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Impact of small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia

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Abstract: This study uses Tobit and Logit models to examine the impacts of selected small-scale irrigation schemes in the Lake Tana basin of Ethiopia on household income and the likelihood of poverty, respectively. Data for these analyses were collected from a sample of 180 households. Households using any of the four irrigation systems had statistically significantly higher mean total gross household income than households not using irrigation. The marginal impact of small-scale irrigation on gross household income indicated that each small scale-irrigation user increased mean annual household income by ETB 3353 per year, a 27% increase over income for non-irrigating households. A Logit regression model indicated that access to irrigation significantly reduced the odds that a household would be in the lowest quartile of household income, the poverty threshold used in this study. Households using concrete canal river diversion had higher mean cropping income per household than those using other irrigation types. Key challenges to further enhancing the benefits of irrigation in the region include water seepage, equity of water distribution, availability of irrigation equipment, marketing of irrigated crops and crop diseases facilitated by irrigation practices.

Key words: Household income, absolute poverty, small-scale irrigation, Lake Tana Basin, Ethiopia

Introduction

Poverty alleviation during the past half century has been largely a result of economic growth (Roemer and Gugerty 1997). Developing countries that promote sustainable economic growth often reduce their poverty levels and can strengthen their democratic and political stability. They may also improve the quality of natural environment and even reduce their incidence of crime and violence (Loayza and Soto 2002). Agriculture is known to be the dominant source of food production and an important sector for sustaining growth and reducing poverty in many developing countries. For Ethiopia, agriculture is the leading sector in terms of income, employment and foreign exchange and national economic growth is determined largely by the performance of agriculture. Irrigation plays a key role in the performance of Ethiopian agriculture. Thus, irrigation may have an important impact on many development indicators for Ethiopia. Irrigation has served as one key driver behind growth in agricultural productivity, increasing household income and alleviation of rural poverty. According to Haile (2008), there are four interrelated mechanisms by which irrigated agriculture can reduce poverty, including: i) increasing overall food production and income, which can also reduce food prices, each of which helps poor households meet their basic needs, ii) protecting against risks of crop loss due to erratic, unreliable or insufficient rainwater supplies, iii) promoting greater use of yield enhancing farm inputs and iv) creation of additional employment, which together enables people to move out of the poverty cycle. In addition, Zhou et al. (2009) discussed how irrigation contributes to increased value of agricultural production by increasing crop yields enabling farmers to increase cropping intensity and to produce higher-value crops. Therefore, irrigation can be an indispensable technological intervention to increase household income. However, the impact of irrigation on income and the prevalence of poverty in a particular setting is an empirical question. The principal objective of this study is to examine the impacts of selected small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia. More specifically, this study examines the impact of access to irrigation on gross household income and the likelihood of the household being in poverty. Because different irrigation methods may have different effects, we also test whether the income levels for households using four different irrigation systems are statistically significantly different.

Methods

To evaluate impact of small-scale irrigation on the annual gross income of the household, all sources of income were considered. The income data were for household agricultural activities (rainfed and irrigated crops, livestock and their products), off-farm and non-farm incomes reported for various time periods during 12 months (from November 2009–October 2010). The income data were collected from November 2010 to February 2011. Data about livestock production and revenues were collected on weekly basis and aggregated to estimate annual income. The values of agricultural incomes are computed by multiplying the amount of each agricultural product (sold and consumed) with their annual average nominal price. Thus, our measure of income includes the total monetary value of production, not just cash income derived from sales. Some households may not derive income from livestock, off-farm and other activities. To control for factors other than irrigation that influence incomes (such as land size, inputs, agricultural production assets etc.), we estimated econometric models based on the agricultural economic household model (Singh et al. 1986). When values of the dependent variable (such as income) can have 0 values, it is appropriate to account for this in the econometric estimation (Barket et al. 2002; Nicholson et al. 2004; Aschalew 2009; Zhou et al. 2009). In this study, the impacts of irrigation on income were estimated using a Tobit model, sometimes referred to as a censored regression model.

The specific form of the Tobit model is:

$$Y_i = \beta X_i + \varepsilon_i$$

We define a new random variable Y_i^* transformed from the original one, Y_i, by

$$Y_i^* = 0, \text{ if } Y_i < 0$$

$$Y_i^* = Y_i, \text{ if } Y_i > 0$$

Where, Y_i is the observed dependent variable measuring combined cropping income, livestock income and off-farm or other income, Y_i^* is a latent variable, X_i is a vector of explanatory variables that influence incomes, β is a vector of parameters to be estimated and ε is a random disturbance term with mean 0 and variance σ^2. Using a Tobit model with zero as the censoring point when censoring occurs at a non-zero value may bias estimated coefficients (such as the impact of irrigation). To avoid this problem, the minimum of the observed values defines the maximum for the censoring value in the econometric model estimation. That means that an upper bound on Y_i is the minimum of the set (Y_i) by the same reasoning, because the observed total income is non-negative. A logical lower bound on total income (Y_i) is zero. In other words, logic constrains the feasible choice for Y_i to the closed interval:

$$Y_i \text{€}[o,\min(Y_i)]$$

This equation provides the censoring points to vary within the range of values that lies below the minimum of the observed, positive quantities (Holloway et al. 2004). The observed total minimum income at household level is ETB 1256, that is, a non-zero value. By considering the above revised approaches Tobit regression model was used with 1256 as lower limit.

Annual mean crop incomes of four different irrigation methods were compared using a single factor analysis of variance (one way ANOVA). Because the variance of the annual household income was statistically significantly different for the four irrigation methods based on the ANOVA *F* (sometimes called the overall *F* or omnibus *F)* post hoc Multiple Comparison tests were applied.

In the poverty analysis herein, the dependent variable is binary. A household is defined as in poverty and assigned a dependent value of 1 if the household's annual income is in the lowest quartile. If the household is not in the lowest income quartile, the value of the dependent variable is 0. Under this limited dependent variable model, the probability that the i^{th} household is in poverty is given by:

$$\text{Prob } (y = 1 \mid X) = F\,(X_{i,}\ \beta) \quad = \frac{e^{Z_i}}{1+e^{Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}}$$

where Z_i is a function of explanatory variables (X_{ki}) and expressed as:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \ldots\ \beta_k X_{ni} + \mu_i$$

where μ_i = error term. If P_i is the probability of the i^{th} household is being in the lowest income quartile, then ($1\text{-}P_i$) is the probability of not being in the lowest income quartile. Because the dependent variable, poverty, is unobserved and the resulting model is nonlinear, it cannot be estimated by using OLS so maximum likelihood estimation (MLE) is used. Greene (2002) indicates that either Probit or Logit models often are used for the dependent variable that takes dichotomous values (e.g. yes or no) or a choice between two alternatives. Both the Logit and Probit models guarantee that the estimated probabilities lie in the range 0 to 1 and that they are non-linearly related to the explanatory variables. Following Habtamu (2009) and Haile (2008), the dichotomous dependent variable is estimated by Logit model, for its mathematical convenience. The probability of being in poverty can be expressed in binary choice models or a logistic distribution function as:

$$\text{Prob (Yi = 1)} = \frac{\exp(\beta X_i)}{1+\exp(\beta X_i)} \text{Prob (Yi = 1)} = \frac{\exp(\beta X_i)}{1+\exp(\beta X_i)}$$

For the nonlinear dependent variable, the marginal effect of each independent variable is not straightforward to interpret. In the Logit model, the marginal effect of each independent variable on poverty should be transformed to Log-odds ratio coefficient, which is defined as:

$$\frac{Pro(Y=1)}{1-Pro(Y=1)} = \frac{\exp(\beta X_i)}{1-\exp(\beta X_i)}$$

The Log odds ratio shows change of the probability that a household is being in poverty if the independent variable (X_i) changes by one unit.

Basic statistical tests such as the t-tests, chi square, minimum, maximum and percentages used Statistical Package for Social Science (SPSS) for Windows Release (SPSS, Inc., Chicago, Illinois). The econometric models used for the income and poverty analyses were estimated in STATA/SE 10.0 for Windows (Stata Corp LP, College Station, Texas USA). Focus group discussions and key informant interviews were employed to provide irrigation users' perspective on the key challenges to enhancing the benefits from irrigation.

Results and discussions

Impact of small-scale irrigation on total income at household level

Controlling for other factors that influence incomes, access to irrigation (IRR) has a significant positive impact on the mean total income of a household (ETB 3353 per year) a 27% increase over the mean income for non-irrigating households. This supports the initial hypothesis that access to irrigation increases households' income, controlling for other factors. Although the econometric analysis alone cannot indicate directly why the increase in income occurs, irrigation allows the farmers to practise crop intensification and diversification, which increases crop yields and revenues from crop sales. Irrigation also increases the marginal land and labour productivity, increases the crop production and then promotes household income (Table 1).

Table 1. Marginal effects of determinants on household total income

Determinant	Marginal effect	Standard error
Age of household head (AGEHH), years	−16.51	50.65
Education of household head (EDUHH), 1 = read and write; 0 = No	4903.33***	1481.80
Gender of household head (GENDERHH), 1 = Male; 0 = Female	98.48	1752.30
Dependency ratio (DEPRATIO), dmnl	−1029.43	691.43
Family size in adult equivalent (FAMSZADUL),	1552.03***	504.99
Number of livestock (LIVESTO), number in TLU (1 TLU = 250 kg)	2281.29***	373.67
Access to irrigation (IRR), 1 = Yes; 0= No	3353.29**	1219.40
Agricultural asset holding (ASSETHH), Ethiopian birr	2.80***	0.34
Land holding size (LANDSZ), hectare	10274.89***	1604.70

***, ** Indicates significant at the 1% and 5% significance levels, respectively.

Impact of small-scale irrigation access on the likelihood of poverty

For the purposes of this study, the poverty line (often defined as households unable to attain their minimum nutritional requirements) was approximated as the value of current income at the twenty-fifth percentile of sample households. Of the sample households who live below the absolute poverty level, 88% did no irrigation and only 12% irrigated. This suggests that irrigation may have a significant impact on rural poverty alleviation. A Logit regression model is used to assess the impact of various factors including irrigation access on the probability that a household is in poverty. The estimated coefficient for dummy variable for access to irrigation was negative and significant and the calculated odds ratio is 0.14 (Table 2). These results suggest that the probability of being in poverty decreases if one has access to irrigation, other factors being constant.

Table 2. Parameter estimates of a logit model for determinants of a household poverty.

Determinants	Coefficient value		Odds ratio
Age of household head (AGEHH), years	0.02		1.02
Dependency ratio (DEPRATIO), dmnl	0.08		1.08
Gender of household head (GENDERHH), 1 = Male; 0 = Female	−1.58	**	0.21
Education of household head (EDUHH), 1 = read and write; 0 = No	−1.73	***	0.18
Land holding size (LANDSZ), hectare	−1.95	**	0.01
Agricultural asset holding (ASSETHH), Ethiopian birr	−0.001		0.99
Access to irrigation (IRR), 1 = Yes; 0= No	−1.95	***	0.14
Number of oxen in a household, number in TLU	−2.40	*	0.09

***, **,* Indicates significant at the 1, 5 and 10% significance levels, respectively.

Comparison of sample small-scale irrigation systems at household level

It is also relevant to compare the total mean annual household crop income under four different types of irrigating and non-irrigating households, even though this does not control for other factors that may influence mean annual crop income of household. For the four types of irrigation and non-irrigation systems, there are nine pair wise comparisons that were tested for differences with a combined overall significance level using the Games-Howell test (Table 3).

Table 3. Small-scale irrigation types and the mean annual crop income of a household

(I) Small-scale irrigation types	(J) Small-scale irrigation types	Mean difference (I–J)
Concrete canal river diversion	Traditional river diversion	20986**
	Motor pump	1689
	Pedal pump	22111***
	Non-irrigating	30063***
Traditional river diversion	Motor pump	–19296***
	Pedal pump	1124
	Non-irrigating	9077**
Motor pump	Pedal pump	20421***
	Non-irrigating	28374***
Pedal pump	Non-irrigating	7952**

***, ** Indicates significant at the 1% and 5% significance levels, respectively.

The statistical mean comparison revealed that concrete canal river diversion has a significant difference with traditional river diversion and pedal pump. Motor pump irrigation has also a significance difference with traditional river diversion and pedal pump. However, there is no significant difference between concrete river diversion and motor pump, nor a significant difference between traditional river diversion and pedal pump. The four irrigation systems have a significant difference with non-irrigation system.

Major constraints encountered in use of small-scale irrigation systems

A field survey with focus group discussion and key informant interviews indicates that small-scale irrigation's great benefits are accompanied with multi-dimensional challenges, some of them are:

Loss of water through seepage: this is caused by non-durability of the physical structure of river diversion.

Problems with irrigation water distribution: this causes conflicts between upstream and downstream irrigating households. There are no standardized programs to irrigate each cultivated crops. Irrigation water use depends only on spatial location of the farm plot; it does not consider the amount of water required for the type of cultivated crop, time interval of water application and the size of each irrigated land sizes.

Lack of spare parts for water pumps: this means lack of imported spare parts for motor pumps and pedal pumps are main causes for reduced efficiency in small-scale irrigation in the study area.

Lack of markets and marketing facility: this means that cultivated vegetables using small-scale are highly perishable and bulky crops, so an efficient marketing channel is necessary. However, the study area marketing system does not always facilitate outcomes desired by farmers. One reason is the similarity of products and marketing patterns. Onion and tomato are the dominant crops, often harvested by farmers at the same time, which leads to a high availability and low prices during the main marketing period. Compounding this, because there is no efficient storage system in the study area, products quality deteriorates rapidly, which means that farmers must sell within a very short time, often at what they consider low prices.

Crop diseases: this means the study area is intensively cultivated with the same crops for long periods of time. In addition to the loss of productivity and fertility, irrigated cultivation facilitates crop disease like root rot and cut warm.

Conclusion

Econometric analyses that control for other factors influencing household income indicate that accesses to small-scale irrigation increases mean household income significantly, by about ETB 3353 per year, or a 27% increase over non-irrigating households. The study indicates that a much higher proportion of households in poverty are non-irrigating rather than irrigating households. This suggests that irrigation has an important influence on rural poverty alleviation. The Logit model analysis indicates that use of irrigation reduces the probability of a household being poor, controlling for other factors. Additional analyses using ANOVA suggest that different irrigation systems may result in different income and poverty outcomes by type of irrigation system. However, this does not control for other factors influencing income, so the results are suggestive and should be explored further with a larger number of observations that would allow econometric analysis of the different systems. Qualitative results from focus groups and key informants suggest that the full potential of irrigation may not be achieved in the region based on problems and challenges identified with existing irrigation systems. The main problems identified by the study are lack of access to surface water, loss of water through seepage, irrigation water distribution, lack of spare parts for water pumps, high cost of fuel for water pumps, lack of market transparency and marketing facilities, crop disease and the perceived high cost of inputs.

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