levels of inefficiency. It is possible that those farmers who reported experiencing the constraint may be so aware of the constraint that they addressed the constraint successfully enough to mitigate its negative effect on technical inefficiency. Moisture deficiency has the correct direction in that those farmers who did not report experiencing moisture deficiency achieved lower technical inefficiency, as would be expected. This may be the case because farmers cannot do much to mitigate the negative impact of moisture deficiency on technical inefficiency unlike in the case of other constraints used in this analysis.

There are two important observations to be made from the stochastic frontier production function and the constraints analysis. The differences in the stochastic frontiers for the purely rain-fed farmers and that of rain-fed farmers with access to irrigation show that there are gains that could be made by improving rain-fed production. The constraints analysis suggests that even though the farmers reported problems, they appear to have developed some ways of addressing the problems because they had low mean inefficiency, although the moisture stress problem is an outstanding problem. We, therefore, recommend that while the government should develop irrigation in an attempt to address the moisture problem, it should not ignore the potential gains from improving rain-fed production.

Gross Margins by Different Systems

As pointed out earlier, economic efficiency is composed of technical and allocative efficiency. The discussion so far has focused on technical efficiency. Also, as mentioned earlier, allocative efficiency involves optimization of a production process given input-output prices. It is beyond the scope of the current study to estimate allocative efficiency and, hence, economic efficiency, but what we can do is compare the technical efficiencies of each production system with their respective financial performances.

In the stochastic frontier production function analysis, we noted that:

1. rain-fed production for farmers with access to irrigation is on a higher frontier than that of rain-fed production for farmers without access to irrigation; and
2. traditional irrigated farmers are producing on a lower frontier than the farmers on the modern irrigated systems, but the traditional farmers have lower technical inefficiency (or are more technically efficient) than the modern irrigation farmers.

The question we try to answer is how these findings on production frontiers and technical inefficiency relate to financial performance, if at all, as measured by gross margin.

Table 14 shows the means of the different gross margins by each production system. We can observe from Table 14 that labor is an important input in all the production systems, because it causes a larger downward shift in the gross margins when accounted for than oxen labor does. It is also evident that the irrigated production systems achieve higher gross margins than the rain-fed systems.

TABLE 14. Mean gross margins per hectare by production system (ETB). *Source*: IIPE survey.

Production system	N	Gross margins per hectare			
		Type	Mean	Range	
				Minimum	Maximum
Rain-fed for farmers without access to irrigation	326	GMNL	2,036	33	1,508
	326	GML	1,638	-2,288	14,972
	326	GMLOx	1,436	-3,171	14,900
Rain-fed for farmers with access to irrigation	415	GMNL	2,165	-258	15,428
	413	GML	1,603	-4,040	14,818
	413	GMLOx	1,386	-5,768	14,434
Traditional irrigation	117	GMNL	4,231	-160	28,800
	117	GML	3,511	-3,980	27,168
	117	GMLOx	3,325	-5,900	27,072
Modern irrigation	267	GMNL	4,814	-1,216	38,400
	265	GML	3,939	-7,680	29,287
	264	GMLOx	3,675	-6,656	28,930

We test whether the two rain-fed gross margins are statistically significantly different, and the t-tests for GMNL, GML and GMLOx were -0.888 (p-value = 0.375), 0.223 (p-value = 0.823), 0.472 (p = 0.637), respectively. We, therefore, conclude that the means are not statistically significantly different. However, from Levine's test for the equality of variances, the F [2, 739] values are 4.550 (p-value = 0.033), 5.036 (p-value = 0.025) and 5.216 (p-value = 0.023) for GMNL, GML and GMLOx, respectively, showing that the gross margins for the rain-fed farm types, although statistically not significantly different, have different variances and, therefore, come from different populations.

Thus, even though we have shown that the rain-fed production for the farmers without access to irrigation is on a lower production frontier than the rain-fed production of farmers with access to irrigation, this does not translate to a difference in gross margin. Although in need of further verification, this finding strongly suggests that, allocatively, the purely rain-fed farmers may be making better decisions on their rain-fed production than farmers with access to irrigation do on their rain-fed production, and in such a way that for the gross margin this better decision-making offsets the effect of the higher frontier for farmers with access to irrigation. The conclusion from Levine's test for the equality of variances is consistent with the evidence from the stochastic frontier production function analysis, i.e., that these are different populations.

We then tested whether the statistics for irrigated gross margins were significantly different, and the t-tests for GMNL, GML and GMLOx were -0.938 (p-value = 0.349), -0.360 (p-value = 0.719), -0.028 (p-value = 0.978), respectively. We, therefore, conclude that the means are statistically not significantly different. Levine's test for the equality of variances, yields F [2,382] values of 0.269 (significance = 0.604), 1.528 (significance = 0.217) and 1.665 (significance = 0.198) for GMNL, GML and GMLOx, respectively, showing that the gross margins for the irrigated farm types have equal variances and, therefore, could come from the same population.

This result is interesting compared to the results of the stochastic frontier production function analysis, because again the higher frontier for the modern schemes does not translate into better gross margins. For the irrigation schemes, there are two possible explanations or a combination of both. First, the lower technical inefficiency (higher technical efficiency) for the traditional farmers might be enough to offset the effect of the higher frontier for the modern irrigated farmers. Second, as for the rain-fed farmers, it is possible that, allocatively, the farmers on the traditional schemes are making better decisions than the modern farmers so as to offset the impact of the higher production frontier for the modern farmers.

The result of Levine's test for the equality of means is an interesting one because it implies that statistically, based on gross margins, we could pool the irrigated samples into one sample, inconsistent with the stochastic frontier analysis which showed that the traditional and modern sample farmers come from different populations. It is possible, that whatever the offsetting variable is, it is offsetting the differences in such a way that there is not much difference in the variances of the gross margins.

Finally, we test whether the irrigated gross margins are different from the rain-fed ones. As expected, a one-way ANOVA shows that the two rain-fed systems are statistically significantly different from the irrigated means for all the gross margin types. Irrigation, as expected, and consistent with the results of the stochastic frontier production function analysis, achieves higher gross margins than rain-fed production.

There is a need to study why, even though the two rain-fed systems are on different frontiers, with the rain-fed production frontier for the farmers with access to irrigation clearly on a higher frontier than that of the purely rain-fed farmers, this does not translate to financial performance. The same also applies to the irrigated systems. Even though the modern systems have been shown to be on a higher production frontier than the traditional systems, this does not translate to financial performance.

From this analysis we conclude that, first, there is a need to establish whether those farmers on the lower frontiers are making better allocative efficiency decisions that offset the impact of the frontiers, which will, in turn, enable such farmers to advise those farmers on the higher frontier to be able to realize financial gains from being on the higher frontier. Second, we need to identify what constraints are faced by the farmers on the higher frontiers that make them fail to translate the higher frontiers into higher gross margins. Addressing these issues can result in improved performance for both rain-fed and irrigated production.

CONCLUSIONS AND RECOMMENDATIONS

From the stochastic frontier production function analysis we showed that the production frontier of the modern irrigation scheme is higher than that of the traditional irrigation farmers. We also show that the benefit of raising the production function of the traditional scheme to that of the modern systems is very high, from a purely technical perspective. Given the differences in the productivities of inputs between the modern and traditional systems, we recommend that the existing traditional irrigation systems be upgraded to modern schemes before, or concurrently with, new small-scale irrigation development. The gains from both upgrading traditional systems to modern systems and new irrigation development can be better achieved if extension recommendations directly pertinent to irrigated production are made easily available to farmers. We also estimated the productivity of land and conclude that it may be viable to put more land under irrigation, especially if developed into modern irrigation systems. However, given that this conclusion is reached from a purely technical analysis, the economic viability of such irrigation investment needs to be evaluated in light of the costs of irrigation development and the relative prices of inputs and outputs.

We also note that the benefit of raising the production function of the rain-fed farmers without access to irrigation to the level of that of the rain-fed farmers with access to irrigation is significant. If these gains can be realized, it is possible they could be realized countrywide and are thus capable of having a more magnified impact on total production than irrigation development. It is possible that the impact of such gains in rain-fed production could be much easier to achieve, could be higher and more cost effective than new irrigation development. Zalla (1987) also asks the question whether it may not be possible to achieve higher gains in rain-fed agricultural projects that are under irrigation.

Given our observations, it is, therefore, important to study the differences between the practices of the rain-fed farmers with access to irrigation and those farmers without access to irrigation, so as to incorporate the lessons learned into the purely rain-fed production process. The difference between the production functions of the purely rain-fed farmers and that of farmers with access to irrigation provides evidence of the possibility that the production function of the purely rain-fed farmers can be raised within the realm of the rain-fed production system. Although the gains from the development of rain-fed production may be more cost-effective than irrigation development, the strategy still leaves the performance of the economy exposed to the vagaries of nature as it does not achieve the objective of 'de-linking' the economy from rainfall variability. This could be achieved by developing water storage facilities that could be used for, among other things, developing irrigation. This strategy can have the impact of smoothing out agricultural production in such a way that it becomes less sensitive to rainfall variability. World Bank (2006) also advocates a similar approach.

It is essential to study why technical inefficiency is so low in the traditional irrigations systems in order to establish whether it is possible to apply the practices that enable the traditional irrigation systems to have this low inefficiency to modern irrigation systems. We do understand that when the production frontier shifts to a higher level, the probability of failing to achieve the frontier values also increases. However, it is still worthwhile to investigate whether there are lessons to be learned from the traditional systems that would enable a reduction in the inefficiency of the modern schemes.

We have also explored whether factors such as age, education and gender of household head, and whether the farmer visited the extension agent to seek advice and whether the extension agent visited the farmer to give advice are associated with technical inefficiency. Age was significant for the rain-fed farms with younger households achieving significantly higher technical inefficiency than the older farmers. Age was also significant in modern schemes with younger farmers achieving significantly lower technical inefficiency than older farmers, the reverse of the rain-fed result. We conclude that it is not only experience that counts in the irrigation schemes but also innovation (managerial skills) and the ability to accept extension advice. We conclude that the younger farmers may be more open to innovation and may also easily accept extension advice than older farmers in the irrigation schemes; hence they have low technical inefficiencies. Gender of the household head was significant in modern schemes, however, the differences in the means of technical inefficiencies was not statistically significant. The small sample of female-headed households may bias this result. This result warrants further investigation using a more representative sample of female-headed households. In the modern schemes those farmers who were visited by the extension agent had higher technical inefficiencies, a counterintuitive result. However, it is possible that the extension agents were targeting those farmers who really needed help, or alternatively extension agents may not have the recommendations that are directly pertinent to irrigated production and hence have little or no impact on inefficiency. The association between extension visits and technical inefficiency shows that extension in irrigated systems is a resource that can still be developed.

We also explored whether there is any association between production constraints, land preparation, soil fertility, weed control, pests and diseases, soil erosion, input access and moisture deficiency, and technical inefficiency. All constraints, except for land preparation, were significantly associated with the levels of technical efficiency for the purely rain-fed farmers. Except for moisture deficiency, those farmers who did not report experiencing the said constraints were seen to consistently have higher technical inefficiencies than those farmers who reported experiencing the constraints, also seemingly counterintuitive. We conclude that the farmers who reported experiencing the constraints may have successfully taken steps to try to reduce the impacts of the constraints; hence, they have lower technical inefficiency. However, farmers cannot do much about moisture deficiency on rain-fed production, and farmers may also not be able to do much about moisture deficiency on irrigation systems if the deficiency is caused by water running out. Therefore, those farmers who reported moisture deficiency did have significantly higher levels of technical inefficiencies than those who did not report moisture deficiency as a constraint. The input access constraint was significantly associated with the technical inefficiency for traditional irrigation farmers.

We also estimated gross margins for rain-fed and irrigated production. We conclude that the gross margins for irrigated production are higher than those of rain-fed production indicating that it maybe viable to put more land under irrigation. However, conclusive evidence of this can only be achieved when costs of establishment are taken into account together with gross margin. This result is only indicative of the viability of irrigation development. The gross margin analysis also showed that there is no significant difference between the gross margins for traditional and modern irrigation systems even though we showed that the production frontier for the traditional irrigation system is lower than that of the modern schemes. We conclude that this may be a result of two possible offsetting effects. First, the lower technical inefficiencies of the traditional farmers may be enough to offset the gross margin advantage of the higher frontier. Second, it is also possible that the traditional farmers may be achieving higher levels of allocative efficiency than the modern farmers. Further investigation is needed to establish why the higher frontier of the modern irrigation systems does not translate into higher gross margins. If the constraints can be identified then the modern schemes could achieve higher gross margins making them more viable.

Finally, we note that these observations are made from data collected from one production season. Agricultural production tends to be variable over seasons. If these results were to be made more robust, it is essential to collect exactly the same data from the same sample of farmers over two or three agricultural seasons. Such a study would lead to more robust conclusions for all the observations made from this study of a single season. Our data came from an above average rainy season based on data from the Ethiopian Meteorological Office. Irrigation tends to perform better in below average rainy years, so these figures may be slightly underestimated assessments of the performance of irrigation systems.

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