IMPACT OF SMALL-SCALE IRRIGATION SCHEME ON POTATO FARMERS TECHNICAL EFFICIENCY AND HOUSEHOLD INCOME IN LEMU-BILBILO DISTRICT, ARSI ZONE, OROMIA NATIONAL REGIONAL STATE, ETHIOPIA

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TAMIRAT TSEGAYE

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Tamirat Tsegaye

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APPROVAL SHEET

POSTGRADUATE PROGRAM DIRECTORATE
HARAMAYA UNIVERSITY

We hereby certify that we have read and evaluated this thesis prepared under our guidance and direction, by **Tamirat Tsegaye**, entitled, *"*Impact of Small-Scale Irrigations Scheme on Potato Farmers Technical Efficiency and Household Income in Lemu-Bilbilo District, Arsi Zone, Oromia National Regional State, Ethiopia*"*, and we recommend that the thesis be submitted as it fulfills the thesis requirements for MSc in Agricultural and Applied Economics.

Jema Haji (Prof.)		
Major Advisor	____________________ Signature	________________ Date
Million Sileshi (PhD)		
Co-advisor	____________________ Signature	________________ Date

As members of the Examining Board of the MSc Thesis Open Defense, we certify that we have read and evaluated the thesis prepared by **Tamirat Tsegaye** and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirements for the degree of Master in Collaborative Master of Sciences in Agricultural and Applied Economics.

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Name: Tamirat Tsegaye

Signature: ________________

Place: Haramaya University

Date: ___________________

BIOGRAPHICAL SKETCH

The author was born on September 26, 1994 in Lemu Dima kebele, Lemu-Bilbilo District of Arsi zone, Oromia National Regional State, Ethiopia. He attended his elementary and secondary schools at Bekoji Elementary and Secondary schools, respectively. After he successfully passed EGSEC, he joined Addis Ababa University in 2015 and graduated after three years with BSc Degree in Agricultural Economics in 2017. After graduation, he joined Oromia Agricultural Research Institute and served as Assistant Socio-Economic Researcher. Finally, in 2021 he joined Haramaya University to pursue his MSc degree in Agricultural and Applied Economics.

DEDICATION

I would like to dedicate this thesis to my mother Askala Gutema!

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First and foremost, I thank my God, my good Father, for letting me through all the difficulties. I have experienced your guidance day by day. You are the one who let me finish my MSc degree. I will keep on trusting you for my future. Thank you, Lord.

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ACCRONYMS AND ABBREVIATIONS

ATE	Average Treatment Effect
ATU	Average Treatment Effect on Untreated
ATT	Average Treatment Effect on Treated
CSA	Central Statistical Agency
DEA	Data Envelopment Analysis
DID	Difference in Difference
ESR	Endogenous Switching Regression Model
FAO	The United Nation Food and Agriculture Organization
GDP	Gross Domestic Product
IV	Instrumental Variable
MoARD	Ministry of Agriculture and Rural development
NGO	Non-Governmental Organization
OLS	Ordinary Least Squares
PSM	Propensity Score Matching
RD	Regression Discontinuity
RSM	Randomized Selection Model
RTC	Root and Tuber Crops
SDG	Sustainable Development Goal
SFA	Stochastic Frontier Model
SSA	Sub Saharan Africa
SSI	Small Scale Irrigation

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Impact of Small-Scale Irrigation Scheme on Potato Farmers Technical Efficiency and Households Income in Lemu-Bilbilo District, Arsi Zone, Oromia National Regional State, Ethiopia

ABSTRACT

Rain-fed production alone cannot solve the problems of low production and productivity in Ethiopia. Development of small-scale irrigation scheme (SSI) expected to enhance production efficiency and income of potato grower's smallholder farmers. This study, therefore, aims to identify factors affecting participation in SSI and its impact on household income and potato farmers technical efficiency in Lemu-Bilbilo district of Arsi zone, Oromia region, Ethiopia. The study used cross-sectional household data collected in 2022/2023 from 371 randomly selected sample households. Both descriptive statistics and econometrics model (stochastic frontier model and endogenous switching regression) were used. The results of the stochastic frontier model (SFA) shows that potato output was positively and significantly influenced by input variables (land, seed, labour and DAP for both irrigators and non-irrigators farms). The estimated technical efficiency scores for irrigators and non-irrigators were 65 and 62 percents, respectively, showing irrigators households were relatively more technically efficient in potato production than non-irrigators households in the study area. The results of probit model shows that participation in SSI was positively influenced by education, total livestock owned, farm size, extension contact and cooperative membership whereas market distance and irrigation water distance influenced participation in SSI negatively. Finally, the results obtained from the endogenous switching regression model showed that if irrigators had decided to not irrigate, their average income and technical efficiency would have decreased by 19617.97 ETB and 0.07%, respectively. Similarly, had non irrigators decided to irrigate, their average income and technical efficiency would have increased by 8240.41ETB and 0.03% respectively. The study recommends, policymakers and development organizations should consider small scale irrigation as main strategy to increase smallholder potato farmer's technical efficiency and household income. This study also argues that, institutional and government assistance in the areas of education, extension service, infrastructure development (particularly access to markets), and cooperatives is critical.

Key words: Impact, Small-scale irrigation, ESR, Arsi zone.

1. INTRODUCTION

1.1. Background of the Study

The agricultural sector is the main source of Ethiopian economy. The sector contributes about 32.5 percent to GDP, generates 85 percent of export earnings and supplies about 70 percent of industrial raw materials (NBE, 2020). This shows that agriculture is the major source of livelihood and it needs great attention for improvement and transformation of the country's economy. Despite its high potential roles, its productivity has been limited and challenged due to a variety of factors such as limited access to irrigation, poor institutional services, inefficient marketing systems, land degradation, high and growing human population, shortage of improved agricultural inputs, and recurrent drought (Tadesse *et al*., 2021; Tesema and Gebissa, 2022). Furthermore, the agricultural sector is heavily dependent on rain-fed which is less efficient both in terms of productivity and profitability as compared to irrigated agriculture (Woldegiorgis, 2021). As solution to the problems of low agricultural production and productivity, investing in irrigation development against relying on rain-fed agriculture alone enables smallholder farmers to increase yields, crop diversification and fosters diversity in farm production (Kassie and Alemu, 2022, Jambo *et al* 2022).

Ethiopia has 3.7 million hectares (41%) of potentially irrigable land with abundant surface water resources. The total estimated area of irrigated agriculture in the country is 626,116ha and the farmers who practice irrigation were estimated at about 1.4 million (CSA, 2022). Sub–Saharan Africa has 9 million hectares of potentially irrigable land (Xie *et al*., 2018). Ethiopia accounts for more than 33.3% of the potentially irrigable land of sub–Saharan Africa. This shows that Ethiopia has an opportunity to raise agricultural production and productivity using irrigation. In this regard, to promote irrigation development in Ethiopia, the government, non-governmental and private investors have established 466 small, 102 medium, and 9 large-scale irrigation schemes with total area coverage of 28,939, 71,924, and 49,675 ha, respectively (ATA, 2021, Mokenen *et al*. 2022). This implies that, irrigation development is one of the policy priority of the government to support rural farmers to use irrigation farming in order to increase agricultural productivity.

Oromia region has 1.3 million ha of potential irrigable land and huge water resource potential. However, the regional agricultural sector almost depends on rain-fed farming and only 2.14% of the total cultivated area is irrigated. The significantly low adoption rate implies that they are unlikely to be taken up by smallholder farmers to withstand the shortage of rainfall and its fluctuations (Mokenen *et al*., 2022). Currently, in the region 33,765.19 hectares of land are irrigated using small-scale irrigation schemes and serving 37,479 households (CSA 2021).

Maize, sorghum, teff and wheat are major crops produced in the Ethiopia using irrigation with estimated area coverage of 36,719ha, 11,715ha, 9,325ha and 6,190ha, respectively (CSA, 2021). Root and tuber crops (RTCs) are also produced using irrigation and rain-fed by small-holder farmers in different parts of the country (Biru *et al*., 2020). Nationally, the area under RTCs with irrigation was estimated to be 30,566 ha produced by 356,503 households (CSA, 2022). It covers about 44% of area as compared to all cereal crops produced using irrigation. In Oromia region, RTCs are produced using irrigation by 109,617 smallholder farmers on 11,123 hectares of land.

Among RTCs produced using irrigation, potato is a major one. Potato plays a vital role in ensuring food security, which is a major concern of the country. According to CSA (2022), potato was produced by 1,127,267 smallholder farmers on 78, 478.72 ha of land, which is 62% of the total RTCs production and 64,009 smallholder farmers participated in the production of potato on 5776 ha of land using irrigation. This shows that potato ranks first in the category of RTCs in terms of area coverage and production using irrigation.

In Oromia region, there are 361,054 smallholder farmers producing potato on 42,542.38 ha of land (CSA, 2022). Accordingly, root crops (potatoes, onion and carrot) vegetables (green pepper, tomatoes and cabbage), cereal (maize and wheat) are the main crops produced using irrigation in Lemu-Bilbilo district (LBDANRO, 2022). Among these crops, potato is widely produced using irrigation in the study area and used as a major source of income and food in the district. However, the introduction of irrigation to increase the production and productivity of this crop remains very low as compared to the irrigation potential in the district. Therefore, this study assessed factors affecting smallholder farmers' participation in small-scale irrigation for potato farming and its impact on potato technical efficiency of production and household income in the study area.

1.2. Statements of the Problem

The population of Ethiopia has been steadily increasing from time to time and there is a gap between food demand and supply. In this situation, it is difficult to feed the increasing population using rain-fed and one season round production (Gadisa *et al*., 2021). In this regard, irrigation plays a fundamental role in improving agricultural production and productivity but, until recent years, its adoption and performance is below expectations.

Despite its high potential, only 5.6 percent is irrigated out of an estimated irrigation potential of 3.7 million ha (Woldegiorgis, 2021; Bidzakin, 2018). This implies that agricultural practice in the country in general is rain-fed and seasonal. There is a huge gap between the potential and the level of irrigation applied to improve agricultural production in the country due to technical, physical and economic challenges (Mekonnen *et al*., 2022), but the determinants of participation in irrigation farming and its impact on income and yield are not exhaustively studied in the country.

Potato is among RTCs that have importance to overcome food insecurity problems for smallholder farmers in Ethiopia (Muthoni *et al*., 2022; Milkias, 2021). The average estimated potato productivity in Sudan and Egypt is 170 and 260 quintals per hectare respectively (CIP, 2018). However, the estimated average productivity of potato in Ethiopia is 166.87 quintals per hectare. This indicates that the productivity of potato is low in Ethiopia as compared to Sudan and Egypt given that 70% of the country's arable land is suitable for potato production (CSA, 2022).

Heavy reliance on rain-fed farming, limited irrigation facilities and climate change are assumed to significantly contribute for low potato production efficiency (Andaregie and Astatkie, 2020). Arsi zone has been affected by the delay onset in rain and its early cessation for different years (Tefera *et al*., 2017; Fekadu *et al*., 2021). In addition, the zone experienced a reduction in crop production by 12% from its potential mainly due to abnormal and inadequate rainfall (CSA, 2022).

Lemu-Bilbilo district was blessed with plenty of water resource potential. However, despite its high potential, farm households failed to produce different agricultural crops when there is shortage of rainfall (Fekadu *et al*., 2021). Similarly, the farmers in the study areas have been affected by the extreme events of climate change such as drought and flood that lead to crop failure in different years (OIDA, 2020). According to Tefera *et al*. (2017) and Mekonnen *et al*. (2022), SSI has a great impact on enhancing farmers' livelihoods through different dimensions, such as diversification of crops grown, increased agricultural production, household income and employment opportunity.

Potato is widely produced by smallholder farmers using irrigation and rain-fed farming in the Lemu-Bilbilo district but the use of small-scale irrigation for potato production is not as expected in the study area. As a result, the production and productivity of potato by smallholder farmers are low. According to CSA (2018), the average productivity of potato in Arsi zone is 97.74 quintals per hectares which is less than the average productivity at national level 137.68 quintal per hectare. There is still a very low utilization of irrigation potential in the study area to boost the productivity of potato (Fekadu *et al*., 2021; Gadisa *et al*., 2021). The reason why farmers are not intensively utilizing the irrigation potential in the study area were not studied empirically using rigorous econometric techniques.

Most of the previous studies investigated the general impact of irrigation. For example, a study conducted by Tefera and Cho (2017) examined the impact of small-scale irrigation on food security and household income. The study conducted by Abdiyo (2021) studied the effect of small-scale irrigation on household food security in Adaba district of Arsi zone. As to the best of our knowledge, the impact of SSI on farm income and technical efficiency has not been conducted in the study area.

Likewise, most of the previous studies dealt exclusively with technical efficiency of crop production under rain-fed farming only. For this reason, variations in technical efficiency under irrigated and non-irrigated farming has not been known. In general, the current available knowledge about the impact of small-scale irrigation on technical efficiency of crop production in general and potato in particular is not conducted in the study district. Lack of such empirical investigations has created a knowledge gap on the contribution and impact of small-scale irrigation on technical efficiency. Therefore, this study aims to identify the factors affecting farmers' participation in irrigation farming and its impact on potato technical efficiency and household income in the study district.

Methodologically, most of the studies used Propensity Score Matching model to quantify the impact of technology intervention like small-scale irrigation. For example, studies by Gebrehiwot *et al*. (2017) and Bidzakin *et al*. (2019) on impact of irrigation on household welfare and impact of contract farming on rice farm performance, respectively used endogenous switching regression and indicated that using PSM model creates an endogeneity and self-selection problems that could potentially bias the true estimate of parameters. But this model suffers from endogeneity problem which arises from self-selection bias

Therefore, this study also employed an endogenous switching regression model to account for both observed and unobserved heterogeneities as well as self-selection bias and attempted to fill the gaps of past studies and provide additional information by evaluating the impact of small-scale irrigation on potato technical efficiency and household income in Lemu Bilbilo district of Oromia region, Ethiopia.

1.3. Research Questions

- ✓ What is the level of technical efficiency of potato producers in the study area?
- ✓ What are the factors that influence farmers' participation in small scale irrigation in the study area?
- ✓ Does participating in small scale irrigation enhance the technical efficiency and household income of potato famers in the study area?

1.4. Objectives of the Study

The general objective of the study is to analyze the impact of small-scale irrigation on potato technical efficiency and household income in the study area.

The specific objectives of the study are:

1. To measure technical efficiency of potato farmers under irrigators and non-irrigators farming systems;
2. To identify factors affecting smallholder farmers participation in small-scale irrigation scheme in the study area; and
3. To evaluate the impact of small-scale irrigation scheme on technical efficiency and household income of potato producers in the study area.

1.5. Significance of the Study

This study will deliver pertinent information on the impact of small-scale irrigation on technical efficiency and income of potato producing households in the study area. Knowledge about potato technical efficiency gaps between irrigators and non-irrigation users will inform policy makers for better design and implementation of intervention programs. In addition, understanding factors that affect farm households' participation in small-scale irrigation will help policy makers to make an appropriate plan to address the households need through improving participation of smallholder farmers in small-scale irrigation. Again, the study results will be used as foundation for government, researchers, individuals, international and others interested organizations to conduct further study in the study area.

1.6. Scope and Limitations of the Study

The study was carried out to identify factors affecting smallholder farmers' participation in SSI and its impact on potato technical efficiency and household income. The study was limited to cross-sectional analysis and only one district of Arsi zone of Oromia National Region state, Ethiopia was chosen for this study. As a result, the findings of a one-year cross-sectional study of household farm on input and production may not necessarily hold true for other years. Additionally, the generalizations drawn from the results would be more relevant to the study's location. Further, potato was the only crop studied because of its importance for food consumption, rising market demand, and agro-ecological suitability for growing in the study area. Therefore, the result of this study might be not true for other crop commodities unless there is a similar condition.

1.7. Organization of the Thesis

This thesis organized into five chapters. The first chapter is introduction part consist of background of the study, statement of the problem, objectives of the study, significance, scope and limitations of the study area. The second chapter considers review of literature on the area of irrigation participation, theoretical and analytical review of production efficiency, conceptual frameworks and empirical studies on irrigation participation. The third chapter includes description of the study area and methodologies used for data collection and analysis. The fourth chapter displays the results of descriptive analysis of input variables, continuous and discrete variables and econometric result of variables affecting participation in SSI and impact of SSI on household income and technical efficiency. Chapter five concluded with a summary and recommendations.

2. REVIEW OF LITERATURE

2.1. Definition of Basic Terms and Concepts

Irrigation: Irrigation is defined as the artificial application of water to land to enhance crop production. According to Reddy (2010), irrigation is the artificial application of water to soil with the goal of providing the moisture required in the plant root zone to prevent stress that could result in a decreased yield and/or a lower-than expected crop harvest. This is a deliberate human operation to apply water for agricultural growth, particularly during dry seasons and periods of low rainfall. Based on area classification there are three types of irrigation in Ethiopia: Large scale schemes that have a total area of greater than 3000 hectares, medium schemes that cover areas between 200 hectares and 3000 hectares, and small-scale schemes which are less than 200 hectares (Mekonnen *et al*., 2022). Accordingly, 46% of proposed irrigation developments are in the small-scale irrigation category. The large-scale and the medium schemes are developed and managed by the government. Small-scale irrigation can be defined based on the area of land irrigated and it differs from country to country. In Ethiopia small-scale irrigation schemes include traditional small-scale irrigation schemes up to 100 ha and 10 modern communal schemes up to 200 ha (Adelodun *et al*., 2021).

Participation: participation in a particular technology (adoption) is also described differently by different authors. According to Rogers (1983), participation (adoption) is the choice to fully or partially implement an innovation (new way of doing things) when it is the most appropriate course of action. According to Loevinsohn *et al*. (2013), participation (adoption) is the incorporation of a new technology into current practice and is typically preceded by a time of 'testing' and some level of adaption. Even though it is difficult to bring into one single definition from the above definitions of the respective terms, participation (adoption) in small-scale irrigation practice can be generally defined as the use of an innovation (new way) of crop production by applying the artificial water to crop land purposively. Participating in irrigation practices can be viewed in this study as one technological choice available to farm households to enable them to grow multiple crops, diversify their production, overcome moisture deficiency partially or completely, and boost agricultural yields.

Productivity: While productivity and efficiency are often used interchangeably in economics, they are distinct concepts. While linked, their differences become apparent when considering the production frontier, which represents the current technological capabilities of an industry. Productivity growth can be achieved through either advancement in technology or improvements in efficiency, as outlined by Coelli (1995. Productivity is a key driver of economic growth and competitiveness. It measures the efficiency of resource utilization in an economy. It assesses how effectively inputs such as land, labor, and capital are converted into output. The effectiveness of resource allocation is critical for international comparisons and assessments of national performance (2013).

Technical efficiency: Technical efficiency (TE) refers to achieving the maximum possible output from a given set of inputs. It is measured in two ways: input-oriented and output-oriented. In an input-oriented framework, TE measures the potential reduction in inputs a farm could achieve without reducing its output. In contrast, an output-oriented framework focuses on the potential increase in output a farm could achieve without using more inputs. In the case of constant returns to scale, both orientations give similar results (Farrell, 1957). Technical efficiency (TE) can be defined as maximizing output for a given input level or, conversely, minimizing input usage for a given output level (Lovell, 1993). A technically efficient producer is characterized by the following: increasing any output requires reducing at least one other output or increasing at least one input; and decreasing any input necessitates increasing at least one other input or decreasing at least one output (Koopmans, 1951). This means a technically efficient producer could either maintain the same output with less input or achieve more output with the same input level.

2.2. Theoretical Framework

2.2.1. Theoretical Framework for Participation in small scale irrigation

Different theories can be used to know why farmers choose to use small scale irrigation. Among this utility maximization theory is the most important theory. The decision to use a new technology is driven by how much utility a household gains from using it (Becker and

Ichino, 2002). According to utility theory, the farmer will adopt/use a new technique if the utility obtained from it exceeds that of the old one. The individual effort is an endogenous process that involves comparing the current expenditure in terms of time and other goods as evaluated against immediate and future returns (Bekele and Holden, 2001). To know the effect of an intervention on a participating individual, we must compare the observed outcome with the outcome that would have resulted had that individual not participated in the program (Jalan and Ravallion, 1999; Baker, 2000).

Small scale irrigation has multidimensional benefits including several economic, social and political functions (Borda-Rodriguez, et al., 2016). The use of irrigation technology helps smallholder farmers in increasing agricultural production and thus improving technical efficiency and household income (Shiferaw et al., 2011).

2.2.2. Theoretical Framework for technical Efficiency

In this world resources are scarce. Scarcity of resources demands goods should be produced with the most efficient method. In economic theory of production, one of the basic economic problems is how to produce, means which combination of resources is to be used for the production of goods and which technology is to be used for their production. The production is said to be efficient if the productive resources are utilized in such a way that through any reallocation it is impossible to produce more of one good without reducing the output of any other good.

The classical theory of production assumed that firms/farms are efficient and any deviation from the frontier output is due to external shocks that are entirely beyond the control of decision-makers. The neo-classical theory of production assumed that producers in the economy operate at different levels of output even if they use the same level of inputs and technology. The difference in observed outputs from the frontier among producers can be explained not only by unforeseen external shocks outside the producer's control but also through differences in the efficiency of using existing resources (Ravallion, 1994).

Improvement in productivity can be attained in two ways. The first one is through improving and developing the use of technology by inventing new mechanization, pesticides, agronomic practices, improved varieties, and the like, which are commonly referred to as technological change, and can represent an upward shift in the production frontier. The other way is an individual can implement procedures, such as improved farmer education, extension advice, and other institutional improvements to ensure farmers use of the existing technology more efficiently (Coelli et al., 1998).

2.3. Analytical framework

2.3.1. Models for technical efficiency Measurement

Estimation of technical efficiency involves estimating the frontier production function and measuring the efficiencies of the farms relative to the frontiers (Greene, 1997). According to Farrell (1957), technical efficiency can be measured using either input-orientated or output orientated approaches. The input-oriented approach addresses the question by how much can input quantities be proportionally reduced without changing the output quantities produced. The output-oriented approach addresses the question by how much can output be increased without increasing the amount of input use by utilizing the given input more efficiently.

There are two commonly used methods of measuring technical efficiency in productivity and efficiency literature; Parametric and non-parametric developed by Aigner (1977) and Meeusen and Van den Broeck (1977). The parametric models are basically estimated based on econometric methods and non-parametric model referred to as Data Envelopment Analysis (DEA) to construct a nonparametric piece wise surface or frontier over the data (Coelli *et al*., 1998).

2.3.1.1. Parametric production frontiers estimation models

Parametric frontier model estimation can also be classified into deterministic and stochastic production frontier.

Deterministic frontier model: the deterministic model assumes that any deviation from the frontier is due to farm specific inefficiency and it does not consider the possible influence of external shocks that beyond the control of the producers. The application of the model in the agricultural sector is limited due to this limitation (Coelli and Rao, 2005; Roshdi *et al*., 2014).

The concept of a deterministic frontier ignores the possibility that a production may be affected by factors both within and outside farmer's control. That is, combining the effects of any measurement error with other sources of stochastic variation in the dependent variable in the single one-sided error term may lead to biased estimation of technical inefficiency.

Stochastic frontier model: Stochastic production frontier was developed and extended by Aigner, Lovell, and Schmidt (1977), Meeusen and van den Broeck (1977), Battese and Corra (1977), Battese and Coelli (1988). The basic assumption behind the stochastic frontier model is that the variations of actual output from the frontier are due to inefficiency and random shocks. According to Aigner *et al*. (1977) a potential advantage of the stochastic production frontier approach over DEA is that it captures noises and exogeneous shocks beyond the producer control and the estimation of standard errors and tests of hypothesis is possible at which the deterministic model fails to fulfill because of the violation of the maximum likelihood regularity conditions.

2.3.1.2. Non-parametric frontier model

The non-parametric approach has been traditionally assimilated into Data Envelopment Analysis (DEA) which is a mathematical programming model applied to observed data that provides a way for the construction of production frontiers as well as for the calculation of efficiency scores relatives to those constructed frontiers. Data Envelopment Analysis (DEA) can easily handle multiple input and output and used when the basic assumption of the stochastic frontier model is failed (Coelli *et al*., 1998).

Moreover, DEA works under the assumption of absence of random error or random shocks in the data set and more specifically the model assumes that all deviations from the frontier are considered as inefficiencies. In DEA the performance of a producer is evaluated in terms of the ability of that producer to expand its output vector subject to the constraints imposed by best observed practice and the main strength of the model is that it avoids parametric specifications of technology and distributional assumptions of the inefficiency term (Roshdi *et al*., 2014).

Even though there are a number of studies which applied DEA to measure the technical efficiency, the method is subject to certain drawbacks. As Coelli *et al*. (2005) pointed out the method is subject to series limitations from four different perspectives. Firstly, it is extremely susceptible to the influence of extreme values or outliers. Secondly, it does not take into account non-constant returns to scale. Thirdly, it does not also take into account uneconomic areas of the production function where the efficiency index is undefined. And finally, it does not lend itself up to standard statistical tests of significance (Coelli and Rao, 2005).

This study opted for a parametric approach over a nonparametric method because the production environment is susceptible to unobservable shocks. This choice stems from the understanding that deviations from the efficient level might stem from both controllable factors and random events beyond farmers' control, particularly impacting smallholder output.

2.3.2. Determinants of participation in small scale irrigation

When the dependent variable is dichotomous type (in this study, Irrigation users and non-users), estimating parameters by using the OLS model or multiple linear regression model leads to the problem of heteroskedasticity so that parameter estimates are inefficient thus classical hypothesis tests such as t-ratios are inappropriate (Maddala, 1998). However, different scholars use different models for the purpose to overcome the limitation of OLS. Many other alternative models that are compatible with binary dependent variables have been developed. Among these, linear probability model and non-linear model are common.

2.3.2.1. Linear Probability Model

The LPM is simply the application of ordinary least squares (OLS) to binary response-dependent variable instead of continuous variables and it is expressed as a linear function of independent variables. The main disadvantage of the LPM is; heteroscedasticity of the disturbance term; lower R^2 values; non-normality of disturbance, the predicted value may be outside 0 to1 range and it also believes constant marginal effects (Maddala, 1998; Gujarati, 2004). It also assumes that the true relationship between a binary outcome and a continuous explanatory variable is inherently nonlinear which means that the functional form of the LPM is generally not correctly specified, which can lead to biased estimates of parameters of interest.

However, the advantage of LPM is that it provides accurate estimates of experimental impacts when the covariates included in the impact model are uncorrelated with treatment status which means that the impact estimate is unbiased regardless of whether the correct functional form is used to adjust for other (possibly continuous) covariates. Standard errors estimated using the LPM are correct, standard errors estimated for logistic regression are sometimes too small. It also used to estimate impacts in cases where logistic regression cannot applicable and, unlike logistic regression, the parameter estimates from the LPM can be directly interpreted as the impact of the intervention on the prevalence rate of the outcome.

2.3.2.2. Nonlinear probability models

Nonlinear probability models become preferable to overcome the limitations of LPM. The commonly used nonlinear probability models are Logit, and probit models are commonly used in literature (Wooldridge, 2009).

Logit model: It examines the relationship between independent factors and a categorical dependent variable. It then calculates the likelihood that an event will occur by fitting data to a logistic curve. Binary logistic regression and multinomial logistic regressions are the two types of logistic regression models. When the dependent variable is a dummy and the explanatory factors are continuous or categorical, binary logistic regression is frequently utilized (Maddala, 1999).

The main advantage of logit model is to fit the nonlinear relationship between the binary dependent variable and predictors that are both continuous and dummy. It also forces the predicted values of the dependent variable to be in between zero and one and produces an S-shaped (Wooldridge, 2005). In most cases, probit and logit models are quite similar, the main difference is that the logistic function has slightly fatter tails than the probit. This difference indicates that conditional probability approaches zero or one at a slower rate in logit than in probit model.

Tobit model: When there are a large number of observations on the dependent variable with a value of zero, Tobit is a more appropriate model to handle such censored data and is used to examine the participation in irrigation. As a result, tobit model analysis should be used in these circumstances since it makes use of both data at the limit and data above the limit. Tobit model is an improvement to probit model which consists two parts, that is probit-part or the slope of the line in the Tobit part and linear part which is the uncensored part of the model (Gujarit, 2004).

Given the evidence, a probit model was chosen to analyze the factors influencing participation in small-scale irrigation. This choice is justified because the adoption of new technology, such as irrigation, is essentially a binary decision: farmers either adopt it or they don't. The probit model is suitable because it analyzes the likelihood of a farmer making this choice based on the perceived marginal net benefits of using the technology versus not using.

2.3.3. Impact Evaluation of technology Adoption

The assignment of the treatment to the target group can be at random (experimental methods) or based on subjective judgments (non-experimental methods). There are different methods that can be used in order to undertake impact evaluation for cross-sectional data. These methods are: Propensity Score Matching (PSM), ESR, Randomized Selection Methods (RSM), IV and Regression Discontinuity Design (RDD).

Propensity score matching (PSM)

Propensity score matching is one of quasi-experimental statistical matching technique that estimate the effects of a treatment given the covariates. It allows finding a control group from sample of nonparticipants closest to the treatment group in terms of observable characteristics so that both groups are matched on the basis of the propensity score and the closer this score, the better the match (Rosenbaum *et al*., 2006). Propensity score is a predicted probability of participation given observed characteristics (Ravallion, 2008). The propensity score is estimated using statistical models, logit or probit and the average treatment effect (ATE) of the outcome of the two groups in absence of baseline data is calculated.

Unlike econometric regression methods, PSM compares only comparable observations and does not rely on parametric assumptions to identify the impacts of programs and it does not impose a functional form of the outcome, thereby avoiding assumptions on functional form and error term distributions, such as linearity imposition, multicollinearity and heteroskedasticity issues. In addition, the matching method emphasizes the problem of common support, thereby avoiding the bias due to extrapolation to non-data region (Dehejia and Wahba, 2002; Rapu, 2016).

In modelling the impact of an intervention, one can use OLS regression by using dummy for the intervention or the method of Propensity Score Matching (PSM). OLS requires essentially the same conditional independence (exogeneity) assumption as PSM, and also imposes arbitrary functional form assumptions concerning the treatment effects and the control variables. In PSM one limits attention to the region of common support and non-participants with a score lower than any participant are excluded but OLS uses the full sample.

The problem of biases from simple regression or logistic models made PSM a good option to look at causal effects in observational studies. According to Li (2013), the PSM model used in the research has the following three expected biases. Firstly, the ‘selection on observables’ which may arise due to sampling bias. Secondly, the selection of a comparison group in the presence of externalities. Lastly ‘selection on unobservable arising due to differences between irrigation users and non-users in the distribution of their unobserved characteristics’. The third bias will not be removed but the quality of the data collection method, identification of relevant variables and the evaluation of matching quality used are expected to reduce it.

PSM model is advantageous in the computation of the causal effect because it is less susceptible to the violation of model assumptions; it eliminates two sources of bias, the bias from non-over-lapping supports and different density weighting (Heckman, 1998). Further, if treatment assignment is strongly ignorable in observational studies, it estimates an Average Treatment Effect on Treated (ATT) close to the ATT calculated from experiments. The matching technique in PSM is non-parametric (did not suffer from problems that are prevalent in most parametric models); it is much easier to understand than the interpretation using ‘‘control all other variables at mean’’ in regression models (Li, 2013).

Randomized selection methods (RSM)

Randomized selection methods (RSM) are the process of randomly selecting treatment and control groups from clearly defined population to evaluate the outcome of the intervention. Based on this, the control group is similar with the treatment group and the only difference is the participation in the required program. This method can do before and after or pre and post matching and this leads to matching of variables that change due to participation. Furthermore, randomization also does not require the untestable assumption of conditional independence on observables (Abadie *et al*., 2004).

Regression discontinuity (RD)

Regression discontinuity (RD) method is one of the non-experimental impact evaluation approaches that can be used to estimate program impacts in situations at which candidates are selected for treatment based on whether their value for a numeric rating exceeds a designated threshold or cut-point (Jacob *et al*., 2012). It allows us to account for observed and unobserved heterogeneity. It initially assigns scores for the intervention unit and then compares the outcome of individuals above the cut-off point with a group of individuals below it. Individuals around the cut-off point are similar (Calonico *et al*., 2014). Regression discontinuity is based on the cut-off point in observable characteristic, often called the rating variable. The key feature of the design is that the probability of receiving treatment conditional on this covariate jumps discontinuously at the cutoff, inducing “variation” in treatment assignment that is assumed to be unrelated to potential confounders.

RD techniques are considered to have the highest internal validity (the ability to identify causal relationships), but their external validity (ability to generalize findings to similar contexts) may be less impressive as the estimated treatment effect is local to the discontinuity. The treatment is not randomized, but there is some process that deterministically dictates whether a unit is treated or not. But, the major technical problem of this method is that it assesses the marginal impact of the program only around the cut-off point for eligibility and nothing can be said of individuals far away from it and the average treatment-effects estimators are usually constructed using local polynomial non- parametric regression, and statistical inference is based on large-sample approximations.

Instrumental variables

An instrument variable (IV) is a variable that predicts exposure, but conditional on exposure shows no independent association with the outcome and employed with cross-sectional data or panel data, allowing selection bias on unobserved features to change over time by identifying a variable (or instrument) that is connected with participation but not with unobserved characteristics impacting the outcome. It corrects selection bias on unobserved traits then used to forecast participation (Baiocchi and Small, 2014). Instruments were originally conceptualized as exogenous variables in structural equation models and assumptions related to the disturbances. It also used to control for confounding and measurement error in observational studies so that causal inferences can be made. Unlike an observed control variable, an instrumental variable is assumed not to have any direct effect on the outcome. Instead, the instrumental variable is thought to influence only the selection into the treatment condition.

Endogenous switching regression model

This model controls for a "hidden bias" that may appear when measuring the impact of technology by taking into account both visible and unobservable variables. Estimated parameters would be biased if the endogeneity of irrigation participation disregarded. The average treatment effect on the treated (ATT) calculates the average difference in outcomes of the farmers with and without irrigation users (Lokshin and Sajaia, 2004). The majority of approaches for calculating ATT, such as PSM, neglect unobservable elements that influence the participation in irrigation and assume that irrigation users and non-users have the same return to attributes.

By estimating a simultaneous equations model with endogenous switching by full information maximum likelihood estimation, it is possible to account for the heterogeneity in the decision to participate or not to participate in irrigation as well as for unobservable characteristics of farmers and their farms without distinguishing between the causal effect of participation and the effect of unobserved heterogeneity of the participation decision. Therefore, based on the above justification endogenous switching regression is more preferred and used for this study, because it has capacity to correct the selection bias associated with the technology use and also handles unobserved factors in addition to observed in the technology impact.

2.4. Review of Empirical Studies

2.4.1. Factors Affecting Participation in Irrigation

Studies conducted by Abdissa *et al*. (2017) on impact Analysis of Small-Scale Irrigation Schemes on Household Food Security in Sibu Sire District of Western Oromia, Ethiopia using Heckman two stage model. The result indicated that distance from the water source, size of cultivated land, access to credit service, access to extension, livestock holding had significant effect on participation in irrigation.

A study conducted by Tefera and Cho (2017) on Contribution of Small-Scale Irrigation to Households Income and Food Security: Evidence from Ketar Irrigation Scheme, Arsi Zone, Ethiopia using Logit model indicated that age of household head, education level of household head and size of the cultivated land found to be influencing household participation on small scale irrigation significantly.

A study conducted by Abera *et al*. (2021) on the determinants of small-scale irrigation and its effects on household food security: The case of Bako Tibe District, West Shoa, Ethiopia used the binary logistic regression model and the result of study showed distance from irrigation scheme, number of livestock, total annual income, access to market information, age, sex and dependency ratio are significantly affecting the participation decision of farmers in small scale irrigation.

Legesse *et al*. (2018) studied Impact of Small-Scale Irrigation on Household Farm Income and Asset Holding: Evidence from Shebedino District, Southern Ethiopia using Heckman selection model. The study has found that age, educational level, contact frequency with agricultural development agent, credit access, access to mass media, participation in irrigation related training and livestock ownership were the variables that significantly influence households' use of small-scale irrigation.

A studies study conducted by Gadisa *et al*. (2021) on impact of small-scale irrigation on household food security in central highlands of Ethiopia: evidences from Walmara district using Logistic regression model revealed that age, livestock holding, sex, family size, land owned, distance from irrigation site and access to credit services were the variables that significantly affected the participation in irrigation.

A study conducted by Abdi (2021) on impact of small-scale irrigation on smallholder farmer income: the case of Melka Belo district east Hararghe zone of Oromia national regional state, Ethiopia using Logistic Regression Model revealed that participation in the small-scale irrigation scheme was significantly and positively affected by educational level of the household head, cultivated land holding and livestock ownership, but significantly and negatively affected by distance to the nearest market and distance of farm from water source.

The study conducted by Jambo *et al*. (2021) on impact of small-scale irrigation on household food security: evidence from Ethiopia using Logistic regression model has found that participation in irrigation is positively determined by age, education, land size, access to extension service. In contrast to this, participation in irrigation is negatively determined by distance from farm plot to water source and distance from the main market.

The study conducted by Abdiyo (2021) on impact of effect of small-scale irrigation on household food security: the case of Adaba district, West Arsi zone, Oromia regional state, Ethiopia using Heckman two stage selection model and the result of the studies identified that variable such as nearness to the water source, household size, size of cultivated land, livestock holding, farmers' perception of soil fertility status and access to credit service are affecting farmers participation in small scale irrigation significantly.

2.4.2. Impact of small-scale irrigation on technical efficiency and income

Bidzakin *et al*. (2018) used an endogenous treatment effect regression model to evaluate the impact of irrigation ecology on smallholder rice farmers in Ghana. The result of their studies showed that the impact of irrigation ecology on technical efficiency is about 0.05, which implies farmers producing under irrigation ecology are more technically efficient in their rice production than those in rain fed production.

Prasad *et al*. (2020) examined the impact of variety type and irrigation on technical efficiency of potato farmers in Nepal. Results showed that irrigation have a significant and positive impact on the technical efficiency of potato production. Likewise, Irrigated potato farming has higher efficiency than rainfed potato farming. Beyan and Jema (2014) investigated the impact of small-scale irrigation schemes on household's technical efficiency in Eastern Oromia, Ethiopia. They used the Propensity score Matching model and the result of finding indicated that irrigation user's household mean income much higher than non-irrigating households and households that participate in irrigation practice have got an improvement of 8.92% in technical efficiency than those households that were not participating in irrigation practice. The result is positive and significant.

Kassie and Alemu (2021) assessed the impact of irrigation on household's food security: The case of Koga irrigation development project in northern Ethiopia. They used Propensity Score Matching Model. The results of study revealed that irrigation has positive and statistically significant impact on household annual income.

Ashu (2022) studied the impact of small-scale irrigation on the income and food security among small-scale farmers in Ethiopia. He used Propensity Score Matching. The result of study indicated that the income of the smallholder farmers was improved positively and significantly due to practicing small-scale irrigation.

Study conducted by Fitsum *et al*. (2019) on impact of small-scale irrigation on poverty reduction; evidence from Ethiopia using Endogenous regression model. Their findings showed that access to small scale irrigation resulted in better living standard for users when compared to non-users. Similarly, farm income of the non-users would increase by 149% had they used irrigation.

Study conducted by Legesse *et al*. (2018) studied the impact of small-scale irrigation on household farm income and asset holding: evidence from Shebedino District, Southern Ethiopia using Propensity Score Matching model. The result of the studies showed that participation in irrigation use has increased annual household farm income by 19,474.8 ETB for participant households than non-participant households which is significant at 1% level. Similarly, it has increased their physical asset holding which is measured in Ethiopian birr valued 27,502 ETB at 1% statistically significance level.

A study conducted by Gadisa *et al*. (2021) on impact of small-scale irrigation on household food security in central highlands of Ethiopia using Propensity Score Matching Model revealed that irrigation user households on average consumed more calories of 529 kcal than irrigation non-users and the result is statistically significant.

2.5. Conceptual Framework of the Study

Small scale irrigation can help smallholder farmers to increase technical efficiency and income by improving the production and productivity and modifying livelihoods of farming households. This is mainly stated that farmers would only adopt a small-scale irrigation if it contributes more to profit than cost, given productive resources. Thus, use of small-scale irrigation implies if the net benefit (i.e. Income and Technical efficiency in this case) is higher than the benefit from not using or rainfed farming. Technical efficiency in general may be increased in different ways. One way of increasing technical efficiency is through improving efficiency of resource utilization which includes the use of small-scale irrigation. However, there are many factors influence the participation in small-scale irrigation practice by farm households. The findings of different studies conducted on irrigation participation in different parts of the world gives an indication that different factors can influence the irrigation participation of farmers. These factors which affect farmers' participation in irrigation practice are categorized into demographic, socio-economic and institutional variables and they affect participation in SSI negatively or positively among farm households. The detailed schematic description is provided in Figure 1 below.

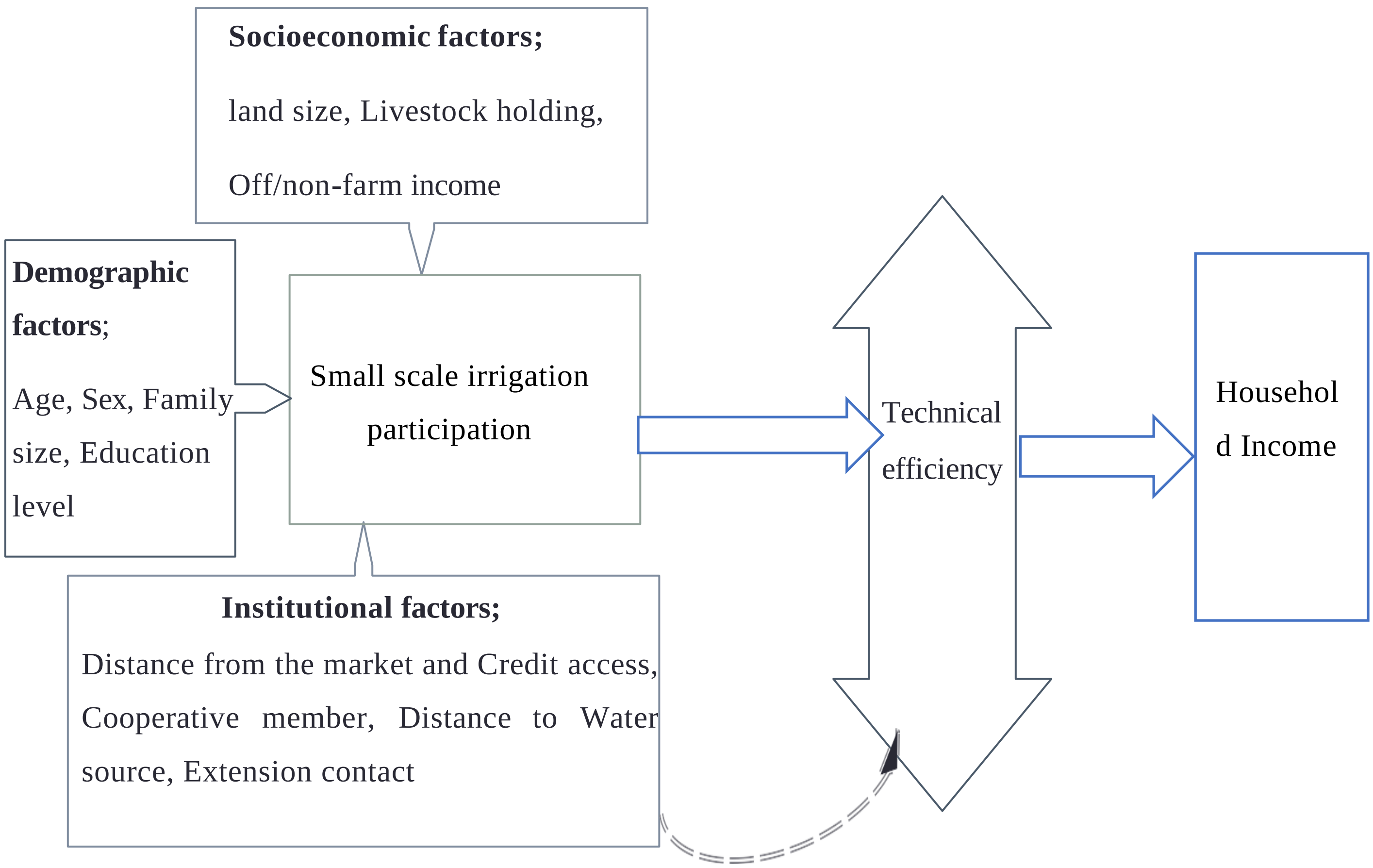

Figure 1. Conceptual Framework of the study:

Source: Adapted from (Baglan *et al.*, 2020) with own modification

3. RESEARCH METHODOLOGY

3.1. Description of the Study Area

3.1.1. Location and physical features

Lemu-Bilbilo district is located in the eastern part of Arsi zone, Oromia National Regional State, Ethiopia. Bekoji is the capital city of the district, which is located about 235 km southeast of Addis Ababa, the federal city of the country and 56 kilometers to south of Asella town, the capital city of Arsi zone. Moreover, the district lies within an elevation range of 1,900 to 4,090 meters above sea level with1100mm mean annual rainfall. The district is also characterized by three agro-ecological zones classified as lowland (Kola), midland (Woinadega), and highland (Dega) areas. Finally, Lemu-Bilbilo district is bound by Shirka, Hankolo Wabe, Munesa, Kofele, Digalu Tijo and Gedeb Woredas (LBDANRO, 2022).

3.1.2. Population

Lemu-Bilbilo district's total number of households is 40,148. Of the total households (93.7%) are male-headed and (6.3%) are female-headed. Around 92.8% of the total population lives in rural areas, while the remaining lives in the capital city of the district and in another urban city, Bekoji (LBDANRO, 2022).

3.1.3. Farming system

The district is characterized by crop-livestock mixed farming system where crop production is dominant in the area. The farmers in the district are practicing agricultural activities ranging from cereals to pulses, vegetable and root and tuber crops. The major crops produced are wheat, barley and potato. Potato is an important food security and a hunger reliever crop in the study area. The planting of potato starts with the onset of summer rain, in early May, matures in August and becomes ready for harvesting and that of irrigation starts in early February, matures in May and becomes ready for harvesting. The study district has high potential of irrigation water and irrigable land for production of potato. Out of 25 rural kebeles in the district, potato is produced in 12 rural kebeles.

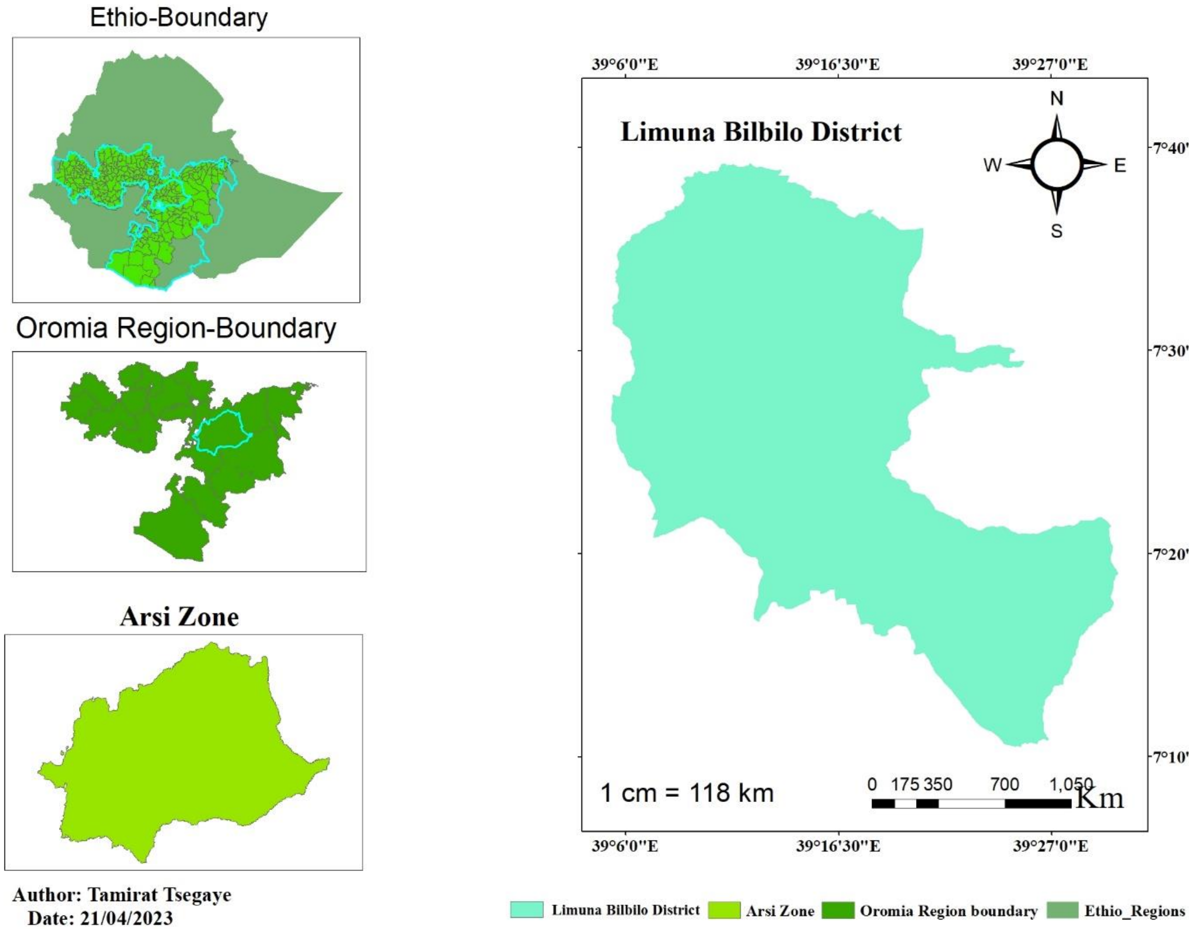

Figure 2 Geographical location of the study area

3.2. Data Type, Sources and Methods of Data Collection

In this study, both primary and secondary data were used. Primary data were gathered from both irrigation users and non-user farm households in the study area. A cross-sectional primary data was collected using a structured questionnaire and official reports and publications were referred for secondary data sources

3.3. Sampling Methods and Sample Size Determination

The target population for this study was smallholder potato farmers in the Lemu-Bilbilo district of Arsi Zone, Oromia National Region State, Ethiopia. Multistage stratified sampling procedure was used to select representative sample household. In the first stage, Lemu-Bilbilo district was selected purposively based on their potato production and irrigation potential. In the second stage, a list of kebeles that have been producing potato were identified, and four kebeles were randomly selected. In the third and final stage, the households were stratified into two strata; those who are irrigation users (the treated group) and those who non users (control group) and sample farm households from each stratum was randomly selected based on proportional to size of each kebeles and districts.

Finally, a total of 371 households (164 irrigation users and 204 non irrigation users) were randomly selected from the sample Kebele using a simple random sampling method with respect to proportional to the size of the kebele from the two Groups. The sample size was determined by a simplified Yamane (1967) formula, which helps inferences and conclusions drawn from the survey to be applied to the complete population from which the sample had been taken.

$$n = \frac{N}{1 + N(e)^2}$$

$$n = \frac{9255}{1 + 9255\,(0.05)^2} = 371$$

Where: n is the minimum number of sample size, e is the tolerable error in the sample or level of precision and N is the total number of farm households in the selected potato producer kebeles. Then, the minimum sample size (n) was determined by choosing the value of e = 0.05 for the 95% level of significance.

Table 1. Sample district, Kebeles and sample size

Sample Kebele	Total households	Irrigation users	Non irrigation users	Total Sample
Lemu Dima	1483	49	64	113
Lemu Burkitu	977	36	47	83
Koma Kera	1164	44	48	92
Koma Ketara	589	38	45	83
Total	**4213**	**167**	**204**	**371**

Source: Lemu Bilbilo district office of agriculture and own computation result

Sampling Methods and Sample Size Determination

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3.4. Methods of Data Analysis

Descriptive statistic and econometric models were used to analyze the data.

3.4.1. Descriptive statistics

Quantitative data was analyzed using descriptive and inferential statistical tools. Descriptive statistics such mean, standard deviation, proportion and percentages was used to analyze the gathered data, while t-test (continuous variables) and $\chi 2$ - test (discrete variables) was employed to test statistical associations among irrigated and non-irrigated farm households in terms of farm characteristics, socio-economic, demographic and institutional factors.

3.4.2. Stochastic frontier model

In the stochastic frontier model, a nonnegative error term representing technical inefficiency is subtracted from the traditional random error in the classical linear model. Aigner *et al*. (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function model of the form:

$$Y_i = f(x_i; \beta) + \varepsilon_i \quad (1).$$

Where Yi measures the quantity of potato output of the i[th] household, Xi is a vector of the inputs used by i[th] household and β is a vector of unknown parameters, $f(x_i;\beta)$ is observed production function. It is postulated that ε_i=$v_i - u_i$ where v_i~$N(0,\delta^2 v)$ and u_i ~$|N(0,\sigma^2 u)|$. v_i errors related to random effects and assumed to be independent of u_i, and identically distributed, which expressed as $N(0,\delta^2 v)$ while u_i errors related to technical inefficiency of the farmers and assumed to be independent of v_i and identically distributed as half-normal, u~$|N(0,\sigma^2 u)|$. The maximum likelihood estimation for variance parameter expressed as:

$$\gamma = \frac{\lambda^2}{[1+\lambda^2]} \qquad (2).$$

$$\partial^2 = \partial_u^2 + \partial_v^2 \qquad (3)$$

.

Where λ is the ratio of the standard errors of the non-symmetric to symmetric error term (i.e. $\lambda = \frac{\sigma_u}{\sigma_v}$. While γ ranges from zero to one and used to measure the total variation in output from the frontier attributable to technical inefficiency.

A value of one indicates that statistical "noise" or exogenous "shocks" are absent from the model, and as a result, the low level of production on a farm relative to the "best" practice (the maximum output) of another farm is entirely due to farm-specific inefficiency. A value of zero indicates that the nonnegative random variable, u_i is absent from the model.

Similarly, the significance of ∂^2 indicates whether the conventional average production function adequately represents the data or not. The parametric specification of frontier in the Cobb-Douglas form for one output and five inputs was given by:

$$logy_i = \beta_0 + \sum_{i=1}^{5} \beta_j lnx_{ji} + v_i - u_i \qquad (4).$$

$$lny_i = \beta_0 + \beta_1 lnland + \beta_2 lnlabour + \beta_3 lnfertilizer + \beta_4 lnseed + \beta_5 lnoxen + v_i - u_i$$

The technical efficiency (TE) of a potato producing household in the study area is defined in terms of the ratio of the observed output (Y_i) to the corresponding frontier output (Y_i*) given the available technology (Coelli *et al*., 2005). Mathematically, this can be expressed as:

$$TE = \frac{Y_i}{Y*_i} = \frac{\beta_0 + \sum_{j=1}^{5} \beta_j ln x_{ji} + v_i - u_i}{\beta 0 + \sum_{j=1}^{5} \beta_j ln x_{ji} + v_i} \quad (5).$$

3.4.3. Endogenous switching regression model

When making an accurate impact assessment of participation in SSI on technical efficiency and household income, the observable and unobservable characteristics of the participants (treatment group) and non- participants (control group) must be captured. However, most impact assessment approaches using nonexperimental data (not randomly assigned) fail to capture observable and/or unobservable characteristics that affect participation and outcome variables. For instance, instrumental variables capture only unobserved heterogeneity, but the assumption is that the parallel shift of outcome variables can be considered as a treatment effect (Musa *et al*., 2017; Million *et al*., 2022). A methodological approach that overcomes the aforementioned limitations is endogenous switching regression (ESR), which is the most commonly used method in impact analysis studies (Di Falco *et al*., 2011; Million *et al*., 2022).

Therefore, this study was used an endogenous switching regression (ESR) to account for endogeneity problems by simultaneously estimating irrigation participation decision and the outcome equation (technical efficiency and income). The endogenous switching regression model was analyzed in two steps. The first stage, participation in SSI, was estimated using a binary probit as selection model. Whereas, in the second stage, regressions such as Tobit (for technical efficiency) and OLS (for household income) were employed separately to assess the association between outcome variables and participation in SSI (Million *et al*., 2019; Milkesa *et al*. 2019).

Farmers decide to participate in irrigation when the expected utility received from participation is greater than the utility received from non-participation. This is due to the fact that participation in irrigation is either voluntary or targeted at a specific group of farmers. In this scenario, the utility maximization theory which stated that farmers decided to participate in SSI if the expected utility from participation (u_p) is greater than the corresponding utility from non-participation (u_{np}). i.e., $u_p - u_{np} > 0$. Let D_i* be the latent variable capturing the benefit of the i^{th} farmer's participation in SSI was adopted and given as:

$$D^* = Z_i\delta + \varepsilon_i \text{ where } D_i = \begin{cases} 1, \text{if } D^* \text{ is} > 0 \\ 0, \text{ Otherwise} \end{cases} \quad (6).$$

where: Z is different household characteristics determining the participation in SSI and δ is unknown parameters to be estimated and ε is an error term.

The participation decision in SSI might be endogenous in the outcome equation (net total income and technical efficiency), and analyzing the outcome variable without adjusting for potential endogeneity could lead to biased estimates (Bidzakin *et al* 2018). As a result, employing an instrumental variables technique to identify the outcome equation from the selection equation is important.

Instrumental variables could affect the participation decision in SSI, but not outcome variables (net total income and technical efficiency). In this study, we employed farmer cooperative membership (dummy, yes=1) and distance from irrigation water source (continuous variable) as a selection instrumental variable with strong assumption that they significantly affect the participation decision in SSI but not outcome variables. We checked the validity of these instrumental variables using a falsification test. After successfully checked the validate of the instrumental variables used in the ESR model, we estimated the outcome equation for both irrigators (regime 1) and non-irrigators (regime 2), then, ESR was estimated as follows:

$$\text{Regime 1: } y_1 = X_1\omega_1 + \epsilon_1 \text{ if } D = 1 \text{ (Irrigation users)} \quad (7)$$

.

$$\text{Regime 2: } y_0 = X_0\omega_0 + \epsilon_0 \text{ if } D = 0 \text{ (Non irrigation users)} \quad (8).$$

Where y_i represents outcome variables (total income and technical efficiency) for irrigation users (y_1) and non- irrigation users (y_0), X_i is farm and socio-economic characteristics of household that affects outcome variables, ω_i is a vector of parameters to be estimated, and ϵ_1, and ϵ_0 are error terms. The error terms from the three equations ε, ϵ_1, and ϵ_0 are assumed to have a trivariate normal distribution with mean vector zero (Maddala, 1983).

$$cov(\varepsilon, \epsilon_{1,}\epsilon_0) = \begin{bmatrix} \sigma_{\epsilon 0}^2 & \sigma_{\epsilon 1 \epsilon 0} & \sigma_{\epsilon 0 \varepsilon} \\ \sigma_{\epsilon 1 \epsilon 0} & \sigma_{\epsilon 1}^2 & \sigma_{\epsilon 1 \varepsilon} \\ \sigma_{\epsilon 0 \varepsilon} & \sigma_{\epsilon 1 \varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix} \quad (9)$$

where σ_ε^2 is the variance of the selection equation (equation 14), $\sigma_{\epsilon 0}^2$ and $\sigma_{\epsilon 1}^2$are the variances of the outcome equations for non-irrigators and irrigators while $\sigma_{\epsilon 0 \varepsilon}$ and $\sigma_{\epsilon 1 \varepsilon}$ represent the covariance between , ϵ_1, and ϵ_0. Maddala (1983), confirm that the covariance of the error terms (ϵ_1, and ϵ_0) is not defined since outcome variables (y_1 and y_0) are not captured at the same time. The expected values of error term of the second stage are non-zero because the error term of the first stage (ϵ_0) and second stage (ϵ_1 and ϵ_0) are associated to each other. The expected value of error terms of question (15) and (16) can be expressed as follows:

$$E(\epsilon_1 | D = 1) = \sigma_{\epsilon 1 \varepsilon} \frac{\phi(Z_i \omega_i)}{\Phi(Z_i \omega_i)} = \sigma_{\epsilon 1 \varepsilon} \lambda_1 \quad (10)$$

$$E(\epsilon_0 | D = 0) = \sigma_{\epsilon 0 \varepsilon} \frac{-\phi(Z_i \omega_i)}{1 - \Phi(Z_i \omega_i)} = \sigma_{\epsilon 0 \varepsilon\, \lambda 2} \quad (11)$$

The probability density and cumulative distribution function of the standard normal distribution are φ and ϕ , respectively. The ratio of φ and Φ evaluated at Z_i is referred to as the inverse Mills ratio $\lambda 1$ and $\lambda 2$ (selectivity terms) (Maddala, 1986). Then the variable included in the second stage questions captures both absorbed and unabsorbed heterogeneity in estimation procedure of ESR. To address the heteroskedasticity arising from the generated regressors, the standard errors in questions (y_1) and (y_0) are bootstrapped (Bidzakin *et al* 2018).

Using the above framework, the average treatment effect on the treated (ATT) and on the untreated (ATU) is examined by comparing the expected outcomes of the actual and counterfactual outcomes. Following the works of Moti *et al*. (2018) and Million *et al*. (2019), the expected values of the outcomes of outcomes of both irrigation and non-irrigation users in reality and the counterfactual are given as follows:

Users with adoption of SSI (real):

$$E(y_1|D = 1) = X_1\omega_1 + \sigma_{\epsilon 1\varepsilon}\lambda_1 \qquad (12a)$$

Non-users without adoption of SSI (real):

$$E(y_0|D = 0) = X_0\omega_0 + \sigma_{\epsilon 0\varepsilon} \qquad (12b)$$

If users had decided to be non-users of SSI (counterfactual):

$$E(y_0|D = 1) = X_1\omega_0 + \sigma_{\epsilon 0\varepsilon}\lambda_1 \qquad (12c)$$

If non-users had decided to be users of SSI (counterfactual):

$$E(y_1|D = 0) = X_0\omega_1 + \sigma_{\epsilon 1\varepsilon} \qquad (12d)$$

While equations (12a) and (12b) represent the actual outcome observed in the sample for irrigation users and non-users, respectively; equations (12c) and (12d) are the respective counterfactual outcomes. These conditional expectations are used to compute ATT and ATU. Average participation effect for irrigation users (ATT) is calculated as the difference between equations (12a) and (12c).

Finally, we calculated the average treatment effect on the treated (irrigation users) (ATT) as the difference between (12a) and (12c)

$$[\, E(y_1|D = 1) - E(y_0|D = 1)] \qquad (13)$$
$$= X_1\omega_1 + \sigma_{\epsilon 1\varepsilon\lambda_1} - X_1\omega_0 + \sigma_{\epsilon 0\varepsilon}\lambda_1$$

Likewise, the average treatment effect on the non- irrigators (ATU) as the difference between (12b) and (12d).

$$E(y_0|D = 0) - E(y_1|D = 0)$$
$$= X_0\omega_0 + \sigma_{\epsilon 0\varepsilon} - X_0\omega_1 + \sigma_{\epsilon 1\varepsilon\lambda_0} \quad (14)$$

3.5. Variables Definition and working Hypotheses

3.5.1. Outcome variables for the impact analysis

Potato technical efficiency level: has been determined as an outcome of interest to estimate the impact of SSI. It is a capacity of farmers that measures the relative ability of farms to get the maximum feasible output from set of inputs used which is measured by technical efficiency scores after estimation of the stochastic frontier model.

Household income: It is a continuous variable and refers to total household income from potato sells measured in Ethiopian Birr during the survey year.

3.5.2. Dependent and Independent variables to estimate technical efficiency

The dependent variable: potato output produced in a given survey year of 2021/22 from sample households and measured in kilogram (Kg). So finally, this is converted into natural logarithm in order to run efficiency

Independent variables: these are variables (inputs) which directly affect the yield of potato production of sample households in survey year. They are;

Land size: This refers to the area of the plot of land allotted for potato production. The unit of measurement for the land different in different parts of the country; hence the data was changed to hectare for smoothness. Accordingly, a hectare of a plot of land used for potato production was used in the analysis. It is one of the important fixed inputs in agricultural production.

Labour: Aggregated family, hired and exchange labour used in potato production measured in man-days and converted to a homogeneous variable using the standard conversion.

Seed: This is a continuous variable representing the total amount of potato seed utilized by the farmer per hectare of land measured in Quintals.

Fertilizer: It is a continuous variable measured in Quintal which refers to the total amount of fertilizer (NPS/DAP and UREA) used by farmer per hectare of the potato production.

Oxen power: It is a continuous variable which represents the number of oxen-days measured in pair of oxen-days per hectare of land used for potato production by a single farmer. It was hypothesized as; farmers who used the number of pair of oxen-days were more productive in potato production than those who used fewer amounts of pair of oxen days.

Table 2. Definition of variables included in technical efficiency estimation

Variable	Description
Dependent variable	
Ln (Potato output)	Total potato output in kg obtained from inputs used
Independent variables	
Ln (Land)	Land used in potato production in ha
Ln (Labor)	Labor used in potato production in persons days
Ln (Fertilizer)	Fertilizer used in potato production in kg
Ln (Seed)	Potato tuber seed used in kg
Ln (Oxen)	Oxen power used in potato production in oxen days

3.5.3. Dependent and Independent variables for participation in irrigation

Dependent variable (treatment variable):

Participation Decision: It is a dummy variable which assumes value of one if the household use irrigation to produce potato and zero otherwise. In this stand, small holder farmers who had used irrigation to produce potato are compared with farmers who have not used irrigation to produce potato.

Independent variables: Based on review of literature, the demographic, economic and institutional factors that are expected to affect the participation decision in irrigation and the outcome variables are the following:

Age of the household head (AGEHH): It is a continuous variable measured in years and is associated with the decision to participate in irrigation. Research by Jambo *et al*. (2021) and Sánchez Toledano *et al*. (2018) suggests that elderly household heads tend to be risk-averse and may transfer their irrigable land to younger generations. In contrast, younger farmers are often more inclined to adopt new technologies, display positive attitudes towards innovation, and have lower perceptions of risk. Consequently, the age of the household head is hypothesized to have a negative impact on the likelihood of households engaging in small-scale irrigation practices and outcome variable.

Sex of the household head (SEXHH): This is a dummy variable indicating whether the household head is male (assigned a value of 1) or not (assigned a value of 0). Gender plays a significant role in determining access to resources and opportunities. In many rural settings, particularly in our country's socio-cultural context, male-headed households tend to be more involved in activities such as attending meetings, conducting follow-ups, and supervising farm operations compared to female-headed households (Ngango and Hong, 2021; Legesse *et al.*, 2018). Conversely, female-headed households often face challenges including limited access to improved technologies, land, and extension services due to resource constraints, added responsibilities such as child-rearing, and other related factors (Abera *et al*., 2021). As a result, it is hypothesized that male-headed households would have a positive influence on their engagement in small-scale irrigation practices and thereby the outcome variable.

Educational level of the household head (EDGLHH): It is a continuous variable and measured in number of years attending formal class. It is argued that educated people can better understand agricultural practices and be able to apply technical skills than uneducated ones (Abdi, 2021). This may help to increase income from small scale irrigation so that one can purchase more physical assets or save more money. Hence, the education status of the household head was expected to have a positive effect on small scale irrigation participation and the outcome variable.

Household size (FAMSZ): This continuous variable is measured as the adult equivalent of each individual residing in a particular household. The adult equivalent is calculated by categorizing individuals based on their age groups and assigning a value using a standard conversion factor. If there are a large number of household members, the greater will be the availability of the labor force that help for production purposes and the adoption of new technologies, and hence, the better will be the possibility of the family participating in small scale irrigation (Gemechis *et al*. 2022: Abadi *et al*. 2015). Hence, Household size was expected to have a positive effect on small scale irrigation participation and the outcome variable.

Land holding size (LHSHH): It is continuous variable which shows the total land coverage operated by the farmer, measured by hectares. Farmers with larger area of cultivated land have the capacity to use compatible technologies that could increase the use of improved agricultural technologies such as irrigation. According to Gadisa *et al.* (2021) this variable has a significant positive effect on irrigation decision participation. Therefore, land holding size was expected to have a positive effect on small scale irrigation participation and thereby the outcome variable.

Livestock holding (TLU): It is a continuous variable measured by the number of livestock holding by the farmers in tropical livestock unit (TLU) considered as a proxy indicator of wealth. Households that own larger number of livestock are relatively rich as compared to those who own a smaller number of livestock. Ownership of more livestock offers an alternative source of cash income in order to participate in new agricultural practices that can increase income that is used for asset building from potato yield (Wubamlak *et al*., 2020; Leta *et al*., 2018). As a result, it was hypothesized that livestock ownership would have a positive effect on small scale irrigation participation and the outcome variable.

Frequency of extension contacts (EC): It is continuous variable measured in number of days farmers contacted with extension agent per month. An extension visit is a kind of service provision given to farmers by agricultural experts. The service has to support and facilitate the supply of agricultural inputs in order to engage producers by supporting them to obtain information, skills, and technologies to solve problems and improve their livelihoods (Temesgen et al., 2018; Sisay *et al*., 2019). Therefore, the number of extension visits was hypothesized to have had a positive impact on small scale irrigation participation decisions and thereby the outcome variable

Off/non-farm income (NFI): This continuous variable is measured in Ethiopian Birr (ETB) and represents the income earned by farmers through engaging in non-farm activities. Non-farm income serves to expand the financial resources available to farmers, allowing them to overcome cash constraints and make necessary purchases of inputs that may not be feasible solely from farm-generated income (Jambo *et al*. 2021: Beyan *et al*., 2014). The additional income generated from non-agricultural sources enhances the financial capabilities of farmers, potentially increasing their likelihood of investing in new technologies. As such, it is hypothesized that this variable has a positive impact on the decision to participate in small scale irrigation and thereby the outcome variable.

Amount of credit obtained (AMCREDO): This continuous variable is measured in Ethiopian Birr. The use of financial credit is an essential issue that affects agricultural production and productivity. Credit use is expected to enhance smallholders' ability to purchase technology participation inputs that can enhance productivity and, therefore, the asset holding capacity of smallholders (Gadisa *et al*., 2021; Temesgen *et al*., 2018). Credit helps farmers get inputs such as fertilizers, potato protection chemicals, mechanizations, improved inputs, and labor wages, which can increase income from potato production and build assets (Gadisa *et al*., 2021). Thus, credit is expected to boost the decision to participate in small scale irrigation and affect the outcome variable positively.

Distance from the nearest market (DM): This continuous variable is measured in kilometers and represents the distance to the market center. Market centers serve as hubs for communication among producers, consumers, and traders, with the distance to these centers acting as an indicator of transaction costs. Household proximity to the market center is beneficial as it reduces costs associated with purchasing agricultural inputs and selling products (Abera et al., 2022). Farmers situated near market centers may engage in income-generating non-farm activities such as trading, which can enhance their purchasing capacity for various inputs. Therefore, the distance to the market center was hypothesized to have a negative impact on participation in irrigation and outcome variable.

Distance from irrigation water source (DIWS): This variable, measured in kilometers, represents the distance between the irrigation water source and farmers' residences. The proximity of the irrigation water source to farmers' homes significantly impacts their access and utilization of irrigation water, potentially influencing their decision to participate in irrigation practices. Previous research by Jambo *et al*. (2021) has highlighted that the distance to the irrigation water source negatively influences households' participation in irrigation. Therefore, it is hypothesized that the distance to the irrigation water source has a negative effect on participation in small scale irrigation and outcome variable.

Farmer Cooperative Membership (FCM): This is a dummy instrumental variable that takes a value of 1 if the household head participates in farmer cooperatives during the study period and a value of 0 if not. Farmers who engage in farmer cooperatives are anticipated to be more inclined towards utilizing agricultural technologies, such as irrigation, compared to non-members. The cooperative setting facilitates the sharing of information among members on the effective use of irrigation and agricultural technologies, thereby enhancing production efficiency (Adeyonu et al., 2019). Additionally, farmers may leverage their cooperative membership to market their potato produce, driving them to utilize irrigation practices for higher yield. As a result, farmers cooperatives membership was supposed to have a positive influence on the participation of SSI and outcome variable.

Table 3. Definition of independent variables, measurement, variable type and effect

Variables	Definition of variables	Variable type	Measurement	Effect on participation
Treatment variables				
PSSI	Participation in SSI	Dummy	1 if participated in SSI, 0 otherwise	
Outcome variables				
NI	Net total income	Continuous	ETB	
TE	Technical efficiency	Continuous	Between 0 and 1	
Explanatory variables				
AGEHH	Age of household	Continuous	Years	-ve
SEXHH	Sex of the household head	Dummy	1 if male and 0 otherwise	+ve
EDLHH	Educational level of the household head	Continuous	Years	+ve
FAMSZ	Family size in adult equivalent	Continuous	Number	+ve
LHSHH	Land holding size	Continuous	Hectares	-ve
DIWS	Distance from the water source	Continuous	Minutes	-ve
TLU	Number of Livestock owned	Continuous	TLU	+ve
ECA	Extension contacts	Continuous	Frequency	+ve
DNM	Distance to the nearest mkt	Continuous	Minutes	-ve
NFMI	Off/non-farm income	Continuous	Birr	+ve
AMCREDO	Amount of credit obtained	Continuous	Birr	+ve
FCM	Farmer Cooperative Membership	Dummy	1 if yes, 0 otherwise	+ve

4. RESULTS AND DISCUSSION

This chapter is structured to present the study results and examine the key findings in relation to similar studies. It is divided into three sections. The first section offers descriptive analyses of the demographic, socioeconomic, and institutional characteristics of the sampled households. The subsequent two sections delve into the outcomes generated from the analytical models articulated in chapter three.

4.1. Descriptive Analysis

A set of variables outlining the socio-economic, demographic, and institutional characteristics of irrigation users and non-irrigation users sample households are presented. The t-test was employed to assess differences in means for continuous variables, while the Chi-square test was utilized to determine any statistically significant associations among categorical variables. Subsequently, the results and discussion commenced with descriptive statistics of continuous variables, followed by categorical variables.

4.1.1. Descriptive statistics of continuous variables

The demographic, socioeconomic, and institutional variables hypothesized to influence the participation of smallholder farmers in small-scale irrigation, and included in the probit model, are provided and described in Tables 4. Across the total sample, the average age of household heads was 52.77 years, with a standard deviation of 9.35. Comparing irrigation users and non-irrigation users, the average ages were 47.86 and 56.79 years, respectively, with standard deviations of 7.75 and 8.61. Test statistics indicated a significant mean difference in average age between irrigators and non-irrigators at the 1% probability level.

In the pooled sample, household heads have attended formal education for an average of 2.99 years. Notably, the results indicated that households using irrigation had higher levels of education compared to non-users, (with an average of 3.71 years for irrigation users and 2.42

years for non-irrigation users). This difference was found to be statistically significant at the 1% probability level.

The sampled households had an average landholding size of 2.08 hectares, with irrigators owning an average of 2.26 hectares compared to 1.93 hectares for non-irrigators. This difference in land size was statistically significant at a 1% probability level. Additionally, the household size in adult equivalents was 6.15 for irrigation users and 5.18 for non-users, a statistically significant difference at the 1% probability level.

Like majority of Ethiopian farmers, livestock takes an important part in the farming business in the Lemu-Bilbilo district, which contributes to the subsistence requirements. The type of livestock owned includes cattle, small ruminant, equine, and chicken. The livestock holding measured by TLU (Table 4) depicts that, irrigators on average had 9.65TLUs while non-irrigators have 8.05 TLUs. The results showed that there is significant difference in average livestock holding between irrigators and non-irrigators at 1% probability level showing that, irrigators had large livestock holdings as compared to non-irrigators.

Extension services play a crucial role in disseminating information on farm technologies and enhancing farmers' technical and managerial skills (Danson *et al*., 2018). According to the study findings, farmers, on average, made 2.22 contacts per month per household with extension agents. Interestingly, irrigation users had more frequent contact with development agents (2.86) compared to non-irrigation users (1.69), with a statistically significant difference at the 1% probability level. This result aligns with previous studies conducted by Bidzakin *et al*. (2018) and Teshome *et al*. (2016).

In the study area, farmers have on average travel distance of 30.57 minutes to the nearest market. Specifically, irrigation users have a slightly shorter average distance of 29.75 minutes to the nearest market, whereas non-irrigation users have to travel an average of 31.24 minutes. The observed difference was statistically significant at the 5% probability level, indicating that non-irrigation farmers reside further away from the nearest market compared to irrigated farmers.

Income from off/non-farm employment serves as a means to alleviate credit constraints for rural households and can be utilized to finance irrigation investments, thereby enhancing income and production efficiency. In the study area, farm households primarily depend on agricultural activities, supplemented by non-agricultural ventures for additional income. The average off/non-farm income for sampled households in the study area was 1788.68 ETB. Notably, irrigation users generated a higher average income of 2546.70 ETB compared to 1168.13 ETB for non-irrigation users, with this difference is statistically significant at the 1% probability level.

Both formal and informal lending institutions play a crucial role in providing credit to farmers in the study area, enabling them to acquire essential inputs such as fertilizer, seeds, chemicals (herbicides and fungicides), and other necessities. Among the sources of credit, Gelema micro-finance and local cooperatives are the formal institutions identified in the study area. On average, farmers accessed credit amounting to 6875.88 ETB from formal institutions, with the range varying between zero ETB and 15000 ETB. Notably, irrigation users secured a higher average credit amount compared to non-irrigation users, with an average of 10517.6 ETB for irrigators and 3894.65 ETB for non-irrigation users. This difference was found to be statistically significant at the 1% probability level.

Table 4. Descriptive statistics of explanatory and outcome variables

Variables	Descriptions	Irrigation users (N=167)		Non irrigation users (N=204)		Total Sample (N=371)	
		Mean	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
Age of hh	Age of household in (years)	47.86***	7.75	56.79	8.61	52.77	9.35
Education of hh	Level of education (years)	3.71***	1.80	2.42	1.67	2.99	1.85
Cultivated land	Total cultivated land holding (ha)	2.26***	0.57	1.93	0.67	2.08	0.65
Family Size	Household size (AE)	6.15***	1.12	5.18	1.33	5.62	1.33
Dist. Irrigation	Distance from irrigation water (Minute)	33.59	7.22	33.07	12.94	33.31	10.74
Livestock TLU	Livestock owned (TLU)	9.65***	3.26	8.05	2.55	8.77	2.99
Ext. Contact	Frequency of Extension Contacts (Number)	2.86***	0..90	1.69	1.12	2.22	1.18
Dist. NM	Distance to nearest market (Minute)	29.75**	6.63	31.24	7.76	30.57	7.30
Off/Non-farm Income	Off /Nonfarm income (ETB)	2546.70***	3041.1	1168.1	2189.9	1788.6	2693.2
Received Credit	Amount of credit received in ETB	10517.6***	9274.5	3894.6	7182.9	6875.8	5975.5
Income from potato	Amount of Income from potato sell in ETB	49833.01	24299.47	35405.85	21665.32	41900.02	23960.31

**, **, and * significant at the 1, 5, and 10 percent probability levels, respectively

Source: Computed from own survey data 2023

4.1.2. Descriptive Statistics of Categorical Variables

Table 5 presents a summary of the Demographic and institutional characteristics for discrete variables in the study. Among the total sampled households, 91.64% (340 out of 371) were male-headed, while 8.36% (31 out of 371) were female-headed households, reflecting a common trend where males typically lead farming activities in rural areas. In the study area, farmer cooperative membership has been shown to enhance farmers' productivity and profitability by reducing transaction costs in input and output markets. The result of chi square test indicates that approximately 81.44% of irrigators and 47.06% of non-irrigators are members of farmer cooperatives, respectively. This figure showed that higher proportion of irrigator participated in farmer cooperative than that of the non-irrigation users. The result is significant and different at 1% significance level.

Table 5: Descriptive statistics of discrete explanatory variables

		Irrigation Users (N=167)		**Non-irrigation users (N=204)**		**Total sample (N=371)**		
Variables	Category	No.	%	No.	%	No	%	χ 2 _value
Sex	Female	13	7.78	18	8.82	31	8.36	0.13
	Male	154	92.22	186	91.18	340	91.64	
Farmer Cooperative	No	31	18.56	108	52.94	139	37.47	46.32***
	Yes	136	81.44	96	47.06	232	62.53	

***, **, and * represent level of significance at 1%, 5%, and 10%, respectively. Source: Computed from survey data (2023).

4.2. Econometric Model Results

4.2.1. Estimation of technical efficiency level

Prior to estimating the production output model, it is crucial to evaluate various assumptions associated with the model specification. Hypothesis testing was conducted to determine the suitable functional form for the dataset. This was carried out through generalized likelihood ratio tests specified as:

$$LR = -2[ln(\text{H0}) - \ln(\text{H1})]$$

Where LR, ln(H0) and ln(H1) defined as Log likelihood ratio, value of log likelihood of null hypothesis and Value of log likelihood of alternate hypothesis respectively, (Greene, 1980).

The most common functional forms reviewed in most previous studies were Cobb-Douglass and Trans-log. This involved testing the null hypothesis of the Cobb-Douglas frontier functional specification, where the coefficients of all interaction terms and square terms are presumed to be zero (H_0: β_i =0), against the alternative hypothesis of the Translog functional form, where these coefficients are expected to differ from zero (H_1: $\beta_i \neq 0$). The likelihood ratio (LR) test statistic was then calculated as $LR = -2[lr(\text{Cobb} - \text{Douglass}) - \text{lr}(\text{Trans} - \text{Log})$.

Table 6: Hypothesis test results for the parameters of the SPF

Null Hypothesis	**DF**	**LL0**	**LL1**	**Calc (LR)**	**Critical (χ2, 95%)**	**Decision on H0**
H0: production is Cobb Douglass. (i.e., H_0: β_6 …. β_{20}= 0)	20	-336.22	-325.28	21.18	31.41	Accept H0

Note: DF=Degrees of freedom Source: Computed from survey data (2023).

According to Table 6, the log likelihood values for the Cobb-Douglas and Translog functional forms were -336.22 and -325.28, respectively. The calculated LR statistic of 21.18 was found to be lower than the tabulated value at a 5% significance level. Consequently, the decision was made to not reject the null hypothesis, indicating that the coefficients of the interaction terms and squared variables in the Translog specification were not significantly different from zero. Thus, it was concluded that the Cobb-Douglas functional form sufficiently represented the dataset.

The dependent variable considered for SFM was potato output (in kilograms), and it was determined based on various production inputs including land (in hectares), oxen (in oxen-days), labor (in man-days equivalent), seed (in kilograms), and fertilizers (in kilograms). The estimation was conducted using Cobb-Douglas stochastic frontier model. The maximum likelihood (ML) estimates from the stochastic production frontier model revealed that all coefficients exhibited the anticipated positive signs and had a significant impact on potato production. Table 7 compares the maximum likelihood (ML) parameter estimates of the Cobb-Douglas stochastic production frontier function with the OLS estimates of the average production function.

The coefficients of the inputs represent the partial elasticity of potato output in response to a relative change in each input. Among the inputs, land and seed exhibit the highest elasticity, followed by labor and fertilizer. The high elasticity of land implies that increasing land usage for potato production could lead to a substantial increase in potato output. As stated in Table 7, the elasticity of land for potato production in the study area was 0.82, indicating that there was relatively more proportionate change in output due to proportionate change in the size of land used to produce potato. The significant coefficient of land indicates that a 1% increase in the cultivation of potato land would increase the potato output of sample households by 0.82% keeping other factors constant. The results align with the findings of previous studies by Hika (2016) and Mustefa *et al*. (2017).

Consistent with expectations, the quantity of fertilizer used had a substantial impact on potato productivity. The coefficient associated with fertilizer use for potato production is significant and positive at a 1 percent probability level, showing that a 1% increase in fertilizer quantity leads to a 0.19% rise in potato yield for the sampled households. This finding aligns with similar results discovered by Belete (2020). Furthermore, the utilization of potato seed also exhibited a significant and positive effect on potato output at a 1 percent probability level. Ceteris paribus, as the farmers increase the potato seeds by 1%, their potato output would rise by 0.18%.

The relative contribution of both typical noises and the inefficiency component to overall variability should be calculated. The ratio of the standard error of inefficiency component u (σ_u) to the standard error of residual v (σ_v), known as lambda (λ). Based on λ, gamma (γ) which measures the effect of technical inefficiency in the variation of observed output can be derived (i.e. $\gamma = \frac{\lambda^2}{1+\lambda^2}$) (Okoye *et al*., 2007). In this case, the value of this discrepancy ratio (γ) calculated from the maximum likelihood estimation of the full frontier model was 0.68. This can be interpreted as the technical inefficiency impact accounted for 68% of the variability in potato production. This suggests that there is room to improve potato output by identifying the socioeconomic farm-specific and institutional variables that are producing the difference.

Table 7. MLE results of the production frontier for the sample households

Variables	**ML estimates**		**OLS estimates**	
	Coefficient	**Std. Error**	**Coefficient**	**Std. Error**
ln (Land)	0.82***	0.07	0.82***	0.07
ln (Labor)	0.26	0.14	0.20	0.14
ln (Seed)	0.18***	0.06	0.15**	0.06
ln (Oxen)	-0.14	0.11	-0.04	0.10
ln (Fertilizer)	0.19**	0.10	0.18	0.11
Constant	6.04***	0.42	5.72***	0.44
Gamma (γ)	0.68***			
Wald $\chi 2$ statistic	485.55***			
Adj R-squared			0.55	

***, ** and * significant at the 1, 5 and 10 percent probability levels,

4.2.2. Technical efficiency score of potato farmers among sample respondent

Table 9 shows the analyzed TE results among irrigation users and non-irrigation users potato producing households. The estimated TE for the sampled households was 0.63 ranged from 0.12 to 0.89, with a standard deviation of 0.13. For irrigation users' farmers, the estimated mean technical efficiency score was 65.2%, whereas the corresponding result for non-users' households was 62.2%, the result is statistically significant and different among two groups at 1% probability level.

Table 8. Estimated technical efficiency scores of the sample farmers

variables	**Irrigation users N = 167**		**Non irrigation users N = 204**		**Total sample N = 371**		**t value**
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	
Technical Efficiency	0.652	0.12	0.622	0.14	0.63	0.13	-2.21**

***, ** and * significant at the 1, 5 and 10 percent probability levels:

4.2.3. Determinants of participation in small-scale irrigation scheme

In the first stage of ESR, binary probit was used to identify determinants of participation in SSI by smallholder farmers in study area. The Wald test of the model (Wald Chi squared = 119.78 and P= 0.000) is significant at 1% level, implies that the overall model is fitted. Thus, the hypothesis that all coefficient of independent variables is jointly equal to zero was rejected. To test for multicollinearity among independent factors, VIF was used. As shown in Appendix 3, VIF result was less than 10. The results suggest that multicollinearity was not significant issues in the data.

The probit model results indicated that ten out of twelve variables significantly influenced the decision to participate in Small-Scale Irrigation (SSI), as shown in Table 9. Factors such as the education level of the household head, family size, total livestock owned, access to credit, market distance, and land dedicated to potato cultivation positively increased the probability of participation in SSI. Conversely, variables like the age of the household head, distance from the irrigation source, and market distance had negative effects on the likelihood of participating in SSI.

The education level of the household had a positive impact on participation in Small-Scale Irrigation (SSI). The marginal effect analysis indicated that an additional year of education, on average, would increase the likelihood of engaging in SSI by 2.2%, which was statistically significant at the 1% level. This is because when the education level of a potato-producing farmer increases, he/she will be able to make meaningful decision on use of new agricultural technology than farmers with less years of schooling. This result is consistent with the research by Woldegiorgis (2021).

The age of the household head had a negative and significant association with participation in irrigation at a 1% significance level. This could be attributed to the labor-intensive nature of irrigation activities, which older household heads may find physically challenging. Studies by Ashu (2022) and Bidzakin *et al*. (2018) support this notion. Research by Eliyas *et al*. (2022) suggests that younger farmers tend to be more productive and innovative compared to their older counterparts. Consequently, a one-unit increase in the age of potato-producing household heads would lead to a 1.8 percent decrease in the probability of participating in irrigation, assuming other factors remain constant.

The size of the household had a positive impact on the decision to participate in Small-Scale Irrigation (SSI) at a 1% probability level, indicating that with each additional household member, the probability of engaging in SSI increases by 4%. Larger household sizes can help reduce the costs associated with hiring additional labor, as household members may be more motivated and efficient in their own work compared to hired labor. Additionally, households with larger household sizes may have an advantage in completing agricultural activities, including irrigation tasks, in a timely manner. This result is consistent with prior studies such as Fikadu (2021), Gadisa *et al.* (2021), and Edilu (2022), but contrasts with the findings of Temesgen (2017).

Livestock serve as an additional source of income and act as a form of insurance against risks and uncertainties in the study area. The revenue generated from the sale of livestock and their products enhances the likelihood of adopting improved agricultural technologies. This study found that participation in Small-Scale Irrigation (SSI) increased in correlation with livestock ownership at a significance level of 1%. Specifically, for each Tropical Livestock Unit (TLU) increase in livestock holdings, the probability of engaging in SSI rose by 1.9%. This aligns with the findings of Abera *et al.* (2022), who also observed that farm households with greater livestock ownership are more capable of managing risks associated with adopting new technologies, leading to their participation in SSI.

Regular contact with agricultural extension services had a positive and significant impact on the decision to participate in small-scale irrigation, noted at a significance level of 1%. This suggests that farmers who engage with agricultural extension services regularly tend to have enhanced skills and knowledge in irrigation practices, thus motivating their participation in such activities. This finding is consistent with the results of previous studies like Bidzakin *et al*. (2018) and Jambo *et al*. (2021). The marginal effect also supports this, indicating that as the frequency of extension contact with the Development agent increases, the probability of participating in small-scale irrigation rises by 9%, assuming all other variables remain constant.

Membership in a cooperative positively influenced participation in Small-Scale Irrigation (SSI) at a significance level of 1%. The marginal effect analysis indicated that households belonging to cooperatives had an 11.9% higher likelihood of utilizing irrigation. This could be attributed to the various supportive roles played by cooperatives, such as supplying agricultural inputs, providing credit services, offering training and information, and facilitating marketing opportunities for farmers. This outcome aligns with a study by Abera et al. (2017), which found that cooperative members were more informed about and engaged in the adoption of new agricultural technologies.

The probit model analysis revealed that the size of landholding had a positive and statistically significant impact at a 5% probability level. In the study area, households with larger cultivated land were able to produce an ample quantity of crops for both consumption and sale through the utilization of irrigation systems. The marginal effect analysis further supports this by indicating that if a household were to possess an additional hectare of land for irrigation, the likelihood of participating in Small-Scale Irrigation (SSI) would increase by 14%. Similar findings were also documented by Abdissa *et al*. (2017).

Table 9: Decision of participating in SSI: Probit model

Variables	Coefficient	Robust Std. Err.	t-value	Marginal Effects
Age	-0.119***	0.015	-7.65	-0.018
Sex	0.101	0.368	0.27	0.126
Education	0.144**	0.053	2.55	0.022
Household size	0.27***	0.087	3.19	0.041
Distance to water	-0.023**	0.010	-2.33	-0.002
Total cultivated Land by HH	0.902**	0.430	3.23	0.140
Livestock	0.133***	0.034	3.94	0.019
Extension contacts	0.595***	0.093	6.33	0.091
Market distance	-0.068***	0.014	-4.60	-0.010
Non-farm income	3.17e-06	3.52e-06	0.90	4.84e-06
Amount of credit	4.82e-04 ***	4.37e-04	3.38	7.35e-04
Farmers coop membership	0.753***	0.217	3.44	0.119
Constant	2.896***	1.011	2.88	
Number of observations	371			
LR chi2(12)	119.60			
Prob > chi2	0.0000			
Pseudo R^2	0.603			
Log Pseudo likelihood	-101.15			

***, ** and * are significant at 1%, 5% and 10% level, respectively.

Source: own computation, 2023

The distance to the nearest market had a negative and significant impact on the participation in Small-Scale Irrigation (SSI) at a 1% significance level. This indicates that farmers located further from the market are less likely to adopt irrigation technologies compared to those in close proximity to transportation routes. For every additional walking minute in distance to the market from the farmer's residence, the likelihood of household participation in irrigation decreases by 1%, all other factors unchanged. This is likely due to the critical role of market proximity in ensuring timely delivery of inputs and disposal of outputs, resulting in lower transportation costs. Furthermore, farmers located far from the market tend to have less market orientation. These findings align with the research of Legesse *et al*. (2018), Jemal (2019), and Abdisa *et al*. (2017).

4.2.4. Impacts of SSI on Household Income and Technical Efficiency

Endogenous Switching regression model was used to assess the impact of participating in SSI on income and technical efficiency of potato producing farmers. Appropriate tests were conducted prior to determining the impact of SSI on Household Income and technical efficiency. The study used Distance from irrigation source and cooperative membership as selection instruments for identification. The identified instrumental variables are expected to fulfill the main conditions for being considered valid instruments.

The validity of instrumental variables hypothesized by the study was tested by using different robustness checks. In this regard, the validation of the selected instrumental variables used in the ESR model (Distance from irrigation source and cooperative membership) was checked using falsification test. The falsification test result revealed that selected instrumental variables jointly and significantly influence participation decision in SSI (in selection equation: Chi^2 = 102.53; P- value = 0.0000) while, not significant for outcome variables total income (F-value = 0.30; P – value = 0.73 for irrigation users and F-value = 1.29; P – value = 0.27 non irrigation users) and technical efficiency (F – value = 0.87; P – value = 0.41 for irrigation users and (F – value = 1.11; P – value = 0.33 for non-irrigation users).

The results of ESR model-based ATT and ATU for the key outcome variables related to the participation decision in irrigation are presented in Table 10. As discussed earlier, the main outcome variables considered in this analysis are household income and technical efficiency of potato farmers. For irrigation users' farmers, their predicted income was 49833.01 ETB, and would have been 30215.04 ETB had they are non-users. The ATT which equals 19617.97 ETB is significant at 1% probability level. This implies that Irrigators had decided to not irrigated, their average income would have decreased by 19617.97 ETB. Similarly, the predicted income for non-irrigation users was 35405.85 ETB, and would have been 43646.26 ETB had they decided non-users. The ATU which equals 8240.41 ETB is significant at 1% probability level. This implies that non irrigators had decided to irrigate, their average income would have increased by 8240.41 ETB.

Regarding technical efficiency, Irrigators mean technical efficiency was 0.65, and would have been 0.58 had they decided not irrigate. The ATT which equals 0.07 is significant at 1% probability level. This implies that Irrigators had decided to not irrigated, their average technical efficiency would have decreased by 0.07. And, the predicted mean technical efficiency was 0.62 for non-irrigators, however, it would have been 0.65 if they decided to irrigate. The ATU results 0.03 were gap between the two groups and significant at 1%.

Table 10: Endogenous switching regression model results (average treatment effects)

Outcome variable		**Decision stage**		**Average treatment effects**
		To irrigate	**Not to irrigate**	
Total income	ATT	(a) 49833.01	(c) 30215.04	(e) 19617.97 ***
	ATU	(d) 43646.26	(b) 35405.85	(f) 8240.41***
Technical Efficiency	ATT	(a) 0.65	(c) 0. 58	(e) 0.07***
	ATU	(d) 0.65	(b) 0. 62	(f) 0.03***

***, ** and * are significant at 1%, 5% and 10% level, respectively.

ATT = Average treatment effect on treated; ATU = Average treatment effect on untreated.

These findings are consistent with the theoretical expectations made before, because the purpose of small-scale irrigation was to boost smallholder income as well as reduce technical inefficiency. This study result was comparable with the results of (Beyan *et al*. 2014; Bidzakin *et al*. 2018; Woldegiorgis 2021) who were reported the use of small-scale irrigation increased household income and technical efficiency.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary

Potato is among root and tuber crops used to overcome food insecurity problems of smallholder farmers in Ethiopia. Inspite of its importance, the production and productivity of potato remains very. Irrigation is the most important technologies to reduce adverse effect of rainfall fluctuation and boost crop production much higher than rainfed. In this regard, the study area had a plenty of water resource potential that can be applied to produce different agricultural crops. But, the participation of smallholder farmers in SSI to produce potato is low as compared to the irrigation potential in the district.

The objective of this study was to measure technical efficiency under irrigated and non-irrigated farming systems in the study area, to analyze the determinants of SSI participation and to evaluate the impact of SSI on potato technical efficiency and net total income of rural farming household in the study area. The study utilized cross-sectional household data collected in 2022/2023 from 371 randomly selected sample households. Multi-stage sampling technique was employed to select the sample households for the study. Descriptive statistics and econometric models were used to analyze the data. The econometric models including endogenous switching regression, Tobit model, stochastic frontier model, and the bivariate probit model were employed.

The results of descriptive statistics for continuous explanatory variables show that, there was a statistically significant mean difference in age of the household head, educational level of the household head, family size, total livestock owned, amount of credit, extension contact, farm size and cooperative membership between irrigators and non-irrigators. However, there was no statistically significant mean difference in sex of the household and non-farm income between the two groups.

The result of stochastic frontier model (SFA) showed that the effect of land, seed, labour and DAP inputs on potato output were positive and significant. Sampled households indicated that the average technical efficiency was 64%. This shows that there was a significant technical inefficiency in production of potato. The results of probit model shows that participation in SSI positively influenced by age, education, total livestock owned, farm size, extension contact with DA and cooperative memberships. Distance from the market, age of household head and distance from irrigation water source influenced participation in SSI negatively.

Finally, the findings from second stage endogenous switching regression showed that decision to use small scale irrigation had a significant positive impact on the technical efficiency and household income of potato farmers in the study area. The results obtained from the endogenous switching regression model showed that if irrigators had decided to not irrigate, their average income and technical efficiency would have decreased by 19617.97 ETB and 0.07%, respectively. Similarly, had non irrigators decided to irrigate, their average income and technical efficiency would have increased by 8240.41ETB and 0.03% respectively.

5.2. Conclusion and Recommendations

The study findings from the ESR model highlighted the significant and positive impact of irrigation on the technical efficiency and household income of potato farmers in the study area. Given the importance of irrigation in improving the technical efficiency of small-scale potato producers. It is essential to prioritize the development of irrigation facilities and encouraging small holder farmers to participate in small scale irrigation in the study area.

Education is an important variable which influence participation in irrigation positively and significantly. Hence, it is urged to prioritize strengthening human and institutional capabilities through enhanced education and ongoing training programs aimed at showcasing the potential advantages of utilizing irrigation technology to boost potato productivity and income from potato sell. The study revealed that regular contact with extension services positively related with participation in Small-Scale Irrigation (SSI). In light of these findings, extension service is a tool for the dissemination of farming technology practices that can affect the participation decisions of producers in agricultural technology farming practices. Therefore, agricultural experts should be required to provide continuous support to potato producers so that they can effectively use new farming practices that help boost their potato productivity and income from potato.

The research results indicate that access to credit had a significant effect on the expected engagement in Small-Scale Irrigation (SSI). Numerous farming households encountered challenges in obtaining credit mainly due to the strict requirements set by financial institutions. Adequate financial resources are crucial for smallholder farmers to utilize irrigation effectively. It is therefore recommended the development of a tailored based financing programs to enable smallholder farmers to access funds through rural financing initiatives. Age of the household head had a negative effect on participation decision in SSI of potato producers. Hence, emphasis should be given to involve elder farmers in exercising and training on the use of new irrigation technologies through demonstration, training and field days.

The ownership of livestock had a significant and positive impact on the decision to participate in Small-Scale Irrigation (SSI). As a result, it is important to encourage and strengthen the integrated crop-livestock mixed farming practices for better use of small-scale irrigation which become a good income source. The size of landholding had a positive and significant influence on the decision of potato producers to participate in Small-Scale Irrigation (SSI). However, the expansion of landholding is not a feasible option as land is a limited resource. It is necessary to implement interventions that focus on enhancing the productivity of potatoes per unit of land by promoting effective land utilization, particularly maximizing the use of currently unutilized land in the region.

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7. APPENDICES

7.1. Appendix Tables

Appendix Table 1: Conversion factors of tropical livestock unit (TLU)

Livestock Category	**TLU**
Cows	0.25
Oxen	0.34
Heifers	0.35
Calves	0.70
Goats	1.25
Sheep	0.75
Donkey	0.13
Mature chicken	1.00
Horses	0.06
mules	1.10
Camels	1.10
Bulls	1.00
Poultry	0.013

Source: Storck et al. (1991)

Appendix Table 2: Conversion factors for Adult –Equivalents

Age group (years)	Male	Female
<10	0.6	0.6
10-13	0.9	0.8
14-16	1.00	0.75
17-50	1.00	0.75
>50	1.00	0.75

Source: Storck et al. (1991)

Appendix Table 3: Multicollinearity test for variables in the ESR

Variable	VIF	1/VIF
TLU	1.24	0.806551
Household Size in AE	1.24	0.806674
Extension contacts	1.24	0.803868
Farming Experience	1.25	0.797717
Age of HH	1.17	0.853214
Amount of Credit obtained	1.22	0.818490
Educational grade level of HH	1.18	0.850076
Distance from Irrigation Water	1.17	0.854025
Land Holding Size	1.10	0.911177
Off/Non-farm Income	1.14	0.877678
Cooperative membership	1.13	0.884084
Market distance	1.09	0.917917
Sex of HH	1.03	0.971014
Mean VIF	**1.16**	

Source: Computed from own survey data of 2022

Appendix Table 4: Multicollinearity test for variables in the SFM

Variable	VIF	1/VIF
Labor	6.23	0.160500
Oxen power	5.08	0.196833
Fertilizer	4.30	0.232340
Seed	3.13	0.319322
Land	1.69	0.593002
Mean VIF	**4.09**	

Appendix Table 5: Second stage ESR estimates of net total income and technical efficiency

Variables	Total income (Birr)				Technical efficiency			
	Irrigation users		Non irrigation users		Irrigation users		Non irrigation users	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err**
Age of HH	-33.9303	279.86	-334.70**	202.364	-0.0015	0.0016	-0.0018	0.014
Sex of HH	-167.63	4561.75	2273.44	3830.887	-0.046	0.033	0.062*	0.034
Educational level of HH	462.74	1024.86	393.97	601.9407	-0.0019	0.0052	-0.0008	0.006
Family size (AE)	-1619.28	1657.16	2117.24*	1114.667	-0.023	0.0089**	-0.025**	0.008
Extension Contacts	2016.783	1901.393	920.75	1112.4	0.017	0.012	0.0011	0.010
Land for potato	65260.63***	7573.00	70049.36***	4506.889	0.064	0.044	-0.049	0.047
TLU	599.86	697.70	840.54	533.80	0.0004	0.0035*	0.0019	0.0039
Market distance	511.83**	223.50	63.11**	192.69	0.0025	0.0015	-0.0003	0.0014
Non-farm income	-0.3106	0.5498	0.608	0.719	-4.66e-06	3.11e-06	4.61e-06	0.00078
Amount of credit	0.1574	0.1889	0.0036	0.193	-1.01e-07	1.14e-06	0.0046*	0.00047
mills1	2158.25	5646.44	8452.12*	4276.15	-0.0107	0.030	-0.018	0.034
Constant	2873.593	19178.16	-6413.36	11315.53	0.865	0.093***	0.628***	0.104
Number of obs.	167		204		167		204	
F-Value/W.Chi2	11.68		38.27		19.77		20.45	
Prob > F	0.0000		0.0000		0.045		0.03	
R-squ. /Pseudo r2	0.412		0.5075		-0.08		-0.09	
Root MSE	19215		15633					
Log pseudo likelihood					127.39		116. 47	

***, ** and * significant at the 1, 5 and 10 percent probability levels, respectively

7.2. Survey Questionnaire

Impact of Small-Scale Irrigation on Potato farmers Technical Efficiency and household in Lemuna Bilbilo District, Oromia National Regional State, Ethiopia

Prepared by Tamirat Tsegaye (MSc candidate, Haramaya University)

The purpose of this questionnaire is to collect household level primary data from rural farmers of Lemuna Bilbilo district for research purpose.!

0. 0. HOUSEHOLD IDENTIFICATION

1. Enumerators Name:	2.[Date/Month /Year]	3. Name of household head:
4. kebele:	5. Name of the survey respondent:	

1. HOUSEHOLD CHARACTERSTICS

1.1. The respondent is: 1. Irrigation user 2. Non-irrigation user

1.2. Age of Household head ___________

1.3. Sex of household head 1. Male 2. Female

1.4. Marital status of household head 1. Single 2. Married 3. Divorced 4. Widowed

1.5. Educational level of household in schooling years ____________________

1.6. Experience in growing (years) potato with Rainfed__________________ with Irrigation ____

2. HOUSEHOLD COMPOSITION

2.1. Total family size of the household ___________in number.

2.1.1. Number of age category __________

Age	Male			Female		
	Number	Primary occupation*	Agriculture Labor contribution**	Number	Primary occupation*	Agriculture Labor contribution**
<10						
11 – 13						
14 – 16						
17 -50						
>50						

*1. Farming (crop+ livestock) 2. Salaried employment 3. Self-employed off-farm 4. Casual laborer on-farm 5. Casual laborer off-farm 6. School/college child 7. Non-school child; **1. 1.Full time 2. Part time 3. Not a worker

3. FARM INPUTS AND OUTPUT

3.1. Crops cultivated and inputs used in rain-fed agriculture in 2022/23 production year

No.	Crops cultivated	Area in hectare	Pair of Oxen		Fertilizer used in kg	Seed used in kg	Output produced in quintal	Quantity sold (qt)	Unit price (Birr)	Total Income (Birr)
			No.	Hrs.						
1	Potato									
2	Wheat									
3	Barley									
4	Sweet potato									
5	cabbage									

3.2. Have you used family labour for different potato production activities in 2022/23 production season 1. Yes 0. No 3.2.1. If yes to 3.2, **Family labour** allocated to farm activities for potato production

Crop cultivated	**Ploughing**								
	Days used to finish it	**Male**				**Female**			
		No of workers	Hrs.	Wage rate per day	Total cost	No of workers	Hrs.	Wage rate per day	Total cost
Rain-fed potato									
Irrigated potato									
			Planting						
Rain-fed potato									
Irrigated potato									
			Weeding						
Rain-fed potato									
Irrigated potato									
Pesticide Application									
Rain-fed potato									
Irrigated potato									
			Harvesting						
Rain-fed potato									
Irrigated potato									

3.2.2. Have you used hired labor for different Potato production activities? 0. No 1. Yes

If yes to 3.2.2 fill the table below for number of **hired labor** hours and days used in each farm activity for potato production.

Crop cultivated	**Ploughing**								
	Days used to finish it	**Men**				**Women**			
		No of workers	Hrs.	Wage rate per day	Total cost	No of workers	Hrs.	Wage rate per day	Total cost
Rain-fed potato									
Irrigated potato									
			Planting						
Rain-fed potato									
Irrigated potato									
			Weeding						
Rain-fed potato									
Irrigated potato									
Pesticide Application									
Rain-fed potato									
Irrigated potato									
			Harvesting						
Rain-fed potato									

Irrigated potato									

3.3. Use of fertilizers and agro chemicals

3.3.1. Have you used chemical fertilizer for potato production? 0. No 1. Yes

3.3.2. If yes to 3.3.1 indicate the quantity fertilizers and chemicals used in rainfed and irrigated potato production

Crops cultivated .	Amount of UREA used in kg	Amount of DAP used in kg	Herbicide used in (lit)	Pesticide used in (lit)	Total potato output in quintal
Rainfed Potato					
Irrigated Potato					

3.3.3. If no to 3.3.1., why?

1) Too expensive 2) Inconvenient to transport 3) Not timely available

4) Not good to apply on potato field 5) Others, Specify___________________

3.4. Use of Seeds

3.4.1. Have you used improved potato seed in year 2022/2023? 0. No 1. Yes?

3.4.2. If yes to 3.4.2, indicate the quantity and source of seed for both rainfed and irrigated potato farming

Crops cultivated	Type of seed 1. Local 2. improved	Source of seed 1. Own source 2. Market 3. Other farmers 4. Cooperatives 5. Ethiopia seed enterprise 6. Other, specify______________	Quantity used in (qt)
Rainfed potato			
Irrigated potato			

4. LAND HOLDING (HA) AND ACQUISITION METHODS

4.1. Do you have your own land? 0. No 1. Yes

4.2. If yes, total land size owned______________ha

4.3. Total size of land rented in, in 2022/23__________(ha)

4.4. Total size of own land rented out in 2022/23_________(ha)

4.5. Total size of own land shared in 2022/23 ____________ (ha)

4.6. Total size of land shared out in 2022/23____________ (ha)

4.7. Total size of own land left for uncultivated in 2022/23_____________ha

4.8. What is the total land you cultivated in 2022/23 __________ha

4.9. Total size of land covered by irrigated potato in 2022/23____________ha

4.10. Total size of land covered by rainfed potato in 2022/23_______ha

5. PARTICIPATION IN IRRIGATED AGRICULTURE IN 2022/23

5.1. Have you used irrigation water for potato production in 2022/23? 0. No 1. Yes

5.2. If yes to 5.1, what is the main source of your irrigation water for potato plot? 1) Hole 2) river 3) lake 4) well 5) others

5.3. If no, what were the reasons for not using irrigation? (1) No farmland in surface water access (2) No awareness about it (3) No capital (4) No labor (5) no irrigation infrastructure (6) Others______________

5.4. Distance from **home to irrigated potato plot** _____________minute

5.5. Crops cultivated and inputs used in irrigated agriculture in 2022/23 production year

No.	Crops cultivated	Area in hectare	Pair of Oxen		Fertilizer used in kg	Seed used in kg	Output produced in quintal	Quantity sold (qt)	Unit price (Birr)	Total Income (Birr)
			No.	Hrs.						
1	Potato									
2	Wheat									
3	Barley									
4	Sweet potato									
5	Vegetables									

6. LIVESTOCK HOLDING DURING 2022/23.

6.1. Do you have livestock 1. Yes 0. No If yes to 6.1. then fill the following table

Livestock	No owned	No of sold	Income Obtained	Livestock	No owned	No of sold	Income Obtained	Livestock	No owned	No of sold	Income obtained
Cows				Calves				Horse			
Oxen				Sheep				Mule			
Heifers				Goats				Poultry			
Bulls				Donkeys							

6.2. Total Tropical Livestock Unit: ______________

7. EXTENSION SERVICE AND TRAINING

7.1. Do you get any extension advice on potato production managements? 0. No 1. Yes

7.2. If yes to 7.1, Source of advices? 1. DAs 2. BoA 3. Research Centers 4. NGOs 5. Other, Specify

7.3. If yes to 7.1, would you state the number of visits by extension services for potato production? ________

7.4. Distance from extension agents' office__________(minutes).

7.5.Did you get any practical training in potato production system in 2022/23? 0. No 1. yes

7.6.If yes on which aspects?

1=Crop management 2=pre and post harvesting handling 3= Fertilizer or compost application 4= Harvesting 5=Composition of all 6=others, specify_______________

8. ACCESS TO MARKET

8.1. How far is your home from the nearest market?_________minute.

8.2. how far is your home from town market? _______________minute

8.3. Where do you sell majority of your potato products? 1. On farm, 2. At cooperative union shops, 3. At local markets, 4. District market 5. Others _______

9. NON/ OFF-FARM INCOME IN 2022/23 PRODUCTION SEASON

9.1. Do you have any source of income other than farming during 2022/23? 0. No 1. Yes

9.2. If yes, what are the sources of income? 1. Off/non-farm activity 2. Pension payments 3. Crop sale 4. Salary/wage 5. Remittances 6. Other specifies ________________

9.3. Did you perform other Off/non-farm income generating activities? 1. Yes 0. No

9.4. If yes, on what types of Off/non-farm activities your family members are engaged in? (Multiple responses are possible) 1. Selling local drink 2. Herding 3. Trading (Crops and Livestock) 4. Hired in another farm 5. Others specify, ___________

9.5. What amount of income you get from off /non-farm activity annually? ___________ETB

10. ACCESS TO CREDIT SERVICES

10.1. Do you have access to credit for your agricultural activities? 0. No 1. Yes

10.2. If yes for 10.1, did you used credit services for potato production during 2022/23?

0. No, 1. Yes

10.3. If yes for 10.1, the source? 1. Commercial banks, 2. Cooperative unions, 3. Neighbors and relatives, 4. Micro finance institutions 5. Other, Specify _________________

10.4. If yes for 10.1, what was the amount of credit that you have received? ______________Birr.

10.5. If yes for 10.1, for what purpose? 1. Purchase of seeds 2. Purchase of fertilizer, 3. Purchase of oxen, 4. For family consumption, 5. Others __________

10.6. If no to 10.1, what are the reasons? 1. Collateral problem 2. No need of credit, 3. High interest rate, 4. Inadequate supply, 5. No access, 6. Others ___________

11. HOUSEHOLD INCOME

11.1. Annual household income from cereals and fruits production during 2022/23 production

Crop type	Cultivated land in (ha)	Total annual harvest (Qt)	Consumed (Qt)	Sold (Qt)	Unit price(birr)	Total income
Cereals						
Wheat						
Barley						
Teff						

Bean						
Fruits						
Mango						
Avocado						
Orange						
Root and Tubers						
Potato						
Sweet Potato						
Total Income						

Note: Use the local price per quintal (market price) for each crop at the time of survey period

11.2. Income from the sales of livestock products and by-products

Type of products and by-products	Amount collected	Amount consumed in a year	Sold in a year (birr)	Total Income
Milk				
Butter				
Egg				
Honey				

12. Annual household expenditure on consumption, closing, education, social obligation and medication in the year of 2022/2023 production season in birr__________________.

12. SOCIAL PARTICIPATION

12.1. Is there any informal or formal social institution in your locality? 0. No 1. Yes

12.2. If yes, mention the major social institution 1. Input supply coop./union 2. Local administration 3. Edir 4. Equb 5. Saving and credit association 6. Other, specify__________

12.3. Are you a member of cooperative or union in 2022/23? 0. No 1. Yes