Access to irrigation water-poverty nexus: Application of an Endogenous Switching Regression in Ethiopia

F.A. Adela[1]; J. Aurbacher[2]

1: Justus-Leibig University, Institute of Agribusiness Management and Food Economics, Germany, 2: Justus-Leibig University, Institute of Agribusiness Management and Food Economics, Germany

Corresponding author email: Fitsum.A.Adela@agrar.uni-giessen.de

Abstract:

The lack of consensus on the role of the agricultural sector in poverty reduction and pitfalls in impact study methodologies resulted in mixed findings on impact of irrigation. This study explores factors that determine farmer's decision to irrigate and whether access to irrigation water enhances livelihood of the farmers. Cross-sectional data from a survey of 240 smallholder farmers in Wondo Genet, Ethiopia was used for the analysis. Foster-Greer-Thorbecke indices indicated high poverty level among farmers without access to irrigation. Further analysis was undertaken using an endogenous switching regression (ESR) model. The correlation coefficient results proved the existence self-selection and endogeneity. Accordingly, variables like scheme governance, level of water scarcity, and access to network found to be some of variables that significantly affected the farmers' decision to irrigate. Model estimates further indicated that access to irrigation resulted in better life conditions when compared to counterfactual situation. Farm income of the households has increased by 107% and 171% for irrigation users and non-users, respectively. Similarly, per adult equivalent consumption expenditure has shown increase by 26% and 57% for irrigation users and non-users. Key Words: Agriculture, Irrigation, smallholder, Wondo Genet, Ethiopia, Endogenous Switching Regression, poverty, Farm income, Consumption

Acknowledegment:

JEL Codes: D01, O13

#1503

Access to irrigation water-poverty nexus: Application of an Endogenous Switching Regression in Ethiopia

Abstract

The lack of consensus on the role of the agricultural sector in poverty reduction and pitfalls in impact study methodologies resulted in mixed findings on impact of irrigation. This study explores factors that determine farmer's decision to irrigate and whether access to irrigation water enhances livelihood of the farmers. Cross-sectional data from a survey of 240 smallholder farmers in Wondo Genet, Ethiopia was used for the analysis. Foster-Greer-Thorbecke indices indicated high poverty level among farmers without access to irrigation. Further analysis was undertaken using an endogenous switching regression (ESR) model. The correlation coefficient results proved the existence self-selection and endogeneity. Accordingly, variables like scheme governance, level of water scarcity, and access to network found to be some of variables that significantly affected the farmers' decision to irrigate. Model estimates further indicated that access to irrigation resulted in better life conditions when compared to counterfactual situation. Farm income of the households has increased by 107% and 171% for irrigation users and non-users, respectively. Similarly, per adult equivalent consumption expenditure has shown increase by 26% and 57% for irrigation users and non-users.

Key Words: Agriculture, Irrigation, smallholder, Wondo Genet, Ethiopia, Endogenous Switching Regression, poverty, Farm income, Consumption

1. Introduction

Agricultural water is usually the major constraint in agricultural production in developing countries (Namara et al., 2010; Singh et al., 2009). And the lion's share of the water poor population lives in already poor regions of the world like South Asia and SSA. Moreover, the average land holding size in developing countries is continually declining and is less than two hectares (Singh et al., 2009). Hence, it has been indicated by several studies in the SSA in general and Ethiopia in particular that, growth in food production only through area expansion is no more possible. It should be complemented with adopting productivity enhancing alternatives. However, use of productivity enhancing techniques and inputs is effective only when there is enough agricultural water availability (Gebregziabher, Namara, & Holden, 2009).

Irrigation in general and small scale traditional irrigation in particular has been practiced in Ethiopia since ancient times (Aberra, 2004; Bacha, et al., 2011). The country has a potentially irrigable land of 5.3 million hectares out of which only 0.7 million hectares is currently under irrigation (Awulachew & Ayana, 2011). Since recently, there has been implementation of projects to develop and renovate significant number of small scale irrigation schemes with the aim of improving the livelihood of the rural poor. Studies made to examine whether such development of irrigation schemes are serving their purpose in the country are limited(Bacha et al., 2011).

Impact studies exhibit difficulties because of the involved theoretical and empirical complications. Studies so far used several approaches depending on the data availability and objectives. These methods range from two-stage least square method (Amare et al., 2012; Bravo-Ureta et al., 2006; Hanjra et al., 2009), Propensity Score Matching (PSM) (Kassie, Shiferaw, & Muricho, 2010), and to econometric modeling like Heckman's selectivity model (Bacha et al., 2011). Econometric models including Heckman's selection model, endogenous and exogenous switching models were applied at different times to deal with drawbacks of impact studies especially relating to selectivity bias and issues of endogeneity (Dutoit, 2007). A study by Bacha et al., (2011) applied Heckman's selectivity model using two stage estimation technique to examine impact of small scale irrigation on household poverty in Ethiopia. Simultaneous estimation of endogenous switching regression model using full information maximum likelihood technique is currently gaining popularity because most research problems involve endogenous switching and exhibit self-selection. Other studies undertaken in SSA used endogenous switching regression to study impacts of soil and water conservation technology (Abdulai & Huffman, 2014), adoption of improved maize varieties (Khonje, Manda, Alene, & Kassie, 2015), effects of modern agricultural technology (Asfaw, 2010).

This study aims at examining factors that affect irrigation decision and the impact of irrigation on welfare of small holder farm households in Wondo Genet, Ethiopia using ESR. It differs from other studies which dealt with irrigation adoption and impact by the methodology and techniques employed while those studies which used the same methods consider adoption of other technologies.

2. The study area and Survey Design

2.1 The study area

Wondo Genet is located about 263 Km south of Addis Ababa in the south central rift valley of Ethiopia. Geographically it is situated between $7^0$1'N38^{0}35'E latitude and 7.017^{0}N 38.583^{0}E longitude. It covers an area with altitude ranging from 1600 to 2580 meters above sea level. The mean annual temperature is between17^0 and 19^0. The climate is characterized as sub-humid with bi-modal rainfall distribution. It receives an annual average rainfall of 1079.7 mm with February– April being low rainfall months and June to September the main rainy season.

Small holder perennial crop farming dominates the agriculture in the area; the major crops being enset, khat, and sugarcane (Dessie & Kinlund, 2008). Water from two major rivers -Worka and Wosha- is used for irrigation during dry seasons based on allocation schedule set by water user association committee members. The WUA lacks legal framework and mentioned for unfair distribution of water. Mode of irrigation is only furrow and related institutional and infrastructural arrangements are weak. Only part of the major canal which is used to divert the river from the head work is constructed with concrete and cement lined; 1.648 km is lined out of 4.6 km long scheme. The rest of the water way is earthen canal dug by the farmers themselves. Local markets are relatively not far compared to other areas in the region; the average distance of the local market being 5.4 km away from the study area. The market systems, however, are underdeveloped and most farmers sell outputs on farm with involvement of brokers. Access to formal credit is very limited.

2.2 Data

2.2.3 Study design

Data from household survey of 240 small holder farmers located in Wotera Kechema Kebele (Peasant Association) pertaining to 2014/15 cropping season was used for this study. Initially, the Woreda (district) was selected purposively for its relative long years of practice of irrigation and accessibility. There are two major rivers (Worka and Wosha) on which the majority of irrigation is undertaken at the moment. Out of the two rivers the irrigation scheme on Worka River is relatively old and covers wider area. It is also the scheme with high level of reported scarcity as indicated by the Woreda Agriculture and Rural Development office. In terms of coverage, it has a potential of irrigating a total area of 345 ha: 225 ha Wotera Kechema and 120 ha Wosha. Accordingly, Worka river irrigation scheme was selected for the study. A sampling frame was prepared from the list of 742 farm households residing in Wotera Kechema Kebele in three categories: Upstream, middle stream, and Downstream. Then from these categories 80 households each were selected using systematic random sampling.

The household survey was undertaken by five enumerators after undertaking an adequate level of training and a pilot survey. The selected enumerators spoke the local language (*Sidamu Afo*) fluently which helped to maintain the reliability of the collected data. A well designed and tested questionnaire was used as an instrument for the survey. Additional data was also collected through key informant interviews. Crop water use and river discharge data was collected by experts in the field using the Area-Velocity method by float technique. Agro-ecological and climate data for the study area is collected from the concerned offices and organization.

2.2.4. Descriptive summary

Table 1 presents descriptive statistics of the data for the relevant variables included in the estimation of the model. For the descriptive analysis t-test was used to show the difference between irrigation users and non-users with respect to relevant continuous variables. In addition, Chi-square test was used to describe the binary variables.

Table 1 Descriptive summary of variables used in estimations

Item and unit	Users	Non-users	p-value
Household characteristics			
Head male (1=male)	0.95	0.98	0.20[1.61]
Age of head (Year)	46.95	43.58	0.038**
Household size adult equivalent (#)	5.61	5.09	0.024***
Labor endowment in adult equivalent (#)	3.86	3.26	0.003***
Education level completed by head (years)	2.96	2.73	0.285
Highest education level completed by adult (years)	4.22	3.37	0.038**
Farm Characteristics			
Land holding per Plot (ha)	0.172	0.148	0.02***
Land covered by cash crop (%)	0.780	0.613	0.000***
Asset			
Landholding (ha)	0.436	0.323	0.007***
Household asset value (ETB)	66708.67	26927.71	0.000***
Income and Consumption			
Farm income per ha (ETB)	432506.60	101688.80	0.000***
Non-farm income (ETB)	3165.71	4033	0.230
Total per adult equivalent food consumption expenditure (ETB)	3964.75	2848.24	0.000***
Access to market and modern technology			
Distance of the nearest market (km)	5.29	5.74	0.060**
Chemical fertilizer per ha (Kg)	929.47	621.81	0.000***
Insect/herbicide per ha (ml)	21.48	12.67	0.002***
Institutional and information access related variables			
Visit by extension officers (Yes=1)	0.88	0.87	0.776[0.08]
Level of scarcity (highly scarce=1)	0.97	0.50	0.000[52.41]***
Governance problem (Yes=1)	0.53	0.71	0.009[6.78]***
Own radio (Yes=1)	0.63	0.46	0.013[6.21]***
Own mobile phone (Yes=1)	0.662	0.35	0.000[21.12]***

***significant at 1% level, **significant at 5%level, t-values in square brackets

Source: own calculation from survey data

As it is presented on the table the irrigation users have significantly higher mean value for all of the continuous variables except for few. As per the binary variables, the number of households among the non-users who responded that there is high level of scarcity is significantly higher than the user households. Similarly, households were asked several questions regarding the current management and governance of the irrigation scheme on the river, how they are adapting to the water scarcity problem they face, what they think is permanent solution to the problem, and what should the concerned stakeholders do to solve the problem. Their responses to all the questions were categorized in to households who indicated that there is governance problem and those who do not. Accordingly, the number of households who indicated the existence of governance problem is significantly higher among the non-user households than the users. Ownership of radio and mobile phone is used to capture access to information and networking.

The descriptive statistic on Table 1, however, provides only the mean differences and cannot be used to conclude about the factors that affect the farmer's decision to irrigate or not. Further, the above analysis does not account for other important unobservable characteristics of the households. Results of further analysis using endogenous switching regression model will be presented and discussed in section 5.

3. Conceptual Framework

3.1 Poverty

The concept of poverty has evolved from the original idea of inadequacy of income consumption and wealth (O'Boyle, 1999; Watts, 1968) to Sen (1981) concept of capabilities and functioning and further to include multidimensional aspects like socio-political rights, access to important service and infrastructure, vulnerability etc. (Namara et al., 2010; Smith, 2004). Moreover, absolute and relative poverty are commonly mentioned in poverty literatures. Absolute poverty refers to the head count of households who are unable to afford certain standard of basic goods and services. Relative poverty, on the other hand, measures the relative shortfall of a household's income from the economy's average. Another concept related to, but wider than poverty is equity. It refers to the level of equality in income and wealth distribution. Poverty is also dynamic in that factors that affect poverty can change from time to time (Smith, 2004).Commonly, the Foster-Greer-Thorbecke (FGT) indices developed by Foster et al., (1984) are used in poverty analysis.

3.2 Water poverty

Water poverty can relate to either physical or economic water scarcity. Most of the time poor people do not have access to adequate quantity and quality of water because the water is physically unavailable. In other cases people face water scarcity or they cannot access water because of poor infrastructure, mismanagement, corruption etc. (Dudu & Chumi, 2008; Namara et al., 2010; World Bank, 2016).

Water scarcity and incidence of poverty are not necessarily linked; access and control is more crucial than endowment in several cases (Namara et al., 2010). One cannot deny, however, that whatever the cause of poverty may be, increasing scarcity of and competition over water is major challenge to poverty reduction efforts of any kind. It is highly likely that scarcity of water will increase into the future mainly because of population growth, reallocation to competing uses like industries, and climate change. This, in turn, more than proportionately affects the already poor segment of the population (Rosegrant, Ringler, & Zhu, 2009).

3.3 Access to irrigation and poverty linkage

Studies show mixed results regarding the impact of investment in irrigation on poverty alleviation. Jin et al., (2002) and Rosegrant & Evenson (1992), for instance, found no direct relation between irrigation, productivity, and poverty reduction in Asia. Similar results were indicated by studies in Ethiopia (Gebregziabher et al., 2009). Contrary to the above claims, other studies indicate a positive linkage between irrigation, productivity, poverty reduction and food security (Bacha et al., 2011; FAO, 2003; Hussain & Hanjra, 2004; Smith, 2004; Wichelns, 2014). This lack of agreement on the impact of irrigation on poverty reduction also follows on the emerging debate on the impact of agriculture in growth and development as a whole (Gebregziabher et al., 2009). The deductions made by this studies, however, are highly influenced by the methodologies employed and the perspectives considered. Micro level studies in this regard, mostly witnessed a strong and positive impact of irrigation on poverty reduction unlike the macro level counterparts (Gebregziabher et al., 2009).

Irrigation impacts poverty reduction in a complex pathway including productivity, employment, resilience and sustainability, consumption and nutrition, and indirect economic impacts on the wider economy. For instance, the benefits of irrigation can be viewed from the perspective of its impact on improved use of productivity enhancing inputs like fertilizer and improved varieties. This use of productivity enhancing inputs in turn results in higher productivity and income to the farmers. The wider economy can also benefit indirectly through backward linkage in the form of income and employment (Gebregziabher et al., 2009; Namara et al., 2010; Smith, 2004). There is, however, concern on the sustainability of the impacts and the long run scenarios. However, ‘with irrigation’ effort is for sure the most likely to help achieve poverty reduction and growth objectives than the without scenario (Smith, 2004).

3.4 Issues in and methods of impact studies

The critical issue in impact study is acknowledging the potential biases. Most of the time two sources of biases are mentioned. The first one relates to the possibility of significant difference between the participants and non-participants due to observable farm and household characteristics. These characteristics may have direct and significant impact on the outcome variable. Secondly, unobservable factors like skill and attitude may result in difference among households and may affect the behavior of the households towards deciding to participate. Therefore it is crucial to recognize that difference between the participants and non-participants may not be attributed only to the treatment but also to initial differences among them. Therefore, the selected impact assessment model should either help to eliminate selection bias or be sound enough to account for it (Bacha et al., 2011; Wooldridge, 2003; World Bank, 2010).

Several methods have been used so far in various impact studies. These methods differ in the way they account for selection bias. Some of the methodologies, however, have major drawbacks of ignoring the issue of self-selection and difference between adopters and non-adopters (Kassie et al., 2010; World Bank, 2010). For instance, the simplest method would be using Ordinary Least Square (OLS) through including the treatment as a dummy variable in the outcome function. However, considering the systematic difference between users and non-users resulting in unobserved selection bias, the results of OLS estimation are biased and inconsistent (Bacha et al., 2011; Di Falco et al., 2011; World Bank, 2010). Such unobservable factors could not be captured and cause correlation between the observed explanatory variables and the error term (Abdulai & Huffman, 2014).

Another commonly used method is Propensity Score Matching (PSM). This method assesses treatment effects between participants and matched individuals. The matching is undertaken only on observed characteristics assuming that a selection bias occurs only due to observable characteristics (World Bank, 2010). It, however, does not account for the possibility that there is a latent variable that simultaneously influences selection and outcome (Ravallion, 2005).

Later econometric models like Heckman's selection model, and endogenous and exogenous switching models emerged. These models assume that the impact of explanatory variables is different depending on which regime applies. There are basic differences on two crucial issues. One relates to the concept that whether the regime is determined inside the model or outside. Hence, the switching could be endogenous or exogenous. Secondly in some instances, both regimes are observable while some others work with only one regime observed (Dutoit, 2007). Comprehensive switching regression was considered by Goldfeld & Quandt (1972) with two regimes. This switching regression model was exogenous because of the assumption made about the error terms. The same exogenous switching regression model was extended by Goldfeld & Quandt (1973) to simultaneous equation systems (Lee et al., 1982).

Maddala & Nelson (1975) extended the model to make it possible to deal with endogenous switching. Studies that used Endogenous Switching Regression approached the modeling in two stage estimation which requires cumbersome adjustment to produce consistent standard errors (Kassie et al., 2010; Khonje et al., 2015). Full Information Maximum Likelihood technique to simultaneously estimate Endogenous Switching Regression models are suggested as the most efficient in this regard (Di Falco et al., 2011; Kassie et al., 2010; Lokshin & Sajaia, 2004).

3.5. Theoretical Model Specification

The decision to adopt a technology can be modeled in a random utility framework by expressing the unobservable utility from adoption and non-adoption through observable variables (Khonje et al., 2015). Accordingly, use of irrigation is modeled considering the assumption that small holder farmers choose between irrigating and not irrigating. It is assumed that the farmers consider the benefit from irrigation through the farm income derived from crop production to decide to irrigate. The following model specifies the selection equation P* where P* is the latent variable which is not observed. P* can, however, be expressed as a function of some observed farm, household and institutional characteristics.

$$P^* = \alpha Z_i + u_i$$

$$I_i = 1 \ if P^* > 0 \ and \ I_i = 0 \ if \ P^* \leq 0 \qquad 1$$

I_i is a binary variable which takes a value of 1 for farmers who irrigate and 0 for those who do not irrigate. Z_i represents factors that affect the irrigation decision. α denotes the vector of parameters indicating the magnitude and direction of each explanatory variable' s effect on the decision to irrigate. The residual u_i captures the unobserved factors and measurement errors.

The two regimes that the small holder farmers fall in to are represented by the following two regression equations.

$$Regime\ 1:\ Y_{1i} = \beta_1 X_i + \varepsilon_{1i} \quad if I_i\ = 1 \qquad 2a$$

$$Regime\ 2: Y_{2i} = \beta_2 X_i + \varepsilon_{2i} \quad if\ I_i = 0 \qquad 2b$$

Y_{1i} and Y_{2i} are the dependent outcome variables determined by the exogenous variables X_i, $\beta 1$, and $\beta 2$, are parameters that show the direction and strength of the relation between the outcome variable and the independent variables. ε_{1i} and ε_{1i} are error terms.

Several approaches are available for use in estimating the endogenous switching model. Two step least square or maximum likelihood estimation can be used through estimating one equation at a time (Lokshin & Sajaia, 2004). These approaches, however, are mentioned to be inefficient and resulting in heteroskedastic residuals in that they need 'cumbersome adjustments' to drive consistent standard errors (Abdulai & Huffman, 2014). This drawback can be tackled by estimating the model using the Full Information Maximum Likelihood (FIML) technique.

4. Empirical Model Specification

Farmers decide to irrigate if they assume that the net benefits in the form of farm income from irrigating is higher than that of not irrigating. Several types of unobservable factors also determine the farmers' decision to irrigate resulting in a selection bias. A selection bias arises if unobservable factors affect both error terms in the selection equation (u_i) and the outcome equation (ε). This results in a correlation between the error terms of the selection and continuous equation: corr (ε,u_i) = ρ≠0. This correlation between the error terms witnesses the existence of an endogenous switching (Maddala, 1986).

The unobservable factors may fall under personal, social or institutional characteristics. They can include natural managerial and technical skills, the farmer to farmer networks and informal associations to formal institutions like water user associations. They can also include transaction costs incurred by the farmers because of poor infrastructure (Abdulai & Huffman, 2014). Provided that different farm and farmers' characteristics determine whether the farm household decides to irrigate or not the following specification gives the outcome regression equations for the two regimes:

$$users\text{: } Y_{1i} = \beta_1 X_i + \varepsilon_{1i} \quad if I_i = 1 \qquad 3a$$

$$non - users\text{: } Y_{2i} = \beta_2 X_i + \varepsilon_{2i} \quad if\ I_i = 0 \qquad 3b$$

Assume that the error terms $\varepsilon_{1i,}$ $\varepsilon_{2i,}$ and u_i have a trivariate normal distribution, with mean vector zero and covariance matrix (Lee et al., 1982),

$$\text{Cov}(ui,\varepsilon 1i,\varepsilon 2i) = \begin{bmatrix} \sigma_u^2 & . & . \\ \sigma_{\varepsilon 1u}^2 & \sigma_{\epsilon 1}^2 & . \\ \sigma_{\epsilon 2u}^2 & . & \sigma_{\epsilon 2}^2 \end{bmatrix} \qquad 4$$

Where σ_u^2 variance of the error term in the selection equation, $\sigma_{\epsilon 1}^2$ and $\sigma_{\varepsilon 2}^2$ are variances of the error terms in the continuous equations. $\sigma_{\varepsilon 1u}^2$ and $\sigma_{\epsilon 2u}^2$ are covariance of ui and ε1i and ε2i respectively. Since Y_{1i} and Y_{2i} are not observed simultaneously a covariance of the corresponding error terms is not defined (Maddala, 1983). This structure of the error terms indicates that the error terms of the outcome equation and the error term of the selection equation are correlated which results in non-zero expected value of ε_{1i} and ε_{2i} given u_i - error term of the selection equation (Abdulai & Huffman, 2014). Therefore, the expected values of the truncated error terms $E(\varepsilon_1 \mid I = 1)$ and $E(\varepsilon_2 \mid I = 0)$ are given below:

$$E(\varepsilon 1 \mid I = 1) = E(\varepsilon_1 \mid u > -Z\alpha)$$

$$= \sigma_{\varepsilon 1u} \frac{\varphi(\frac{Z\alpha}{\sigma})}{\Phi(\frac{Z\alpha}{\sigma})} \equiv \sigma_{\varepsilon 1u}\ \lambda_1 \qquad 5a$$

And,

$$E(\varepsilon_2 | I = 0) = E(\varepsilon_2 \mid u \leq -Z\alpha)$$

$$= \sigma_{\varepsilon 2u} \frac{-\varphi(\frac{Z\alpha}{\sigma})}{1 - \Phi(\frac{Z\alpha}{\sigma})} \equiv \sigma_{\varepsilon 2u} \ \lambda_2 \qquad 5b$$

φ and Φ are the probability density and cumulative distribution function of the standard normal distribution, respectively. The ratio of φ and Φ evaluated at Zα is referred to as the inverse Mills ratio λ_1 and λ_2 (selectivity terms). If the estimated covariance $\sigma^2_{\varepsilon 1u}$ and $\sigma^2_{\varepsilon 2u}$are significantly different from 0 the decision to irrigate and the outcome variable (farm income) are correlated. This implies endogenous switching and the presence of a sample selectivity bias (Maddala, 1986; Maddala & Nelson, 1975).

Where ρ_1 and ρ_2 are correlation coefficients between the selection equation error term u_i and the error terms of the outcome equations ε_1 and ε_2. Further, estimations of treatment effects were made. Average Treatment effect on the Treated and Untreated (ATT and ATU) are computed using the results for expected values of the dependent variable for users and non-users in actual and counterfactual scenarios:

$$E(Y_{1i} \mid I_i = 1, X_{1i}) = \beta_1 X_{1i} + \sigma_{\epsilon 1u}\rho_1 \frac{\varphi(Z\alpha)}{\Phi(Z\alpha)} \qquad 6$$

$$E(Y_{2i} \mid I_i = 0, X_{2i}) = \beta_1 X_{2i} - \sigma_{\epsilon 2u}\rho_1 \frac{\varphi(Z\alpha)}{\left(1 - \Phi(Z\alpha)\right)} \qquad 7$$

$$E(Y_{2i} \mid I_i = 1, X_{1i}) = \beta_2 X_{1i} + \sigma_{\epsilon 2u}\rho_2 \frac{\varphi(Z\alpha)}{\Phi(Z\alpha)} \qquad 8$$

$$E(Y_{1i} \mid I_i = 0, X_{2i}) = \beta_2 X_{2i} - \sigma_{\epsilon 1u}\rho_2 \frac{\varphi(Z\alpha)}{\left(1 - \Phi(Z\alpha)\right)} \qquad 9$$

ATT is the difference between the expected value of the outcome variable from equation 6 and 8. It is the difference between the expected value of the dependent variable for users and if they had not used. ATU is the difference between equations 7 and 9 estimating the difference between the expected value of the outcome variable for non-users and if they had used the water.

5. Results and discussion

5.1. Poverty analysis

The level of poverty was tested between irrigation water users and non-users using Foster-Greer-Thorbecke (FGT) indices. Based on the recommended daily energy requirement of 2100Kcal Poverty line (Z) of Birr 3329.27 (=USD 123.30) per adult equivalent per year is used to estimate the FGT indices of poverty. The poverty line was constructed using food and non-food per adult equivalent consumption expenditure of the households. Table 2 below shows the results:

Table 2 FGT indices on consumption at α=0, 1, and 2 and Z= ETB 3746.77

Poverty estimates	Groups	
	Users	Nonusers
Incidence	0.28	0.67
Depth	0.03	0.18
Severity	0.008	0.06

Source: computation on own survey date

The incidence of poverty is measured by the head count index and shows that 67% of the households who do not irrigate fall below the consumption based poverty line (Z) of ETB 3329.27. On the other hand, only 28 % of the farmers who irrigate are below the poverty line. This result reinforces the claim by several studies that prevalence of poverty is higher in rain fed areas than irrigated areas (Bacha et al., 2011; Hanjra et al., 2009; Wood et al., 2004). The depth and severity of poverty is also higher among the non-users. The consumption expenditure of the non-users should be pushed up by 18% of its current amount if they have to be lifted out of poverty while it takes only 3% for users. These results are in line with most micro level empirical studies on poverty and irrigation linkage. Bacha et al., (2011), for instance, found out that depth of poverty among non-irrigators in Ambo district in Western Ethiopia is 21 % while it is only 10% among users.

5.2. Results of switching regression analysis

As indicated by the descriptive and poverty analysis above there is significant difference in several relevant variables and wellbeing indicators between the users and nonusers. These differences could be due to several observable and unobservable factors in addition to access to irrigation. Two outcome variables were used as proxy for welfare of the households for further analysis: Farm income per ha and per adult equivalent food consumption expenditure. Table 3 presents the estimation results for the model with farm income per hectare as the outcome variable.

Table 3: Full information maximum likelihood estimates of the switching regression model for farm income per ha

Variables	Model Estimates		
	Irrigation 1/0	Users	Non-users
Highest Education level of adult member	0.023(0.66)	-0.020(1.73)*	0.008(0.37)
Age of the head of the household	0.011(1.26)	-0.003(0.99)	0.003(0.48)
Log of distance to nearest market	-0.011(0.24)	-0.017(0.90)	-0.045(1.37)*
Visit by extension workers	0.116(0.39)	0.185(1.49)*	0.200(0.93)
Log of Landholding	0.367(1.15)	0.412(3.68)***	0.584(2.41)***
Log of landholding per plot	-0.375(0.91)	-0.264(1.92)**	-0.655(2.27)***
Log of percentage of land covered by cash crop	1.170(3.38)***	0.417(3.02)***	-0.286(1.31)*
Log of Time endowment in adult equivalent units	-0.086(0.28)	0.038(0.36)	0.068(0.32)
Log of non-farm income	-0.088(2.91)***	0.002(0.26)	0.041(2.27)***
Log of chemical fertilizer applied	0.136(1.04)	0.198(3.67)***	0.096(1.18)
Log of pesticide applied	0.124(1.55)*	0.151(4.20)***	0.143(2.61)***

Owned radio(1/0)	0.522(2.44)***		
Owned mobile phone (1/0)	0.870(3.96)***		
Scarcity level (high= 1/Low =0)	-2.177(5.64)***		
Governance (1/0)	-0.578(2.52)***		
Constant	0.415(0.33)	11.41(27.08)***	9.31(12.50)***
ρ_1, ρ_2		-0.734[0.107]**	-0.478[0.263]*
Model diagnosis			
Wald x^2	109.28***		
Log likelihood	-268.58		
LR test of independence	19.66***		

Note: Absolute value of z statistics in parenthesis standard errors in square brackets

*Significant at the 10% level, ** Significant at the 5% level, ***Significant at the 1% level

Source: Own calculation using survey data

The second column of table 3 reports the estimates for the determinants of the decision to irrigate. Education and age as explanatory variables have positive non-significant association with the irrigation decision of the farmers. Generally, education tends to have positive association with new technology adoption among farmers because of better access to and comprehension of information on the technologies (Norris & Batie, 1987). Studies have indicated a positive relationship between education and age and adoption of new technology (Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Lin, 1991; Nhemachena & Hassan, 2007) while others found out negative association between the variables (Shiferaw & Holden, 1998). Huffman (2001), however, argues that when an intervention has been there for relatively long time education and experience may not significantly affect decision to participate. This reinforces the above result considering irrigation has been practiced in the study area for at least the last 30 years.

Land covered by cash crops has positive impact the decision to irrigate. The common cash crops grown in the study area are sugarcane and khat on which irrigation is widely practiced. Therefore, households with larger share of their land covered by cash crop are likely to irrigate than the others. Land size per plot, on the other hand, has negative effect on the decision to irrigate. This is possibly because farmers with smaller plots can increase their production only by intensifying through adopting of technologies like irrigation. Previous studies indicated mixed results on the association of land size and probability of adoption of technology (Bradshaw et al., 2004; Deressa et al., 2009; Khonje et al., 2015). Similarly time endowment shows negative association with the decision to irrigate. The negative relationship can be attributable to the fact that the study area is one of the areas with high population density and resulting land fragmentation. In southern Ethiopia the rural youth is forced to search for other livelihood options because of scarcity of agricultural land (Bezu & Holden, 2014). The average land holding in the country is 1.37 ha (Central Statistical Agency & World Bank, 2013). Some studies in Ethiopia identified similar result (Tizale, 2007) while others showed positive association between labor endowment and adoption decision (Deressa et al., 2009). Non-farm income has negative and significant impact on practice of irrigation. This result is reinforced by the findings of Wozniak (1984) that participation in non-farm activities may constrain the amount of labor hour available for farm activities.

The variables representing amount of chemical fertilizer and pesticide applied show positive relationship. This is because farmers who irrigate tend to use modern inputs to enhance productivity. It is commonly argued that stable supply of agricultural water would encourage farmers to invest on productivity enhancing inputs (Aberra, 2004).This relationship is supported by findings of Gebregziabher et al., (2009), Namara et al., (2010) Smith, (2004) who indicated that irrigation enhances the use of productivity boosting inputs.

Proper specification of the model requires the inclusion of at least one explanatory variable in the selection equation which directly affects the irrigation decision but not the outcome variable (Abdulai & Huffman, 2014; Khonje et al., 2015). Accordingly, proxy variables for access to information and networks represented by ownership of a radio and mobile phone were used. Estimates for both variables are positive and significantly different from zero. Bandiera & Rasul (2006) found out similar result in their study that farmers' decision to participate in an intervention is influenced by their network with family and friends. The 'scarcity level' is another variable used to represent the level of scarcity of water farmers are facing with negative and highly significant result. This shows that scarcity of water is hindering the farmers from irrigating. This is reinforced by the empirical findings of several studies indicating water as the major constraint in agriculture in most developing countries in the world as well as Ethiopia (Hanjra et al., 2009; Namara et al., 2010).

The variable governance is a dummy variable used to capture the institutional, scheme governance and allocation of water issues in the area. The estimate for the proxy variable is positive and significantly different from zero. The result is plausible knowing that one of the major problems shared by all small-scale irrigation schemes in Sub-Saharan Africa is related to the application of irrigation water attributable to excessive abstraction of water by upstream users(Aberra, 2004). Studies pointed out that the common type of water scarcity in Sub-Saharan Africa is economic scarcity which results from poor governance and mismanagement (CTA, 2011; Dudu & Chumi, 2008). The findings of a study by (Awulachew & Ayana, 2011) also indicated proper management of the already developed schemes should be given equal attention as developing new ones. If implementation of small scale irrigation scheme is to be successful 'group organization and cohesion' is crucial (Aberra, 2004) and 'well organized' water user associations and farmers cooperatives need to be established (Setegn et al., 2011).

Another important finding is the sign and significance of the correlation coefficients ρ_1 and $\rho_{2.}$ The results show that the coefficients are statistically significant for both users and non-users indicating the existence of self-selection. The estimate is also negative for both users and non-users indicating positive selection bias such that farmers with above average farm income tend to decide to irrigate. The likelihood ratio test is also significant indicating the existence of joint dependence between the outcome and selection equation between users and non-users.

The model estimates of the variables against farm income per ha for users and non-users are presented on the third and fourth column of table 3. Education shows negative and statistically significant result for users. Di Falco et al., (2011) found similar results for literacy and production per ha in Ethiopia. The adult members of the households with higher level of education tend to get involved in non-farm employments. This in turn suppresses the farm income because the time allocated to farm activities will be less. Distance to local markets measured in kilometers also negatively and significantly affects the farm income per ha for both the users and non-users. Advice and information from the agricultural extension workers as measured by visit by the officers shows positive association with farm income for both users and non-users. This is in line with the argument that farmers with better information and advice from extension workers are likely to have better productivity (Abdulai & Huffman, 2014).

Land holding has positive and significant impact on the outcome variable for both users and non-users. On the contrary, landholding per plot has negative and significant impact on farm income per hectare for both users and non-users. The negative and significant impact of the farm size per plot follows well the argument of the inverse farm size productivity relationship. Studies proved that small farms are more productive than big farms (Abdulai & Huffman, 2014). A study in Ethiopia also found out that land pressure is strongly associated with crop yield and income proving the holding of Boserup's hypothesis (Headey, Dereje, & Taffesse, 2014) The amount of non-farm income earned by the non-user farm households has a positive and significant impact on their farm income unlike the users. This is because the income from non-farm sources can be invested to purchase productivity enhancing inputs like fertilizers and improved crop varieties (Abdulai & Huffman, 2014). The amount of chemical fertilizer and insect/herbicide applied has positive association with farm income of both users and non-users with highly significant impact on farm income of only users.

The proportion of farm covered by cash crops also has significant positive and negative impact for users and non-users, respectively. Users harvest Khat, one of the most traded cash crops in the area, at least twice per year. The non-users on the other hand harvest this crop only once per year because they produce using rainwater. Regarding sugarcane the non-users complain about quality and yield compared to the one exposed to enough water. As the largest source of farm income, therefore, as the share of farm covered by cash crops increase the farm income per ha of the non-users decreases significantly while in increases for the users.

A model was also with the total per adult equivalent food consumption as dependent variable. Table 4 below presents the model results:

Table 4: Full information maximum likelihood estimates of the switching regression model for total per adult equivalent food consumption

Variables	Model Estimates		
	Irrigation 1/0	Users	Non-users
Log of farm income	1.562(6.69)***	0.070(1.92)**	0.103(1.34)*
Highest education level of adult member	-0.010(0.24)	0.001(0.27)	0.002(0.24)
Age of the head of the household	0.009(0.75)	3.4 e-^{05} (0.02)	5.9e-^{05}(0.02)
Log of landholding	-0.870(2.47)**	0.035(0.68)	0.035(0.48)
Ratio of Log of land size allocated to cash crop to food crop	0.385(1.46)*	0.031(0.91)	0.073(1.40)
Log of adult equivalent household size	-0.564(1.42)*	-0.366(7.26)***	-0.593(5.72)**
Ratio of Log of productive adult equivalent labor to total adult equivalent household size	-0.071(0.10)	-0.217(2.68)***	-0.187(1.08)
Log of non-farm income	-0.047(1.24)	-0.001(0.25)	0.016(2.07)**
Log of value of household asset	0.177(2.37)***	0.034(3.06)***	0.031(1.83)**
Log of number of visit by extension officers	-0.175(1.38)		
Owned radio(1/0)	0.146(0.54)		
Owned mobile phone (1/0)	0.316(1.08)		
Scarcity level (high= 1/Low =0)	-1.668(3.54)***		
Perceived scheme governance problem (1/0)	-0.270(0.95)		
Constant	-18.56(5.93)***	7.73(14.89)***	7.62(8.84)***
ρ_1, ρ_2		0.24[0.266]	0.58[0.353]**
Model diagnosis			
Wald x^2	79.46***		

Log likelihood	-44.23
LR test of independence	1.66

Note: Absolute value of z statistics in parenthesis and standard errors in square brackets
*Significant at the 10% level, ** Significant at the 5% level, ***Significant at the 1% level
Source: Own calculation using survey data

The results for the selection equation of the ESR model with food consumption considered as outcome variable is presented on the second column of Table 4. The estimates for the determinants of the decision to irrigate, that are common with the previous model, are similar for both models in direction with some variation on the significance level. New explanatory variables like farm income and the value of household assets have positive and highly significant impact on the farmers' decision to irrigate. Bacha et al., (2011) and Deressa et al., (2009) found the same result for value of asset and farm income versus probability of adoption of irrigation, respectively.

The factors that affect the outcome variable, food consumption, are reported on the third and fourth column of the table. The estimates for household size related variables are negative and significantly different from zero for both users and non-users. This situation holds in most cases because higher big household means less per- head consumption other things kept constant. The same results are reported by Khonje et al., (2015) and Bacha et al., (2011) for impact studies in Eastern Zambia and Western Ethiopia, respectively. The model estimates for the amount of non-farm income show positive and significant impact on consumption of non-users. Mostly non-farm income is used to augment the household income and cover for consumption expenditure shortfall (Dorward et al., 2004) Similarly, the variable for the total value of household asset gives positive and significant result for both groups of farmers which confirms with findings of (Bacha et al., 2011).

Finally, the average treatment effect on the treated (ATT) and untreated (ATU) are presented in the following tables.

Table 5: Impact of irrigation on farm income and consumption-ATT

Outcome variable	Mean outcome		ATT		t-value
Log of farm income per ha	354 895.97	171320.26	183575.71	107%	10.80***
Log of total per adult equivalent consumption	3818.30	3008.62	809.68	26%	10.42***

***significant at 1% level, Source: own calculation from survey data

Table 6: Impact of irrigation on farm income and consumption-ATU

Outcome variable	Mean outcome		ATU		t-value
Log of farm income per ha	214490.34	79 082.74	135407.60	171%	11.78***
Log of total per adult equivalent consumption	4232.32	2691.09	1541.23	57%	16.08***

***significant at 1% level

Source: own calculation from survey data

As presented in Table 5 and 6 above irrigation significantly affects both outcome variables for both groups. This finding is in line with previous studies that argue the existence of direct income and employment impact of irrigation (Bacha et al., 2011; Smith, 2004; Wichelns, 2014). Generally, technology adoption results in reduced poverty and improved food security by improving agricultural production and productivity (Khonje et al., 2015). The report of FAO (2003) claiming that crop yields increased by 100-400% with irrigated crops as compared to rain fed is another reinforcing evidence for the above result.

6. Conclusion and Implications

This study examined the determinants of farmers' decision to irrigate and impact of irrigation on welfare of households using ESR. The results indicate the existence of a selection bias among the users and non-users as can be seen from the significant correlation coefficient between the error terms of the selection equation and outcome equation. Variables relating to information and social network, water scarcity level, and governance issues have significant impact on farmer's decision to irrigate. The ATT and ATU are positive and significant for both users and non-users indicating that access to irrigation has resulted in significant positive impact on welfare of the farmers.

Considering the findings of this study, several policy implications could be drawn. Significant share of the water scarcity is created by poor infrastructure and resulting wastage of water. Renovating and improving the conditions of the scheme canals is the best starting point to ensure access of more people to irrigation water. Moreover, the current irrigation and production technology is far from modern like elsewhere in the country. The government could work on promoting the adoption and provision of better technologies. Moreover, water storage facilities could significantly enhance the availability of water. Such facilities also make possible multiple uses of water like fisheries which can be considered to enhance livelihood of households especially of women and vulnerable groups with small landholdings. Related with this is a promoting and developing alternative source of irrigation water.

Access to irrigation water by itself does not necessarily lead to better life conditions. Households who have access to irrigation water but still below the poverty line witness the existence of transaction costs involved in securing access to water, purchasing other inputs, and selling outputs claiming huge share of the their income. This calls for intervention in relevant institutional settings and markets to fully realize the potential of irrigation. WUA should be supported by sound legal framework with proper monitoring and evaluation systems in place to ensure fair allocation of water.

There is huge involvement of brokers and middlemen in the market especially for khat and sugarcane. In this regard, it would be beneficial for the farmers if they could be organized in producer cooperatives for collective marketing. Especially, with the highly developing sugar industry in the country, there is huge market demand for sugarcane and the farmers could seize this opportunity. Facilitating access to small and medium credit facility can also improve the farmers' capacity to invest in alternative irrigation water sources like shallow well and rainwater harvesting facilities and modern agricultural inputs.

Last but no least is making sure that the interventions are integrated, pro-poor, and targeted. The study area is one of the densely populated areas in the country with very small and fragmented landholdings. The young generation is running out of land resource to stay in the agriculture sector. The importance of non-farm sector is critical in such situations.

Reference

Abdulai, A., & Huffman, W. (2014). The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. *Land Economics*, *90*(1), 26–43. https://doi.org/10.1353/lde.2014.0009

Aberra, Y. (2004). Problems of the solution: Intervention into small-scale irrigation for drought proofing in the Mekele Plateau of northern Ethiopia. *Geographical Journal*, *170*(3), 226–237. https://doi.org/10.1111/j.0016-7398.2004.00122.x

Amare, M., Asfaw, S., & Shiferaw, B. (2012). Welfare impacts of maize-pigeonpea intensification in Tanzania. *Agricultural Economics*, *43*(1), 27–43. https://doi.org/10.1111/j.1574-0862.2011.00563.x

Asfaw, S. (2010). Estimating Welfare Effect of Modern Agricultural Technologies: A Micro-Perspective from Tanzania and Ethiopia. *Chronicpoverty.Org*, 1–27. Retrieved from http://www.chronicpoverty.org/uploads/publication_files/asfaw_agricultural_technologies.pdf

Awulachew, S. B., & Ayana, M. (2011). Performance of Irrigation: an Assessment At Different Scales in Ethiopia. *Experimental Agriculture*, *47*(S1), 57–69. https://doi.org/10.1017/S0014479710000955

Bacha, D., Namara, R., Bogale, A., & Tesfaye, A. (2011). Impact of small-scale irrigation on household poverty: empirical evidence from the Ambo district in Ethiopia. *Irrigation and Drainage*, *60*(1), 1–10. https://doi.org/10.1002/ird.550

Bandiera, O., & Rasul, I. (2006). Social Networks and Technology Adoption in Northern Mozambique Author (s): Oriana Bandiera and Imran Rasul Published by : Wiley on behalf of the Royal Economic Society Stable URL : http://www.jstor.org/stable/4121936, *116*(514), 869–902. https://doi.org/10.1111/j.1468-0297.2006.01115.x

Bezu, S., & Holden, S. (2014). Are rural youth in ethiopia abandoning agriculture? *World Development*, *64*, 259–272. https://doi.org/10.1016/j.worlddev.2014.06.013

Bradshaw, B., Dolan, H., & Smit, B. (2004). Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies. *Climatic Change*, *67*(1), 119–141. https://doi.org/10.1007/s10584-004-0710-z

Bravo-Ureta, B. E., Solís, D., Cocchi, H., & Quiroga, R. E. (2006). The impact of soil conservation and output diversification on farm income in Central American hillside farming. *Agricultural Economics, 35*(3), 267–276. https://doi.org/10.1111/j.1574-0862.2006.00161.x

Central Statistical Agency, & World Bank. (2013). Ethiopia Rural Socioeconomic Survey (ERSS) Survey Report, 1–64.

CTA. (2011). The water we eat – tackling scarcity in ACP countries.Technical Centre for Agricultural and Rural Cooperation (ACP-EU). *CTA Policy Brief*, *2*(June), 4.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dessie, G., & Kinlund, P. (2008). Khat expansion and forest decline in wondo genet, Ethiopia. *Geografiska Annaler, Series B: Human Geography*, *90*(2), 187–203. https://doi.org/10.1111/j.1468-0467.2008.00286.x

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 825–842. https://doi.org/10.1093/ajae/aar006

Dorward, A., Fan, S., Kydd, J., Lofgren, H., Morrison, J., Poulton, C., … Wobst, P. (2004). Rethinking agricultural policies for pro-poor growth. *O.D.I*, *94*(94), 1–4. Retrieved from http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/894.pdf

Dudu, H., & Chumi, S. (2008). Economics of Irrigation Water Management : A Literature Survey with Focus on Partial and General Equilibrium Models.Policy Research Working Paper 4556. The World Bank Development Research Group Sustainable Rural and Urban

Development Team March 2008, (March).

Dutoit, L. (2007). Heckman's Selection Model, Endogenous and Exogenous Switching Models: A survey.

FAO. (2003). The State of Food Insecurity in the World: monitoring progress towards the World Food Summit and Millennium Development Goals. Published in 2003 by the Food and Agriculture Organization of the United Nations Viale delle Terme di Caracalla, 00100 Rome, Ita. Retrieved from https://www.presseportal.de/download/document/25159-fao-sofi-all-v5.pdf

Foster, J., And, J. G., & Thorbecke, E. (1984). A Class of Decomposable Poverty Measures Author (s): The Econometric Society Stable URL : http://www.jstor.org/stable/1913475, *52*(3), 761–766.

Gebregziabher, G., Namara, R. E., & Holden, S. (2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agricultural Water Management*, *96*(12), 1837–1843. https://doi.org/10.1016/j.agwat.2009.08.004

Goldfeld, S. M. and, & Quandt, R. . (1972). Nonlinear methods in econometrics (North-Holland, Amsterdam). *Journal of Econometrics*, *1*(4), 399–401.

Goldfeld, S. M. and, & Quandt, R. E. (1973). A Markov model for switching regressions. *Journal of Econometrics*, *1*(1), 3–15. https://doi.org/10.1016/0304-4076(73)90002-X

Hanjra, M. A., Ferede, T., & Gutta, D. G. (2009). Reducing poverty in sub-Saharan Africa through investments in water and other priorities. *Agricultural Water Management*, *96*(7), 1062–1070. https://doi.org/10.1016/j.agwat.2009.03.001

Headey, D., Dereje, M., & Taffesse, A. S. (2014). Land constraints and agricultural intensification in Ethiopia: A village-level analysis of high-potential areas. *Food Policy*, *48*, 129–141. https://doi.org/10.1016/j.foodpol.2014.01.008

Huffman, W. E. (2001). Agricultural Production. *Handbook of Agricultural Economics*, *1*, 333–381. https://doi.org/10.1016/S1574-0072(01)10010-1

Hussain, I., & Hanjra, M. (2004). Irrigation and poverty alleviation: Review of the empirical evidence. *Irrigation and Drainage*, *53*(1), 1–15. https://doi.org/10.1002/ird.114

Jin, S., Huang, J., Hu, R. and, & Rozelle, S. (2002). T OTAL F ACTOR P RODUCTIVITY IN " P HOENIX M IRACLES ": Working Paper 0605. *American Journal of Agricultural Economics*, *84*(3), 916–930.

Kassie, M., Shiferaw, B., & Muricho, G. (2010). Adoption and impact of improved groundnut varieties on rural poverty: evidence from rural Uganda. *Environment for Development Discussion Paper - Resources for the Future (RFF)*, (May), 10–11. Retrieved from http://www.rff.org/RFF/Documents/EfD-DP-10-11.pdf

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia. *World Development*, *66*, 695 706. https://doi.org/10.1016/j.worlddev.2014.09.008

Lee, L.-F., Maddala, G. S., & Trost, R. P. (1982). TESTING FOR STRUCTURAL CHANGE BY D-METHODS IN SWITCHING SIMULTANEOUS EQUATIONS MODELS. *CENTER FOR NAVAL ANALYSES. PROFESSIONAL PAPER 342*.

Lin, J. Y. (1991). Education and Innovation Adoption in Agriculture: Evidence from Hybrid Rice in China. *Agricultural Economics*, *73*(3), 713–723. https://doi.org/10.2307/1242823

Lokshin, M. (1977). of Endogenous Switching Regression Models, 1–8.

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *The Stata Journal*, *4*(3), 282–289. https://doi.org/The Stata Journal

Maddala, G. S. (1983). *Limited-dependent and qualitative variables in econometrics (No. 3). Cambridge university press*.

Maddala, G. S. (1986). DISEQUILIBRIUM , SELF-SELECTION , AND SWITCHING MODELS * 2 . Estimation of the switching regression model : Sample separation known 3 . Estimation of the switching regression model : Sample separation unknown 4 . Estimation of the switching regression mod. *Science*, *III*(1982).

Maddala, G. S., & Nelson, F. D. (1975). Switching regression models with exogenous and endogenous switching. *Proceedings of the American Statistical Association*, *5*, 423–426.

Namara, R. E., Hanjra, M. A., Castillo, G. E., Ravnborg, H. M., Smith, L., & Van Koppen, B. (2010). Agricultural water management and poverty linkages. *Agricultural Water Management*, *97*(4), 520–527. https://doi.org/10.1016/j.agwat.2009.05.007

Nhemachena, C., & Hassan, R. (2007). *Micro-level analysis of farmers adaption to climate change in Southern Africa. Intl Food Policy Res Inst.*

Norris, P. E., & Batie, S. S. (1987). Virginia farmers' soil conservation decisions: an application of the tobit analysis. *Southern Journal of Agricultural Economics*, *19*, 79–90. https://doi.org/10.1017/S0081305200017404

O'Boyle, E. J. (1999). Toward an improved definition of poverty. *Review of Social Economy*, *57*(3), 281–301. https://doi.org/10.1080/00346769900000003

Ravallion, M. (2005). Evaluating Anti-Poverty Programs, *4*(May), 1–90.

Rosegrant, M. W., & Evenson, R. E. (1992). Agricultural Productivity and Sources of Growth in South Asia. *Journal of Agricultural Economics*, *74*(3), 758–761.

Rosegrant, M. W., Ringler, C., & Zhu, T. (2009). Water for Agriculture: Maintaining Food Security under Growing Scarcity. *Annual Review of Environment and Resources*, *34*(1), 205–222. https://doi.org/10.1146/annurev.environ.030308.090351

Sen, A. (1981). *Poverty and famines: an essay on entitlement and deprivation. Oxford university press.*

Setegn, S. G., Chowdary, V. M., Mal, B. C., Yohannes, F., & Kono, Y. (2011). Water Balance Study and Irrigation Strategies for Sustainable Management of a Tropical Ethiopian Lake: A Case Study of Lake Alemaya. *Water Resources Management*, *25*(9), 2081–2107. https://doi.org/10.1007/s11269-011-9797-y

Shiferaw, B., & Holden, S. T. (1998). Resource Degradation and Adoption of Land Conservation

Technologies by Smallholders in the Ethiopian Highlands : A case study in Andit Tid, North Shewa. *Agricultural Economics*, *18*(1998), 233–247.

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272–284. https://doi.org/10.1016/j.foodpol.2013.09.012

Singh, A. K., Rahman, A., Sharma, S. P., Upadhyaya, A., & Sikka, A. K. (2009). Small holders' irrigation - Problems and options. *Water Resources Management*, *23*(2), 289–302. https://doi.org/10.1007/s11269-008-9275-3

Smith, L. E. D. (2004). Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods. *International Journal of Water Resources Development*, *20*(2), 243–257. https://doi.org/10.1080/0790062042000206084

Tizale, C. Y. (2007). The dynamics of soil degradation and incentives for optimal management in the Central Highlands of Ethiopia, (February), 263. https://doi.org/https://repository.up.ac.za/bitstream/handle/2263/25333/Complete.pdf?sequence=6

Watts, H. W. (1968). *An economic definition of poverty (pp. 316-329). Institute for Research on Poverty.*

Wichelns, D. (2014). Investing in small, private irrigation to increase production and enhance livelihoods. *Agricultural Water Management*, *131*, 163–166. https://doi.org/10.1016/j.agwat.2013.09.003

Wood, S., You, L., & Zhang, X. (2004). Spatial patterns of crop yields in Latin America and the Caribbean. *Cuardernos de Economia / Latin American Journal of Economics*, *41*(124), 361–381. Retrieved from http://www.scielo.cl/pdf/cecon/v41n124/art03.pdf

Wooldridge, J. M. (2003). Introductory Econometrics: A Modern Approach. *Economic Analysis*, *2nd*, 824. https://doi.org/10.1198/jasa.2006.s154

World Bank. (2010). *Handbook on Impact evaluation: Quantitative methods and practices. The*

World Bank, Washington, D.C. World (Vol. 41).

World Bank. (2016). World Development Indicators, 46. https://doi.org/10.1596/978–1-4648–0683–4

Wozniak, G. D. . (1984). The Adoption of Interrelated Innovations : A Human Capital Approach Source : The Review of Economics and Statistics, *66*(1), 70–79. Retrieved from http://www.jstor.org/stable/1924697