

**IMPACT OF IRRIGATION ACCESS ON POTATO PRODUCTION
EFFICIENCY AND RURAL HOUSEHOLDS' POVERTY IN EAST
GOJJAM ZONE OF ETHIOPIA**

PhD DISSERTATION

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Households' Poverty in East Gojjam Zone of Ethiopia**

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OF PHILOSOPHY IN AGRICULTURAL ECONOMICS**

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As dissertation research advisor, I hereby certify that I have read and evaluated this dissertation prepared under my guidance, by Assefa Delesho Kulo, entitled **IMPACT OF IRRIGATION ACCESS ON POTATO PRODUCTION EFFICIENCY AND RURAL HOUSEHOLDS' POVERTY IN EAST GOJJAM ZONE OF ETHIOPIA**. I recommend that it be submitted as fulfilling the dissertation requirement.

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DEDICATION

This dissertation is dedicated to my wife Agegnehush Hirpa for her sincere love and support she has provided to me. The blessing of my elders is always in my mind. Thanks to God for accepting their prayers and fulfilling their vision. I pray, from my side, to God to give them longer lives.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this dissertation is my original work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this dissertation. Any scholarly matter that is included in the dissertation has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born in Bullen district, Metekel zone, from a rural family in 1976. He completed his primary and junior secondary school education in Bullen primary and junior secondary school. He attended his high school education at Chagni Senior Secondary School. He joined Ethiopian Civil Service College (now University of Ethiopian Civil Service) in January 1995 and graduated with BA degree in Economics in January 1998.

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ACRONYMS AND ABBREVIATIONS

ADB	African Development Bank
AE	Allocative Efficiency
ANRS	Amhara National Regional State
ARARI	Amhara Regional Agricultural Research Institute
ATE	Average Treatment Effect
ATT	Average Treatment Effect on Treated
CIDA	Canadian International Development Agency
CSA	Central Statistics Agency of Ethiopia
DEA	Data Envelopment Analysis
DID	Difference-in-Difference Method
DMU	Decision Making Unit
EE	Economic Efficiency
EU	European Union
FAO	Food and Agriculture Organization of the United States
FDRE	Federal Democratic Republic of Ethiopia
GNI	Gross National Income
GTP	Growth and Transformation Plan
HCI	Head Count Index
HYV	High Yielding Varieties
MoFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resources
NEP	New Extension Program

NN	Nearest Neighbour
NPC	National Planning Commission
OLS	Ordinary Least Squares
PGI	Poverty Gap Index
PSM	Propensity Score Matching
RDD	Regression Discontinuity Design
SERAR	Sustainable Environmental and Agricultural Rehabilitation for Amhara Region
SFA	Stochastic Frontier Analysis
TE	Technical Efficiency
TFP	Total Factor Productivity
UNDP	United Nations Development Program
WB	World Bank

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Impact of Irrigation Access on Potato Production Efficiency and Rural Households' Poverty in East Gojjam zone of Ethiopia

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ABSTRACT

The growing gap between food demand and supply in Ethiopia and hence rural poverty is mainly attributed to the low productivity of the agricultural sector. Access to irrigation by smallholder farmers is believed to enhance production efficiency, and hence considered as a cornerstone of food security and poverty reduction. The objective of this study was to assess the impact of irrigation access on potato production efficiency and alleviating farm households' poverty in east Gojjam zone. A random sample of 288 rural households was selected for the study using systematic random sampling method. Stochastic frontier analysis was used for estimating production efficiency and a tobit model was used to identify the determinants of efficiency. Propensity score matching method was used to evaluate the impact of participation in irrigation farming on farm households' potato production efficiency and welfare. The results of the study indicated that variable inputs such as land, seed and oxen power positively and significantly affected potato output. The estimated mean technical, allocative and economic efficiency scores for irrigation user were 77, 74.5 and 0.57 and for non-user households they were 0.63, 0.63 and 40 percent, respectively showing potato production inefficiencies among sample farm households. The significant factors affecting allocative and economic efficiencies in potato production are mainly access to irrigation, loan size, extension contact, livestock holding, agro-ecology, off/non-farm income and sex of household head. Poverty indices developed from consumption expenditure using FGT formula were used to identify the poor. About 74.4% and 72.3% of the sample households gained annual per adult equivalent income which is more than the income poverty line in irrigated and non-irrigated farming systems, respectively. The income poverty gap and severity indices for irrigation users were 0.19 and 0.14 and for non-users they were found to be 0.22 and 0.17, respectively. Results further show that participation in irrigation farming significantly increased annual expenditures, technical, allocative and economic efficiencies of participants by 459.05 Birr (11.7%), 0.035 (4.9%), 0.030 (4.08%) and 0.039 (7.4%), respectively compared to non-participants indicating the significant production efficiency and welfare improvement due to participation in irrigated farming.

Keywords: Efficiency, expenditure, propensity score matching, stochastic frontier, tobit.

1. INTRODUCTION

1.1. Background of the Study

Ethiopia is predominantly an agricultural country having a total land area of more than one million km². It has 14.6 million hectares arable land (WB, 2011) and 5.1 million hectares potential for irrigation development (MoFED, 2010). It has projected human population of 94.31 million for the year 2017 (CSA, 2013). Its economy is heavily dependent on the agricultural sector, which contributed 38.5 percent to the GDP in 2014/15 fiscal year (NPC, 2016), providing livelihood for 85 percent of the population (CSA, 2015) and accounting for 70 percent of the foreign exchange earnings (UNDP, 2013).

As stated by NPC (2016) looking at the performance of the overall economy during the last five years 2010/11 to 2014/15, supply side real GDP growth rate averaged 10.1percent. During the last 12 years (2003/4-2014/15), real GDP growth rate averaged 10.8% per annum. As such, living standard of citizens has improved. This is reflected in the increase in per capita income from USD 377 in 2009/10 to USD 691 by the end of 2014/15. Provision of essential public services has also expanded as a result. Absolute poverty has declined from 26.9% in 2010/11 to an estimated 23.4% by 2014/15. The national Gini Coefficient remained close to 30% from 2004/05 to 2010/11. Although, promising improvements have been registered in poverty reduction, still close to one fourth of the population live below the poverty line. Thus, to eradicate poverty the rapid and broad based growth has to be sustained mainly through accelerating growth of agriculture.

Improving the productivity of the agricultural sector is believed to be the key to alleviate poverty, food insecurity and to ensure overall growth of the Ethiopian economy. But, it was claimed that Ethiopia cannot ensure food security and reduce poverty with rain-fed agriculture alone without a substantive contribution of irrigation. The Growth and Transformation Plan (GTP II) of the Ethiopian government states that in GTP II period, agriculture will remain the main driver of the rapid and inclusive economic growth and development. It is also expected to be the main source of growth for the modern productive sectors. Therefore, besides promoting the productivity and quality of staple food crops production, special attention will also be given to high value crops, industrial inputs and

export commodities. To this end irrigation based agriculture, horticulture, fruits and vegetables, livestock and fisheries development will be promoted (NPC, 2016).

The first GTP plan has played a role in expanding irrigation in the country. The government of Ethiopia has prepared a water sector development program to be implemented in 15 years between 2002 and 2016 (MoWR, 2001) which is revised by this GTP I and assigned a prominent role to the development of irrigation in the country for food production (MoFED, 2010). However, over the last five years (2010/11-2014/15), construction works on 658,340 ha of irrigation schemes was planned but only 283,408 hectares was developed. Area of land developed with large and medium irrigation schemes was 658,340 ha in 214/15 (NPC, 2016). Despite a relative increase in utilization of irrigation, however, the productivity of crops has been low.

Irrigation schemes are also planned and became operational in east Gojjam zone of Amhara region since 1994. Irrigation schemes were constructed by the Government of Ethiopia and NGOs in east Gojjam zone during the period of 1994 to 2013 are 37 among which two are medium and 35 are small scale schemes covering about 2,553 hectares of land area. All these-medium and small-scale irrigation schemes are using surface water only, i.e., base flow of streams and river diversion canals. The total beneficiaries of irrigation water both from medium and small-scale schemes are 11,020 households in 2011/2012 production year (EGZOARD, 2013). This implies that the extent of water use for irrigation in the zone is at a rudimentary stage or participation in irrigation farming is low. According to EGZOARD (2013) the main crops produced by irrigation in the zone are mainly root crops (potatoes, onion and carrot) vegetables (green pepper, tomatoes and cabbage), cereal (maize) and pulses (lentils and chick pea), among others. Among these crops either only potato or potato together with other crops is widely produced over all irrigation schemes of the study area.

Ethiopia has the highest potential for potato production. An estimated 70 percent of the country's arable land is potentially suitable for potato cultivation (ARARI, 2013). The FAO (2008) statistics indicates over one million Ethiopian holdings are producing potatoes (about 10% of all crop producers). Over 80% of the production area can be found in Amhara and Oromia regions and around 15% in South Nations, Nationalities and Peoples Region (SNNPR). However, one should bear in mind that in 2008 the main production

season for ware potato represents only 22% (34,000 ha), while the off season production was around 128,000 ha. The reason for gradual shift from *Meher* to *Belg* is the late blight pressure. In contrast to the FAO statistics indicating yields above 10 ton/ha in 2009 and 2010, the yields derived from the Ethiopian Central Statistics Agency (2011) are below 10 ton/ha. The latter is also in line with the findings of Abay *et al.* (2011) who states that yield is below 10 t/ha.

Similarly, potato is the major crop produced in all irrigation schemes of the study area, among other crops produced by irrigation farming. However, in spite of its growing importance to Ethiopia's food security, the introduction of new technologies and infrastructural development to increase the production and productivity of this crop remains very low. Efficient irrigation utilization could be severely undermined by a wide range of economic, social, institutional and cultural constraints (ARARI, 2013). Therefore, this study was designed to evaluate the impact of irrigation on potato production efficiency and rural households' poverty using rigorous econometric technique.

1.2. Statement of the Problem

The growing gap between food demand and supply in Ethiopia is mainly attributed to the low productivity of the agricultural sector. Heavy reliance on obsolete farming techniques, unequal access to land, dwindling farm size (one ha per household which remain well below those of African average of 1.6 ha), poor land management, poor complementary services such as extension and innovation, access to credit, access to input and output markets, climate change and related food security challenges, infrastructure and food and global financial and economic crises are among the major constraints that have greatly retarded the development of Ethiopia's agriculture (ADB, 2010). These constraints are not new, but rather long-standing and perhaps even chronic.

The 'poor-but-efficient' theory of Schultz (1964) regarding the development strategies for small scale farmers in the developing countries was proved to be invalid by several empirical studies such as Coelli *et al.* (2002), Hopper (1965) and Sahota (1968) that farmers in the developing countries experience considerable inefficiencies as they use high level of inputs to produce a given level of output. This, in turn, implies the existence of a potential for increasing agricultural production and productivity through irrigation access

and improvements in efficiency of the farmers by using the existing resources. Since most farmers are poor and they face land and credit constraints, they may not be in a position to raise agricultural productivity. So, the most plausible option left to these farmers is to raise their productivity through irrigation access and improvement in efficiency. It is argued that access to reliable irrigation water can intensify cultivation, leading to increased productivity, overall higher production, and greater returns from farming (Hussain and Hanjra, 2004).

The microeconomics theory of production function that transforms input into output is a base for measurement of efficiency of production. The neoclassical theory of production postulates that firms maximize profits and/or minimize costs subject to certain technological constraints. However, a number of empirical studies revealed that there is production efficiency variability within and in different sectors in the developing as well as developed countries (Wilson *et al.*, 1998). The estimated mean technical, allocative and economic efficiencies of farmers show as to what extent production can be increased in a given area if the level of technical efficiency is improved given the existing level of input use. Conversely, as to what extent inputs or costs of production can be minimized if the level of allocative efficiency is improved at the existing level of output (Coelli *et al.*, 1998). Furthermore, knowledge of the factors that influence agricultural productivity differentials among farmers is very important. This requires identifying factors that lead some farmers to produce more than others under the same technology and inputs, given their prices. This, in turn, may help policy-makers to design appropriate policies to increase agricultural productivity by improving on factor productivity and on farm-and crop-specific efficiencies. As land is becoming a constraint and climate change increases because of increased population pressure and stiff competition, the potential to increase the level of crop production including potato by bringing more land into use becomes more and more limited and uneconomical.

Potato (*Solanum tuberosum L.*) is an important food source globally. The tuber is known to supply carbohydrate, high quality protein, and substantial amounts of essential vitamins, minerals, and trace elements (Horton and Sawyer, 1985). It is an important food and cash crop in the highlands and urban areas mainly due to the growing number of fast food industries and hotels. Potato is among the most efficient commodities for converting natural resources, labor and capital into a high quality food. Because of its short duration, it

is very strategic for mitigating food crisis in disaster situation. Like many other countries in the world, potato is a very important food and cash crop especially on the highland and mid altitude areas of Ethiopia (Borgal *et al.*, 1980).

Ethiopia has possibly the highest potential for potato production of any country in Africa. An estimated seventy percent of the country's arable land is potentially suitable to potato cultivation. To this end, the livelihood of thousands of highland farmers in the country in general and Amhara region, in particular rely on potato production. But, there exists a substantial efficiency gap in irrigated farms between achievable and actual efficiency. In spite of the importance of potato production on Ethiopia's food security, the introduction of new technologies and infrastructural development to increase the production and productivity of potato remains very low (ARARI, 2013). The average potato production throughout Ethiopia is 8 to 10 t/ha (Haverkort *et al.*, 2012). Nevertheless, the yields are below those of Sudan (17 t/ha) and especially Egypt (26 ton/ha). This is a relatively low average, especially when considering the potential of Ethiopia with its favourable climate at higher elevations, soils (an estimated 70 percent of the country's arable land is potentially suitable for potato cultivation) (Bezabih and Mengistu, 2011) and irrigation potential (5.1 million hectares potential for irrigation development) (MoFED, 2010). This is one of the main reasons why this study was based on potato production efficiency among other irrigated crops.

Like in other developing countries, the technical efficiency of the food crop production including potato has been researched in Ethiopia. But, most of the previous studies dealt exclusively with technical efficiency of rain-fed farming. Many studies on efficiency measurements in Africa, except that of Arega *et al.* (2002), Jema (2008) and Weir (1999) dealt exclusively with technical efficiency of farmers which is only one aspect of the efficiency of production. None of them have estimated and identified the determinants of technical, allocative and economic efficiencies of potato under irrigated and rain-fed small-scale farming systems in the study area.

The impact of irrigation on production efficiency and farm household poverty largely remains unexplained. That is, previous research efforts in conducting efficiency and farm households' poverty in Ethiopia also did not consider variations in irrigated and non-irrigated farming systems and their determinants. In other words, the research efforts

investigated only the very general efficiency of production in agriculture and poverty. Little is also known and no detailed evidence is available in Ethiopia on the impact of irrigation on farm households' poverty and efficiency particularly for medium and small-scale irrigation systems in East Gojjam zone of Ethiopia. Most of the studies conducted on small-scale irrigation schemes focused on the role and performance of irrigation schemes which are of qualitative type and descriptive. That is, there are no empirical studies on the issue using standard econometric techniques. For example, studies on the importance of irrigated agriculture to the Ethiopian economy by Fitsum (2009), on the role of irrigation and water for sustainable development in Ethiopia by Seleshi *et al.* (2008) and on small-scale irrigation and household food security in North Wollo zone by Seid (2002) used descriptive statistical methods and did not quantify the contribution of irrigation to improving efficiency and reducing poverty.

This study thus attempted to evaluate the impact of irrigation on potato production efficiency and rural households' poverty in East Gojjam zone of Amhara region, Ethiopia. It was designed to address the following research questions: (i) Are there efficiency differentials among potato farming households of the study area? (ii) What are the determinants of technical, allocative and economic efficiencies of potato farming households of the study area? (iii) How are the prevalence, gap and severity of poverty of irrigation users and non-user households of the study area? (iv) Were there improvements in efficiency of potato production and rural households' living standard due to participation in irrigation of potato fields?

1.3. Objectives of the Study

The general objective of the study is to assess the impact of irrigation access on potato production efficiency and rural households' poverty in East Gojam zone of Ethiopia.

The specific objectives of the study were:

- i. to measure technical, allocative and economic efficiencies in potato production under irrigated and non-irrigated farming systems;
- ii. to identify the determinants of technical, allocative and economic efficiencies in potato production under irrigated and non-irrigated farming systems;
- iii. to measure the prevalence, gap and severity of poverty of irrigation users and non-user households;

- iv. to evaluate the impact of participation in irrigation on efficiency in potato production and rural households' poverty in the study area.

1.4. Significance of the Study

Firstly, the mean technical efficiency of sample farmers in the study areas will show as to what extent potato production can be increased in the area if the level of efficiency is improved given the existing level of input use. Secondly, the mean allocative efficiency will show as to what extent inputs or costs of potato production can be minimized if the level of efficiency is improved at the existing level of potato output. Thirdly, since efficiency level of each farmer will be measured, this can show the differences in efficiency level among farmers in the study area in the production of potato. Fourthly, based on the efficiency level of each farmer, factors affecting efficiency will be identified. Identification of the determinant factors will be important for various planning and policy purposes.

An investigation of producer's production efficiencies and the underlying factors affecting efficiencies under irrigated and non-irrigated farming systems greatly helps policy makers to take the necessary corrective measures for enhancing potato production through better and efficient use of irrigation alongside the limited farm resources. The study would also help to generate knowledge that will serve as the basis for making sound policy decisions with a view to enhancing the effectiveness of irrigation and other technological resources in the realization of the intended poverty reduction, food security and agricultural development objectives. Knowledge about the extent of factors affecting potato production efficiency under irrigated and non-irrigated farming will greatly help policy makers to explore untapped potentials of technological resources and increase food production with existing resources by addressing the identified constraints. It also enables the identification of those farmers who need the most support from the government and NGOs, and hence help for better targeting and priority setting. Further, knowledge about potato production efficiency gaps between users and non-users of irrigation will inform policy makers of the impact of irrigation which is very valuable for better design and implementation of intervention programs.

The study also attempted to provide realistic information on the impact of irrigation on potato production efficiency and farm household poverty reduction in the study area and

for formulating future strategies on smallholder irrigation investment. Agricultural bureau officials, extension workers, community in the study are and other concerned bodies would get an insight on the problems being faced by farm households associated with factors affecting potato production efficiency. The research results are also expected to serve as stepping stone for government, NGOs, individuals, international and other interested organizations to conduct further study in the area of efficiency and poverty under irrigated farming.

1.5. Scope and Limitations of the Study

The study focused on technical, allocative, economic efficiencies and their determinants and households' rural poverty. It assessed the impact of irrigation access on efficiency in potato production and rural households' poverty. The study was carried out in irrigated and non-irrigated potato farming systems of three randomly selected districts of east Gojjam zone, north-western Ethiopia. It was conducted on three small-scale and one medium-scale irrigation projects.

The limitation of this study is related to types of data collected and methods used. Since most of the farm households did not keep their farm input, output, income and expenditure records, it was difficult to obtain accurate data on these variables which can create some bias in this study. Furthermore, the study was mainly based on the information generated from the sample household survey during a single cropping season due to the limitation of time and logistics. Because of these limitations, the results of the study would not be absolutely free from error.

1.6. Organization of the Dissertation

The dissertation is organized into five chapters. The remaining part of the dissertation is organized as follows. Chapter two presents the review of related theoretical, methodological, analytical and empirical literature in order to identify the research gaps and give insights for this study. Chapter three presents the methodology including description of the study area, data types and sources, sampling design, methods of data collection and analysis used in the study. Chapter four presents results and discussions in the view of past studies. Finally, chapter five gives the summary, conclusion and recommendations based on the findings of the study.

2. REVIEW OF LITERATURE

In this chapter, review of relevant literature on production efficiency, poverty and impact evaluation of an irrigation intervention are provided. In each section, theoretical framework, methodological and analytical framework and empirical literature are presented. The review also provides insights on key variables and analytical models to be used in examining and measuring production efficiency, poverty, and impact of irrigation intervention. The empirical literature provides empirical evidences from previous related studies and the gaps to be filled by this study. The theoretical and empirical reviews serve as a foundation in constructing a conceptual framework of the study.

2.1. Production Efficiency

In this section review of theoretical, methodological and analytical framework and empirical literature on efficiency of production are provided.

2.1.1. Concepts and definition of production efficiency

Many scholars use productivity and production efficiency interchangeably and consider both as the measure of performance of a given firm. However, these two interrelated terms are not precisely the same. In simple term, productivity is the quantity (level) of a given output of a firm (a farmer) per unit of input. Productivity on the other hand shows the ability of the firm to produce a given output (it may not be the maximum possible output) at a given level of input. Hence, productivity does not show the relative performance of farmer in getting the maximum possible output given input level (Coelli *et al.*, 1998).

The concept of efficiency is concerned with the relative performance of the processes used in transforming given inputs into outputs. Following the pioneer work by Farrell (1957), efficiency of a firm consists of two components: Technical Efficiency (TE) and Price efficiency (later renamed as Allocative Efficiency (AE)). But, other economic theories identify at least three types of efficiencies. These are technical, allocative and economic efficiencies (Carlson, 1968).

Technical efficiency (TE) (that part of efficiency which explains the physical performance of a firm) measures the relative ability of a firm to get the maximum possible output at a given input or set of inputs. Technically efficient farmers are those farmers that are

operating on the production frontier that represents the maximum output attainable from each input level (Coelli *et al.*, 1998). Technical efficiency shows the ability of firms to employ the best practice in an industry, so that no more than the necessary amount of a given sets of inputs is used in producing the best level of output. Technical efficiency in a production unit refers to the achievement of the maximum potential output from given amounts of factor inputs, taking into account physical production relationships (Carlson, 1968). This implies that technical efficiency is meant to characterize the relationship between observed or actual production and some ideal or potential production.

Stated differently, technical inefficiencies reflect the failure of attaining the highest possible level of output given inputs and technology, it is using more inputs than is necessary. In the case of a single output, we can think in terms of Total Factor Productivity (TFP), the ratio of actual output to the optimal value as specified by a production function. When productivity is measured as the ratio of output to single input, it is called partial productivity measure like output per worker or per hour worked; and the ratio of output to all inputs combined is total factor productivity (Coelli *et al.*, 2005).

Allocative efficiency refers to the choice of an optimum combination of inputs consistent with the relative factor prices. It refers to the ability to meet the marginal conditions for profit maximization where the marginal value of applying an additional unit of input is equal to the price of the input (Fischer *et al.*, 2009). Thus, technical inefficiency is related to deviations from the frontier isoquant while allocative inefficiency reflects deviations from the minimum cost input ratios. In other words, a productive entity is allocatively inefficient when it is not using the combination of inputs that would minimize the cost of producing a given level of output (Walter and Hezron, 2003).

Economic efficiency is the product of technical and allocative efficiencies. In other words, technical and allocative efficiency together make up the overall efficiency of a firm, sometimes called its economic efficiency. Efficiencies take value between zero and one, and a value of one shows fully or 100 percent technically efficient firm. Inefficiency is therefore, defined as the difference between the actual output achieved and the output achieved by potential or best producers on the production frontier. Farrell (1957) defined the Economic Efficiency (EE) or overall efficiency as the capacity of a firm to produce a predetermined quantity of output at minimum cost for a given level of technology.

Another productivity improvement for a firm when compared with other firms can be achieved by exploiting economies of scale. Potential economies of scale can be identified by the scale elasticity, calculated as the ratio of the proportionate increase in output to the proportionate increase in all inputs. Exploiting economies or diseconomies of scale is a productivity improvement, characterised by a movement on the frontier. It is the potential productivity gain from achieving optimal size of a firm. Scale efficiency gives insights into whether the firm operates at an optimal or sub-optimal size. Firms that are scale efficient operate under constant returns to scale (CRS) and have a scale elasticity of one, while scale inefficient firms could exploit scale economies or diseconomies (Latruffe, 2010).

Efficiency is a very important factor of productivity growth, especially in developing agricultural economies where resources are meagre and opportunities for developing and adopting better technologies are dwindling. Such economies can benefit greatly by determining the extent to which it is possible to raise productivity or increase efficiency, at the existing resource base or technology. For efficient production, non-physical inputs, such as experience, information and supervision, might influence the ability of a producer to use the available technology efficiently. Each type of inefficiency is costly to a firm or production unit (e.g., a farm household) in the sense that each in-efficiency causes a reduction in profit below the maximum value attainable under full efficiency (Ali and Chaudhry, 1990). In this study, TE, AE and EE were measured and their determinant actors were identified.

2.1.2. Theoretical framework of production 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 physical relationship between inputs and outputs, and this physical relationship along with prices of factors goes to determine the cost of production. The cost of production governs the supply of goods which together

with demand for them determines the prices of goods (Varian, 2005). Thus, it can be said that the theory of production is about the study of production functions.

The traditional microeconomic theory, which deals with the behaviour of firms, presupposes full and efficient utilization of resources, perfect knowledge and free mobility of resources. However, a number of empirical studies revealed that there is inefficiency variability in efficiency in different sectors in the developing as well as developed countries (Wilson *et al.*, 1998). The microeconomics theory of production function that transforms input into output is a base for measurement of efficiency of production. The neoclassical theory of production postulates that firms maximize profits and/or minimize costs subject to certain technological constraints. The foundation of the revealed preference approach to production analysis (Farrell, 1957) and the refinement of this approach to production modelling in the context of static decision making (Varian, 1984) provide a consistent static theoretical framework to measure and evaluate production efficiency.

Production function describes production performance of a firm using productivity. Productivity is defined as the ratio of the value of total farm outputs to the value of total inputs used in farm production (Coelli *et al.*, 2005). Harsh *et al.* (1981) defines productivity as the ability of a unit of an input to produce a certain level of output. Thus, it shows how efficient a farmer is in the use of that particular input given the range of alternative technologies available to him. In crop production, yield per area (amount of crop harvested per amount of land planted) is the most commonly used indicator of productivity (Diskin, 1999). The productivity measure is given by the average physical product of the input which itself is defined as the total physical product divided by the total amount of the input used in production (Ellis, 1993).

The usual measure of productivity assumes a ratio of output to input. When a single output is produced with a single input, productivity is measured by taking the output-to-input ratio. In this case, output per unit of input is a comprehensive measure of the level of productivity and it can be used in comparing the performance of firms. However, it is more complex when multiple outputs are produced using multiple inputs. In this case productivity is often measured using partial productivity measures such as output per worker or output per hectare. Though commonly used, partial productivity measures are of limited use can potentially mislead and misrepresent the performance of a firm (Coelli *et al.*, 2005).

Total factor productivity accounts for the use of a number of factor inputs in production, and are more suitable for performance measurement and comparisons across firms and for a given firm over time. In the presence of multiple outputs and inputs, TFP is defined as the ratio of aggregate output produced to aggregate input used. The overall productivity performance involves the measurement of efficiency and effectiveness (Greene, 1997). As noted in Cooper *et al.* (2002), moving from partial to total factor productivity measures by combining all inputs and all outputs to obtain a single ratio helps to avoid imputing gains to one factor (or one output) that are really attributable to some other input (or output). For instance, a gain in output resulting from an increase in capital or improved management might be mistakenly attributed to labor, (when a single output to input ratio is used) even though the performance of labor deteriorated during the period being considered. However, an attempt to move from partial to total factor productivity measures encounters difficulties such as choosing the inputs and outputs to be considered and the weights to be used in order to obtain a single-output-to-single-input ratio. Other problems and limitations are also incurred in traditional attempts to evaluate productivity or efficiency when multiple outputs and multiple inputs need to be taken into account.

There are several methods for performance measurements. The methods differ according to the type of measure they produce and the data they require; and the assumptions they make regarding the structure of the production technology. Some methods require data on the quantities of inputs and outputs, while others require price data and various behavioural assumptions such as cost minimization, profit maximization, etc (Farrell, 1957; Aigner and Chu, 1968; Varian, 1984; Coelli *et al.*, 2005).

2.1.3. Methodological and analytical framework of production efficiency

The concepts of output and input distance functions were discussed by Coelli *et al.* (2005) based on the concepts of efficiency proposed by Farrell (1957). Farrell (1957) proposed that the technical efficiency of a firm reflects the ability of a firm to obtain maximal output from a given set of inputs and allocative efficiency reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices and the production technology. These two measures are then combined to provide a measure of total economic efficiency.

To illustrate the distinction between productivity and efficiency concepts, Coelli *et al.* (2005) used a production frontier which defines the current state of technology in an industry. Firms in that industry would presently be operated either on that frontier, if they are perfectly efficient or beneath the frontier if they are not fully efficient. Changes in agricultural productivity are depicted by a shift of production frontier. The following reviews the distance and cost efficiency measurement techniques as discussed by Coelli *et al.* (2005).

Let us examine the difference between efficiency and productivity by taking a one input and one output case. Consider a production frontier described by the curve OG and a farmer operating at point A (Figure 1). The farmer operating at point A is technically inefficient because he could increase the output to the level of the farmer that is operating at point B without requiring more input. However, the productivity of the farmer operating at point A is given by the slope of the ray through the origin and point A, which is equal to x/y . If the farmer operating at point A were to move to the technically efficient point B, the slope of the line would be greater, indicating higher productivity at point B. However, by moving to the point C, the ray from the origin is tangent to the frontier and hence represents the point of maximum possible productivity, which is a productivity increase attained by scale economies. Hence, a farmer may be technically efficient without being attaining optimal productivity level.

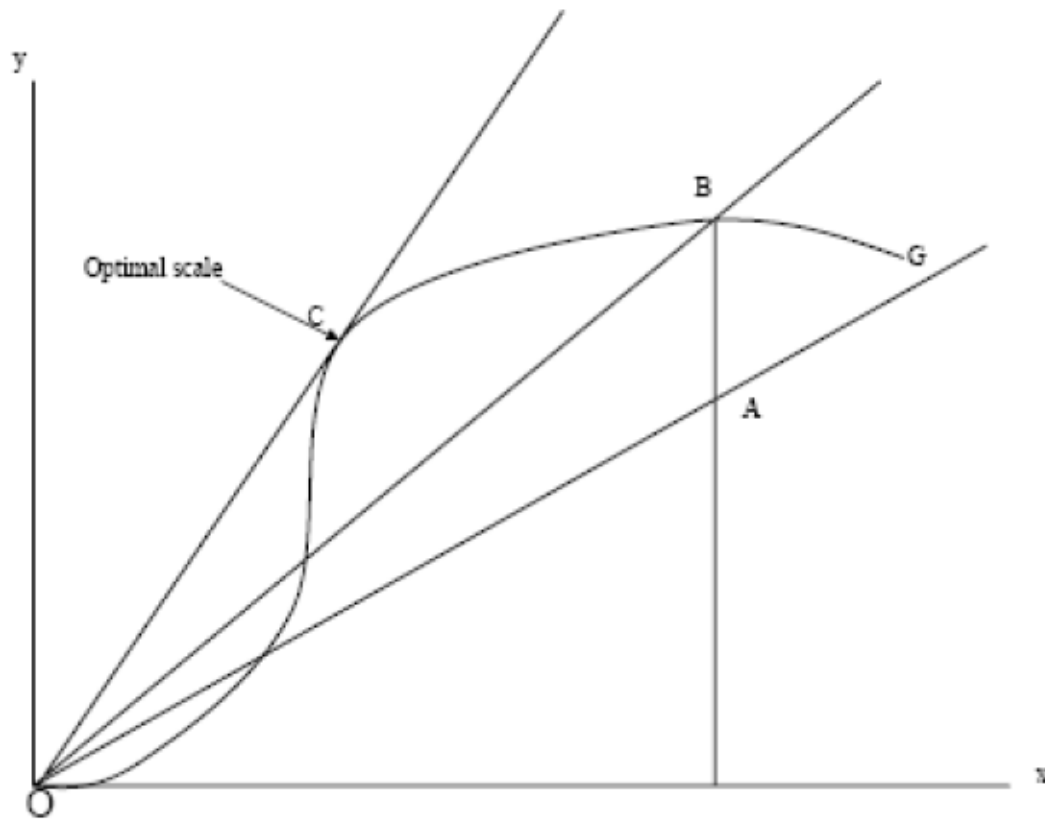


Figure 1. Productivity, technical efficiency and scale economies

Source: Coelli *et al.* (2005)

According to Farrell (1957), 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. In the input approach, we evaluate the ability to minimize inputs keeping outputs fixed, whereas in output approach we evaluate the ability to maximize outputs keeping inputs fixed (Debreu, 1951; Farrell, 1957). Brief descriptions of these methods using graphs are shown subsequently in Figures 2 and 3 based on Coelli *et al.* (2005).

To illustrate the input-oriented method of measuring efficiency, Farrell (1957) used a simple example involving firms which use (X_1 and X_2) to produce a single output (q), under the assumption of constant returns to scale. Knowledge of the unit isoquant of fully efficient firms, represented by SS' in Figure 2, permits the measurement of technical efficiency. If a given firm uses quantities of inputs, defined by the point P , to produce a

unit of output, the technical inefficiency of the firm could be represented by the distance QP, which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/OP, which represents the percentage change by which all inputs need to be reduced to achieve technically efficient production.

The technical efficiency (TE) of a firm is most commonly measured by the ratio:

$$TE = OQ/OP \quad (1)$$

which is equal to one minus QP/OP. It takes a value between zero and one, and hence, provides an indicator of technical efficiency of the firm. A value of one implies that the firm is fully technically efficient because it lies on the efficient isoquant.

The input-oriented measure of technical efficiency of a firm can be expressed in terms of input-distance function $d_i(x, q)$ as:

$$TE = 1/d_i(x, q) \quad (2)$$

In the presence of input price information, it would be possible to measure the cost efficiency of the firm under consideration as follows:

$$CE = \frac{w'x^*}{w'x} = \frac{OR}{OP} \quad (3)$$

Where w represents the vector of input prices, x represents the observed vector of inputs used associated with point P and x^* represents the minimizing input vector at Q' . If the input price ratio, represented by the slope of the isocost line AA' in Figure 2, is known, then allocative efficiency measures can be calculated using the isocost line. These are given by:

$$AE = \frac{w'x^*}{\hat{w'x}} = \frac{OR}{OQ}$$

$$TE = \frac{\hat{w'x}}{w'x} = \frac{OQ}{OP} \quad (4)$$

where $\hat{x}$ represents the input vector associated with technically efficient point Q. These equations follow from the observation that the distance RQ represents the reduction in production costs that would occur if production were to occur at the allocatively (and technically) efficient point Q', instead of at the technically efficient, allocatively inefficient, point Q. Given the measure of technical efficiency, the total overall economic efficiency (EE) can be expressed as a product of technical and allocative efficiency measures:

$$TE \times AE = (OQ/OP) \times (OR/OQ) = (OR/OP) = EE \quad (5)$$

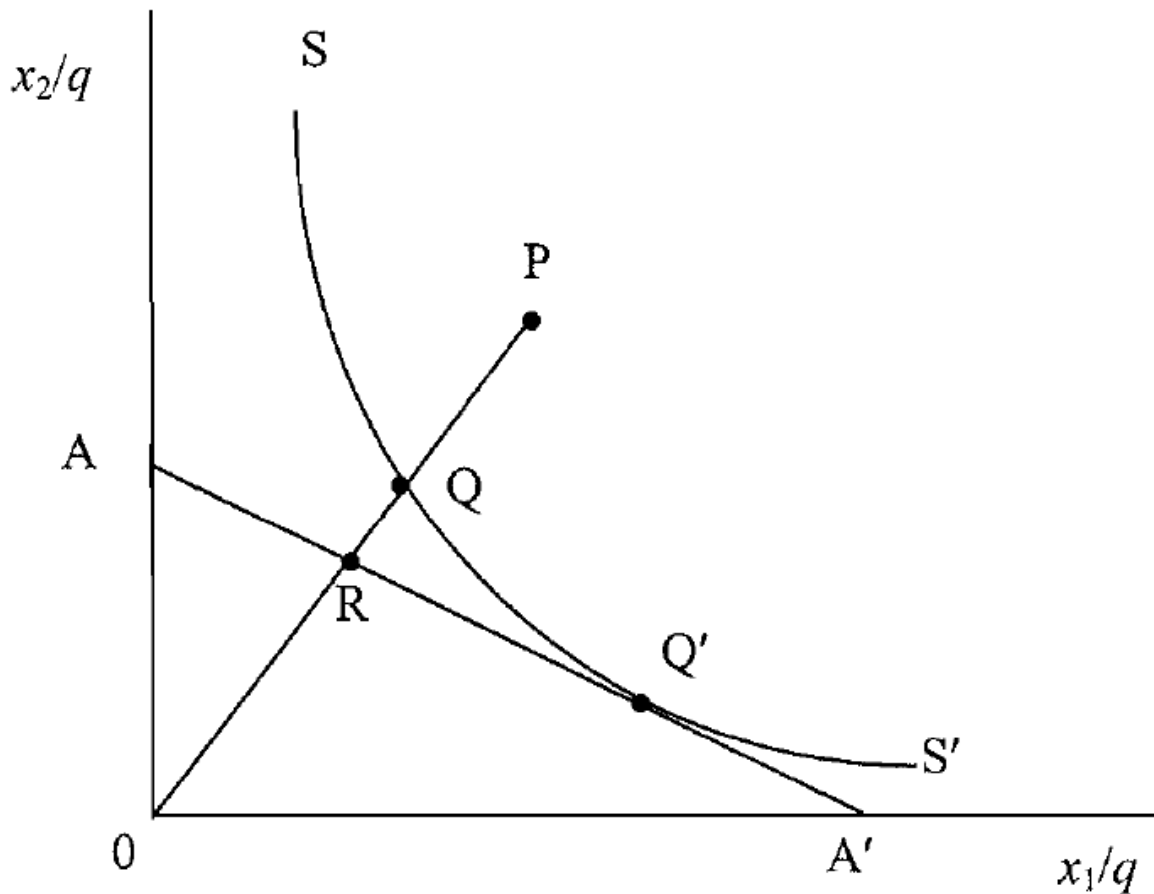


Figure 2. Technical and allocative efficiency

Source: Coelli *et al.* (2005)

According to Farrell's (1957), output-oriented measures address the question "By how much can output quantities be proportionally expanded without altering the input quantities used". The output-orientated measures of technical efficiency can be illustrated by

considering the case where production involves two outputs (q_1 and q_2) and a single input (x). If we assume constant return to scale (CRS), we can represent the technology by a unit production possibility curve in two dimensions. This example is depicted in Figure 3, where the curve ZZ' is the unit production possibility curve and the point A corresponds to an inefficient firm. An inefficient firm operating at point A lies below the curve, because ZZ' represents the upper bound of the production possibilities.

The Farrell output-orientated efficiency measures are defined as follows. In Figure 3, the distance AB represents technical inefficiency, which is the amount by which outputs could be increased without requiring extra input. Hence, a measure of output-orientated technical efficiency is the ratio

$$TE = OA/OB = do(x, q) \quad (6)$$

If we have price information then we can draw iso-revenue line, DD' , and define the allocative and technical efficiency measures as below. AE is the ratio of $\frac{OB}{OC}$ and TE is the ratio of $\frac{OA}{OB}$. Furthermore, the EE or overall efficiency can be obtained as the product of these two measurers (i.e., $\frac{OA}{OC}$).

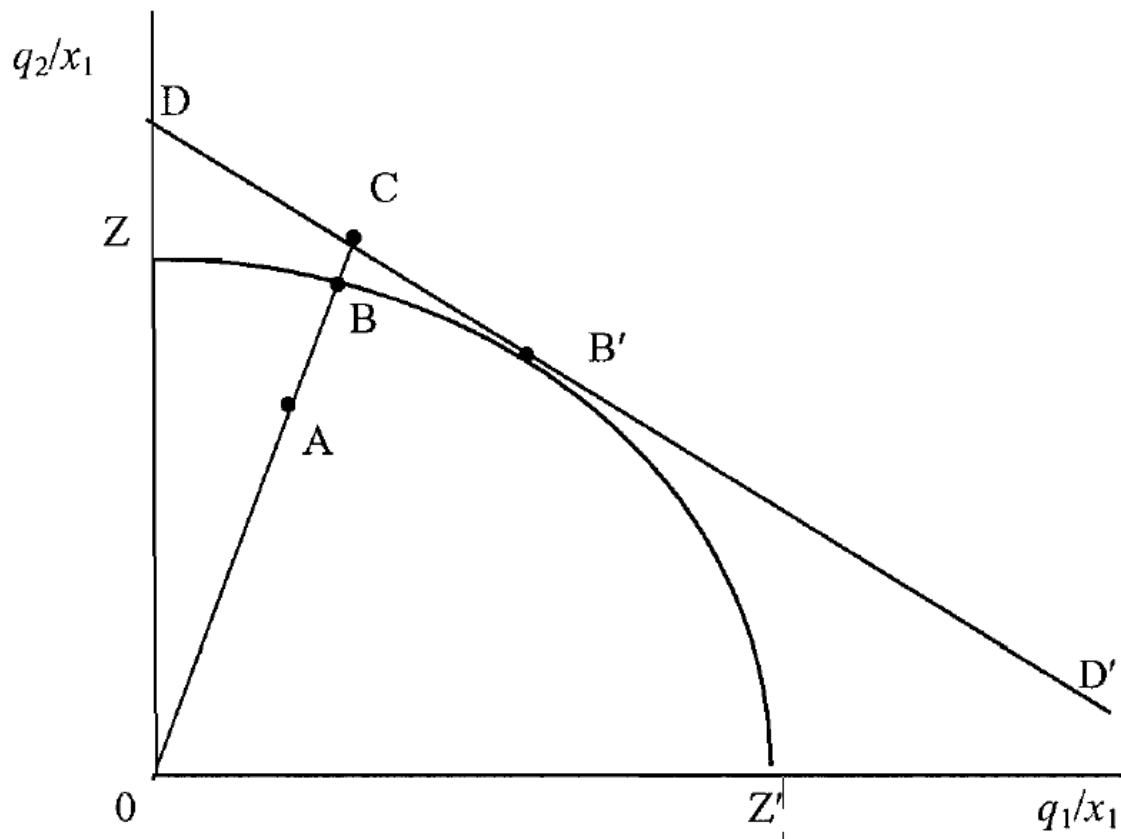


Figure 3. Technical and allocative efficiencies from an output orientation

Source: Coelli *et al.* (2005)

Thus, it is possible to measure the efficiencies of production using output oriented and/or input oriented methods. In this study, output-oriented analysis was applied and it indicates the magnitude of output of the i^{th} farmer relative to the output that can be produced by fully efficient potato producer farmer using the existing level of inputs.

Since the seminal work of Farrell (1957), there are two widely used methods of measuring efficiency: the non-parametric Data Envelopment Analysis (DEA) and the parametric Stochastic Frontier Analysis (SFA). The two techniques use different methods to analyse data, and in doing so they account for random noise and for flexibility in the structure of production technology. Non-parametric frontiers do not impose a functional form on the production frontiers and do not make assumptions about the error term. They use linear programming approaches, and the most popular nonparametric approach has been the Data Envelopment Analysis (DEA). Parametric frontier approaches impose a functional form on the production function and make assumptions about the data (Headey *et al.*, 2010).

The strengths of the stochastic frontier approach are that it deals with the stochastic noise and permits statistical tests of hypotheses pertaining to the structure and the degree of inefficiency. Its main weakness is the assumption of an explicit functional form for the technology and the distribution of the inefficiency terms (Kumbhakar *et al.*, 1996). The non-parametric method initiated as DEA by Charnes *et al.* (1978) builds on the individual firm evaluation of Farrell (1957). The method extends the engineering ratio approach to efficiency measures from a single-input, single-output efficiency analysis to multi-input, multi-output situations. In contrast to the parametric approach, DEA does not require any assumptions about the functional form. The efficiency of a Decision-Making Unit (DMU) is measured relative to all other DMUs with the simple restriction that all DMUs lie on or 'below' the efficient frontier. That is, a piecewise-linear convex isoquant is constructed such that no observed point lies to the left or below it. In general, a large number of studies on efficiency measurements argue that a researcher can safely choose any of the methods since there are no significant differences between the estimated results (Abdourhmane *et al.*, 2001; Coelli *et al.*, 2002).

However, the main criticism of DEA is that it assumes all deviations from the frontier are due to inefficiency. Due to this, nonparametric frontier methodology may overstate inefficiencies and hence outliers may have profound effect on the magnitude of inefficiency (Llewelyn and Williams, 1996). Moreover, Neff *et al.* (1993) noted that many of the observations in non-parametric frontier method are self-referencing and hence the method is unable to form a reference technology that includes other DMUs. The previous studies used either parametric or non-parametric analytical approaches to estimate efficiencies of production such as Wambui (2005), Jema (2006), and Endrias *et al.* (2010). However, other studies such as Arega and Rashid (2005), Ajibefun (2008), Headey *et al.* (2010), and Aye and Mungatana (2011) applied both approaches and compared the prediction capacity of the two methods. Their studies found that although there is a variation in the distributional patterns of the estimated efficiencies, they agreed that application of either approach proposed as the preferred set of efficiency measurement for policy decision making. Theoretical as well as empirical findings revealed that the smaller the random noise present on the data in question, the closer will be inefficiency estimates between these two deterministic and stochastic frontier models. But, most empirical studies on technical efficiency analysis in agriculture used stochastic frontier model due to the

very nature of agricultural output, which is affected by natural hazard, climatic condition and measurement errors that could attribute to the presence of noise in the data.

The frontier production function specifies what output can be achieved if all decisions were taken according to their best practices. In smallholder farming, a farm's technical efficiency is a measure of its ability to produce relative to the smallholder's best-practice frontier, the maximum output possible from a given set of inputs and production. If farm households wish to estimate the maximum possible production, but not average production or average cost, given a set of inputs, an ordinary least square (OLS) regression cannot be used. This is because the OLS estimates the mean of the dependent variable conditional on the explanatory variables, but not the maximum possible outputs given a set of inputs or the minimum possible cost of a set of outputs. To estimate the maxima or the minima of the dependent variable given explanatory variables, the frontier functions, either econometric stochastic frontier analysis (SFA) or linear programming DEA is used. However, DEA is a non-parametric method that estimates the efficiency of production of a group of farms, sometimes called decision-making units (DMU). Since DEA is a non-parametric method no information is provided by the analysis as to the reasons or sources of inefficiencies (Coelli *et al.*, 2005).

Data envelopment analysis does not make allowance in the analytical method for measurement error or missing data or information in estimating the efficiencies of production. The main advantage of the stochastic frontier model is the ability of the model to separate the random error or noise, such as weather that are stochastic and not due to operator inefficiency, from deviations arising from technical inefficiency. Due to this, most empirical studies especially in agriculture where random errors due to random shock and measurement error are high focus on stochastic frontier model. Coelli *et al.* (1998) recommended that SFA is more appropriate than DEA models in agricultural applications, especially in developing countries, where the data are heavily influenced by measurement errors, and the effect of weather, disease, etc plays a significant role.

Stochastic frontier analysis has a probability distribution error term which is the basis of maximum likelihood estimation. In frontier functions, the disturbance has a distribution all on one side of zero. Models with one-sided errors that represent inefficiency are known as stochastic frontier models. The maximum production must be greater than or equal to any value in the sample, and the minimum cost must be less than or equal to any value in the

sample. Coelli and Battese (1996) argued that estimating the efficiency analysis using the parametric approach in the field of agriculture provides better results as compared with the non-parametric approaches. They justified their reasoning based on the fact that the parametric approach accounts exogenous factors in addition to accounting measurement errors, which is inherent in agriculture production. As a result of the above argument, this study employed a parametric stochastic frontier approach introduced by Aigner *et al.* (1977).

The most common functional forms used in SFA include linear, the Cobb-Douglas, constant elasticity of substitution and translog production functions. The Cobb-Douglas and translog models overwhelmingly dominate the applications literature in stochastic frontier and econometric inefficiency estimation (Greene, 1993). Cobb-Douglas production function is a special form of the translog production function where the coefficients of the squared and interaction terms of input variables are assumed to be zero. Its most attractive features are simple, its logarithmic transformation provides a model which is linear in the logs of the inputs and hence easily lends itself to econometric estimation methods. Besides, it imposes a severe prior restriction on the farm's technology by restricting the production elasticity to be constant (assumes constant return to scale) and the elasticity of input substitution to unity (Wilson *et al.*, 1998; Coelli *et al.*, 2005).

In a production (or cost) model, the choice of functional form brings a series of implications with respect to the shape of the implied isoquants and the values of elasticities of factor demand and factor substitution. The Cobb-Douglas production function has universally smooth and convex isoquants. The implied cost function is likewise well behaved. This good behaviour is due to the strong assumption that demand elasticities and factor shares are constant for given input prices for all outputs (Greene, 1993). The choice of flexible second order functional form (e.g. translog) relaxes the restrictions on demand elasticities and elasticity of substitution but susceptible to multicollinearity and degrees of freedom problems (Kopp and Smith, 1980). Moreover, it is not monotonic or globally convex as in the Cobb-Douglas model (Coelli *et al.*, 2005). Cobb-Douglas production function is also selected due to its advantage of computing self-dual cost function, which is a basis for estimating allocative and economic efficiencies. Hence, in this study Cobb-Douglas production function was estimated and computed the self-dual cost function using parametric approach among potato producing smallholder farmers of the study area.

Productivity is generally measured in terms of the efficiency with which factor inputs, such as land, labor, fertilizer, herbicides, tools, seeds, oxen power and equipment etc are converted to output within the production process. Fischer *et al.* (2009) points out that yield gaps and efficiency gaps are often measuring the same things. However, efficiency gaps may exist even where there are no yield gaps. Farmers may achieve the economically attainable yield, but using above optimum input levels. As for yield gaps, factors related to farmer characteristics and system wide constraints explain variation in efficiency across farmers and fields. Technical efficiency relates largely to timing and technical skills in using inputs and is often explained by farmer specific knowledge and skills. However, system-level factors, for instance, irrigation systems and management of farm land can also explain technical inefficiency. That is, in efficiency analysis, it is not only the level of inefficiency that is important, but the identification of the demographic, socio-economic, marketing and institutional factors that cause it.

There are two methodological approaches to analyze the sources of technical inefficiency using stochastic production functions. The first approach is the two-stage estimation procedure in which the stochastic production function is first estimated, and then efficiency scores are derived. Then, in the second stage, the derived efficiency scores are regressed on explanatory variables using ordinary least squares method or tobit regression. This approach has been criticized on grounds that the firm's knowledge of its level of technical inefficiency affects its input choices; hence inefficiency may be dependent on the input variables.

The second approach advocates a one stage simultaneous estimation approach as in Battese and Coelli (1995), in which the inefficiency effects are expressed as an explicit function of a vector of farm-specific variables. Following the former approaches, studies by Endrias *et al.* (2010) and Aye and Mungatana (2010) used two-limit Tobit model, whereas Arega (2003), Arega and Reshid (2005) applied OLS method to identify the determinants of efficiencies of maize production. The use of OLS model in such types of dependent variable (efficiency scores), which takes values between 0 and 1 leads to the problem of heteroskedasticity so that parameter estimates obtained are inefficient, thus classical hypothesis tests, such as t-ratios are inappropriate (Gujarati, 1995). In this study, therefore, two-stage estimation approach using tobit model with non-zero censoring point was applied to identify the determinants of technical, allocative and economic efficiencies of

potato farmers because the dependent variables (efficiencies) in this case assumed non-zero minimum efficiency index as lower limit and the maximum efficiency index as upper limit (censored).

2.1.4. Empirical studies on production efficiency

Khudu and Ahmad (2006) estimated the technical efficiency in potato production in Punjab, Pakistan by employing the Cobb-Douglas stochastic production frontier approach and identified that extension services are not being properly disseminated in the study area. Karanja *et al.* (2014) evaluated the key challenges facing potato production in Oljoro-Orok division, Kenya. The data collected were analyzed using descriptive statistics namely frequencies, percentages and means and a SWOT matrix computed. Rainfall variations, lack of clean seeds and crop diseases have been found to be the major challenges facing potato production in the division.

Otitoju and Arene (2010) found that the amounts of land available, availabilities of seeds, and labor (both family and hired) have strong impact on the productivity of a given land. The quantity of and the amount spent on fertilizer and agro-chemicals like pesticides and herbicides, and mechanization (the use of a tractor) are all important predictors of productivity. Shehu *et al.* (2010) stated that most of the factors that determine the level of efficiency of farmers are also identified in the literature as important predictors of productivity, regardless of the measure of productivity in use and the quantity and quality of inputs used.

Fernandez and Nuthall (2009) analyzed the technical efficiency of sugarcane farmers in Philippines to identify the source of input use inefficiency. They find out that technical efficiency of farmers is positively related to farmer's age and experience, access to credit, fertilizer application, and soil type and farm size. Headey *et al.* (2010) estimated TFP growth in agriculture for 88 countries over the 1970 to 2001 period using DEA and SFA methods. They argue that the SFA results are more appropriate, and SFA based series are less volatile, more correlated with labor productivity, and also avoid the technical regress often found with DEA estimates. They reported that SFA method show advantages over the commonly used DEA technique. Accesses to advisory services, rural credit, and membership to agricultural association, use of improved agricultural technology

(irrigation, seed, animal traction, and chemicals) are found to significantly reduce the level of farm household's inefficiencies.

Factors such as participation in irrigation, access to credit, agro-ecological zones, family size, market access, having the male household head, educational attainment levels, family literacy, frequency of contact with extension agents, membership of farmer's association or cooperative societies, farmers who practice mono-cropping, oxen holding, size of livestock holding, farm machinery (such as tractor) and access to improved agricultural technologies (such as use of improved seed, chemical fertilizer and agro-chemicals) are reported as having a positive effect on efficiency of crop production (Arega and Reshid, 2005; Wambui, 2005; Endrias *et al.*, 2010; Aye and Mungatana, 2011).

Asadullah and Rahman (2005) examined the debate over the role of education in farm production in Bangladesh using a large dataset on rice producing households from 141 villages. Average and stochastic production frontier functions are estimated to ascertain the effect of education on productivity and efficiency. Their findings revealed that in addition to raising rice productivity and boosting potential output, household education significantly reduces production inefficiencies.

Masterson (2007) estimated and analyzed farm productivity and technical efficiency based on primary data collected from sample households in Paraguay. He predicted farm productivity and technical efficiency using both DEA and stochastic production frontier function approach. His findings indicated that the impact of tenure security is an interesting phenomenon. It was estimated to decrease land productivity and technical efficiency. In theory, titling is supposed to improve farm productivity by providing secure collateral for input loans. Female land rights were never significant in their impact on productivity or efficiency. Moreover, rising shares of household labor employed in agriculture result in lower productivity and efficiency. This is in opposition to theory on this point is that household labor requires less supervision and is more motivated than hired labor, and so should be more productive and efficient. Finally, they concluded that there is inverse relationship between farm size and farm productivity.

Using a stochastic frontier production model Msuya *et al.* (2008) estimated the levels of technical efficiency of smallholder maize farmers in Tanzania. Results showed that

smallholder productivity is very low and highly variable. Low levels of education, lack of extension services, limited capital, land fragmentation, and unavailability and high input prices are found to have a negative effect on technical efficiency. Smallholder farmers using hand-hoe and farmers with cash incomes outside their farm holdings (petty business) are found to be more efficient. However, farmers who use agrochemicals are found to be less efficient.

Bifarin *et al.* (2010) identified determinants of technical, allocative and economic efficiencies in the plantain (*musa spp.*) production industry, Ondo state, Nigeria. They analyzed data using the stochastic parametric technique. Results of the estimated coefficients indicated that age is significant and positively correlated to technical and economic efficiencies, while extension services contributed significantly to technical efficiencies. These results suggest that experience in plantain farming and increased investment in extension services could jointly contribute to an improvement in efficiency of plantain farmers in Ondo state of Nigeria.

Tsoho *et al.* (2012) investigated the determinants of technical, allocative and economic efficiencies among small-scale dry season vegetable farmers in Sudan Savannah (SS) zone of Sokoto State, Nigeria, using a stochastic frontier production function. The findings revealed that four variables (extension visits, source of irrigation water, crop diversification and location of the farm), two variables (extension visits and location of the farm) and three variables (extension contact, source of irrigation water and crop diversification) were found to be significant at different levels of significance for technical, allocative and economic efficiencies, respectively. These variables were therefore the important policy determinants of inefficiency in study area. These results suggest that farmers' location in vegetable farming and increased investment in extension services could jointly contribute to an improvement in efficiency of vegetable farmers in the study area.

Arega and Rashid (2002) measured the impact of New Extension Program (NEP) on the productive efficiency of farmers in two districts of Babile and Meta in eastern Hararghe. In the study, they measured the impact of NEP on technical, allocative and overall efficiency (economic efficiency) using stochastic frontier approach. They estimated a separate Cobb-Douglas functional form, since this function is self-dual, for the two groups (participant and nonparticipant of NEP) and investigated the determinants of efficiency (both technical

and allocative) on a second stage linear regression model. While, they found that education (in terms of reading and writing) determines technical efficiency of both participants and nonparticipants in both districts; off-farm income, the number of years of participation in extension programs and credit usage found to be determinants of TE in either districts and/or groups.

Seyoum *et al.* (1998) compared the efficiency level and determinants of efficiency of farmers in the production of maize in *Kersa* and *Kombolcha*. They grouped 40 sample farmers into two, within the Sasakawa-Global 2000 (SG2000) project and outside the SG2000 project 20 sample farmers from each. Using stochastic frontier approaches, they estimated that technical efficiency of farmers within SG2000 ranged from 0.748 to 0.990 with a mean of 0.937. For the farmers outside the project ranged from 0.557 to 0.965 with the mean estimated to be 0.794. While age determined inefficiency positively, extension and education were found to determine inefficiency negatively within the SG2000 project. It was quite opposite for farmers outside the SG2000 project except age as a determinant of efficiency.

Temesgen and Ayalneh (2005) estimated the technical efficiency of farmers in the production of irrigated potato based on cross-sectional data collected from randomly selected 80 farmers in four districts of Awi zone in North-western Ethiopia. The stochastic frontier production function, which considers deviation from the frontier to be due to the effect of technical inefficiency and random noise, is used for data analysis. Technical efficiency of farmers was estimated independently for the farms under modern irrigation schemes and traditional irrigation schemes. Using likelihood ratio test, Translog production function is found to be an adequate representation of the production behaviour of farms under the two types of schemes. The mean level of technical efficiency was found to be 77 percent and 97 percent respectively for modern and traditional schemes. Irrigation experience, commodity rate of production and size of livestock are found to be the important variables that determine the level of efficiency.

Potato yields in SSA (South Africa excluded) are below 10t/ha while the attainable yields with good crop management are well above 30t/ha if applied with good seed, fertilizers and crop protectants (Haverkort *et al.*, 2012). In Ethiopia, in contrast to the FAO statistics indicating yields above 10 ton/ha in 2009/2010, the yields derived from the Ethiopian Central Statistics Agency are below 10 ton/ha. The latter is also in line with the findings of

Abay *et al.* (2011) who stated that yield is below 10t/ha, 47.5% for household consumption and 15.6% as cash crop.

The results of crop growth model showed the highest attainable yields of 74 t/ha for the pre-rain season (Belg), followed by 61t/ha for the rainy season (Meher) and 55 t/ha at the winter season. The latter has the greatest need of irrigation water (3 mm/t), whereas the rainy season crop has an excess of rain so then irrigation is not needed. However, the actual potato yields per hectare ranged between 8 ton to 12 ton per hectare in Ethiopia, slightly below the average of Africa. In 2009 and 2010, Ethiopia achieved yields between 11 and 12 tons per ha, the highest level in the last decade (Haverkort *et al.*, 2012). But the Ethiopian Central Statistical Agency (2011) mentions production levels of around 8 ton/ha. The study by Bezabih and Mengistu (2011) shows even maximum level of 64 ton/ha in *Shashemene*, however the minimum level has been 1.6 ton/ha. The mean in *Shashemene* is 14.3 ton/ha which is high compared to the CSA and FAO statistics. Nevertheless, the yields are below those of Sudan (17 ton/ha) and especially Egypt (26 ton/ha). The yield and quality of table potato production depend on the quality of the seed. But, most of the farmers use potatoes from previous harvest as seed. In sum, the reviewed literature shows that SFA technique is widely used in efficiency analysis, and the technique shows advantage over DEA technique in efficiency analyses. The studies also show that farmers are inefficient in agricultural production in developing countries. The sources of inefficiencies are related to farmers' demographic and socio-economic characteristics, access to institutional and market services and improved farm technologies.

2.2. Poverty

In this section review of theoretical, methodological, analytical framework and empirical literature on poverty are provided.

2.2.1. Concepts and definition of poverty

There are many different concepts of poverty in various disciplines. But, it can be perceived in two broadly distinct ways: absolute poverty (lack of access to a basket of basic survival needs). Poverty defined in this way focuses on the absolute economic well-being of the poor and requires some knowledge of the minimum standard of living referred to as the poverty line; and relative poverty (lack of access to the level of resources accepted

as normal in a society). It is now widely recognized that poverty is multi-dimensional, embracing issues such as social exclusion, vulnerability and lack of participation (FAO, 1999). World Bank (2005) stated poverty to include hunger, lack of shelter, being sick and not being able to see a doctor, not having access to school and not knowing how to read and write, not having a job, fear for future, losing a child to illness brought about by unclean water, powerlessness, and lack of representation and freedom.

There is no global consensus on what the exact definition of poverty should be. However, most authors seem to include in their definition the notion that poverty is a low level of standard of living below an acceptable minimum level in terms of minimal necessities of nutrition, clothing, health, education, housing, water and sanitation, in a given economy. Or poverty should be understood as the inability of an individual to meet the minimal necessities of life such as food, housing, clothing, health, sanitation and education (Shitundu and Luvanga, 1998). Chronic poverty refers to a situation where an individual is poor as a result of long-term structural factors. Transient poverty is a situation where an individual is poor because of some temporary shocks which could be reversed over time. Often transient poverty constitutes a large proportion of total poverty (Hussain and Hanjira, 2004).

The components of poverty are usually divided into income poverty and non-income poverty. Reducing income poverty enables households to achieve food security, accumulate assets, reduce vulnerability to external shocks and provide for the future. Reduction of income poverty often also improves access to education, health services and clean water. Thus, although poverty is a multi-faceted condition, we consider a household as poor if its per adult equivalent annual income falls below the poverty line determined based on the past national poverty line or in terms of the \$1.25 a day income threshold (World Bank, 2009) for extreme poverty rather than the other aspects of material deprivation or lack of access to services or the multidimensional indicators of poverty such as income, housing, food, clothing, literacy, health, and information (Peacock *et al.*, 2007).

In recent years, it has been increasingly realized that poverty is a multidimensional concept, extending from low levels of incomes and expenditures to lack of education and poor health, and includes other social dimensions, such as powerlessness, insecurity, vulnerability, isolation, social exclusion and gender disparities. Similarly, the concepts of

livelihoods, basic capabilities and entitlements have broadened the concepts of poverty. While these concepts are very useful in understanding poverty from various dimensions, most empirical work on poverty measurement is based on incomes or consumption expenditures, and poverty is defined as a situation where a household's or a person's income or consumption level falls below some minimum level necessary to meet basic needs (FAO, 1999). That is, while acknowledging the importance of nonmonetary dimensions of poverty, most of the authors focus on income/expenditure poverty and a poor household are defined as one with income/expenditure less than a specified level to meet basic food and non-food needs. This study is based on monetary dimension of poverty representing income by expenditure of food and non-food items needed by the households to meet their basic needs.

2.2.2. Theoretical framework of poverty

2.2.2.1. The poverty-growth-inequality triangle

Consumption poverty approach is an amalgam of two variants of utility theory, revealed preference theory and money metric utility, and nutrition science. The preference part is due to the fact that consumer preferences over goods and services, known by observing consumer behavior or asking about consumer choices (revealed preference theory) are the building blocks from which levels of well being and poverty are derived. Nutrition science is used to distinguish between basic and non basic preferences, as the poverty line is usually anchored on minimal levels of dietary energy, or caloric, intake. Poverty is given a numeric representation in that preferences are represented by consumption expenditure (money metric utility) which facilitates the aggregation of persons or households below the poverty line and comparisons of well-being across persons or households (Ravallion, 1994).

In the consumption poverty approach, utility is the chosen dimension of well-being. It is equated with preference fulfillment and rendered observable by restricting preferences to consumer preferences revealed by choice. These are subsequently transformed into consumption expenditure, or money. This process facilitates subject-invariance in that any two competent persons should be able to rank individuals in the same way once this money metric criterion has been adopted. Money becomes a representation of wellbeing or poverty which subsequently facilitates the aggregation of those below the poverty line as

well as consistent interpersonal comparisons of well-being. The key point is that the wellbeing metric itself, utility, is transformed into an intersubjectively observable datum, revealed preferences, to which an empirical scale, money, is applied (Kanbur *et al.*, 1999).

Once it has been accepted that reducing absolute income poverty is a meaningful development goal, a direct link may be established between development, growth and distribution. Analytically, it is easily shown that a kind of arithmetic identity links the growth of the mean income in a given population, the change in the distribution or in relative incomes and the reduction of absolute poverty. In other words, poverty reduction in a given country and at a given point of time is fully determined by the rate of growth of the mean income of the population and the change in the distribution of income. As illustrated in Figure 4 by the Poverty-Growth-Inequality (PGI) triangle, a development strategy is thus fully determined by the rate of growth and distributional changes in the population. Formally, the relationships implicit behind the PGI triangle is not simple. For instance, the elasticity of poverty with respect to growth for a constant distribution is neither constant across countries with different development levels and distribution, nor across the various ways of measuring poverty. The same observation applies to the elasticity of poverty with respect to inequality indicators (Bourguignon, 2003).

The real challenge in establishing a development strategy aimed at reducing poverty is not so much in the essentially arithmetic relationships between poverty and growth on the one hand, and poverty and inequality on the other. It lies instead, in the interactions between distribution and growth. There is indeed little controversy among economists that growth is essential for (income) poverty reduction, with the assumption that the distribution of income remains more or less constant. In effect, much evidences point in this direction (for example, Deininger-Squire, 1996; Dollar and Kraay, 2001; Ravallion, 2001, 2003; Bourguignon, 2003). Likewise, there is much evidence that a worsening of distribution tends to increase poverty. Yet, the real issue in establishing a development strategy is whether growth and distribution are independent of each other or, on the contrary, are strongly interrelated (Bourguignon, 2003).

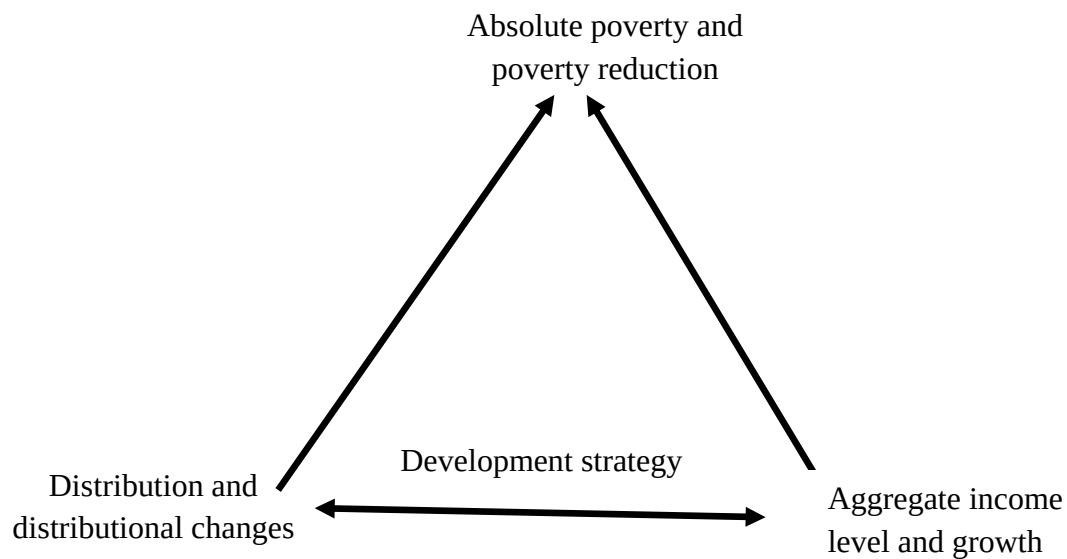


Figure 4. The poverty-growth-inequality triangle

Source: Bourguignon (2003)

Changes in the poverty rate are the result of changes in average income and shifts in income distribution. A change in income distribution can be broken down into two effects: a proportional increase of all income with distribution unchanged (the growth effect) and a change in the distribution of relative income (the distribution effect). The reduction of poverty in a given country at a given time thus depends on the income growth rate, and changes in income distribution. Thus, the change in poverty can be expressed as a function of the growth in mean income and changes in the distribution of relative income (Bourguignon, 2003).

Change in poverty = F (growth, distribution, change in distribution)

Thus, the question of economic development in the sense of a rising per capita income becomes a separate one from the question of the structure and morphology of poverty (Sen, 1981). The problem, however, is not only one of measuring poverty but of explaining its origin, its persistence and of proposing solutions to it.

2.2.2.2. Causes for poverty

There are different theories that explain causes for individual poverty. Most of these are widely discussed by Blank (2003), World Bank (2005) and Bradshaw (2006). According to Bradshaw (2006), theories of the determinants of poverty can be classified into five based on what they claim to cause poverty. These are poverty caused by economic, political, and

social distortions or discriminations, poverty caused by individual deficiencies, poverty caused by geographic disparities, poverty caused by cultural belief systems that support the subculture of poverty, and poverty caused by cumulative and cyclical interdependence.

Those theorists who think that poverty is caused by economic, political, and social distortions or discriminations argues that individuals and culture should not be blamed to make one poor rather the economic, political and social distortions or discriminations should be blamed. Social and economic systems override and create individual poverty situation (Harvey and Reed, 1992; Bradshaw, 2006; Henry, 2007). According to Bradshaw (2006), people like Marx argue that capitalism created poverty by keeping wages low and increasing the profit of the capitalists. Blank (2003) explaining this school of thought says that the market development generated by first-world corporations in the third-world economies benefits only the companies and their home customers and impoverishes local producers by buying up their land and forcing them into producing cash crops for the company or displacing them off the land and into sweatshop labor.

According to this theory, poor people fall behind regardless of how competent they may be. Poor people cannot get better jobs in the political system in which the interests and participation of the poor is kept either impossible or deceptive. Supporters of this school of thought also argue that, coupled with racial discrimination, poor people lack the influence in the political systems that they might use to mobilize economic benefits and justice. System flaws associated with poverty related to groups of people being given a social stigma because of race, gender, disability, religion, or other groupings leading them to have limited opportunities regardless of personal capabilities (Blank, 2003; Bradshaw, 2006). World Bank (2005) also states that gender, ethnic, racial, religious and other forms of inequality are some of the dimensions and causes of poverty.

The other group of theories that believe poverty is caused by individual deficiencies argue that individuals seek to maximize their own well being by making choices and investments, and that (assuming that they have perfect information) they seek to maximize their well being. They have the stand that individuals are largely responsible for their individual choices in a sense that through hard working and better choices, the poor can avoid and remedy their problems (Bradshaw, 2006). The implicit assumption of this school of thought, according to Blank (2003), is that alternative lifestyles were available to be chosen that would have provided greater economic opportunity, hence the problem is not

in the larger structure of the market or the economy but within the flawed personal attributes of the individual. Neo-classical economists argue that if poverty is to be eliminated, it is the poor, not the economic system as such that must undergo radical change (Harvey and Reed, 1992).

Blank (2003) citing a limitation of such an approach says that some persons are not inherently unable to participate in the markets due to the forces outside their direct control—being too young or too old, nor can an individual be blamed for lack of education when educational resources are not available. Henry (2007) on the other hand argues that individual decision-making cannot be the fundamental basis of poverty or any social consequences. According to Henry (2007), for a decision to be bad requires that the decision-maker knows with certainty the outcome of that decision before it is made but in the real world this is impossible. He adds that one cannot know what the future brings, as the future is dependent on a multitude of actions taken now; any individual cannot know how these actions will work themselves out to produce the observed results. According to him individuals must know not only the effect of their actions, but also the effects of actions of all within the collection of individuals making up the aggregate. Emphasizing this, he says that the individualist approach, which is largely based on Neoclassical Economic Theory, informs our ideological perspective, permeates thinking on matters of theory and policy, and generally dictates our understanding of perceived reality. The individualist perspective, according to him, conditions our thinking that it hinders us from seeing the interplay between the individual and society and precludes questions pertaining to that interplay from even being asked.

The other theory also argues that geographic disparities are the major causes of poverty. According to this theory, poverty explained in terms of rural poverty, ghetto poverty, urban disinvestment, southern poverty, third-world poverty, and other framing of the problem represent a spatial characterization of poverty that exists separate from other theories (Bradshaw, 2006). According to this theory, people, institutions, and culture in certain areas lack the objective resources needed to generate wellbeing and income. Many investments in a country concentrate in the center of a country and where the infrastructure is already developed. People from underdeveloped areas with highest levels of education, the greatest skills, widest world view, and most extensive opportunities were the ones who migrate out of their original places, according to this school of thought. According to this

theory, rural poverty is highly attributable to such selective out migration (Bradshaw, 2006).

Those who consider culture as a source of poverty, on the other hand, argue that poverty is created by the transmission over generations of a set of beliefs, values, and skills that are socially generated and individually held. According to this school, individuals are not necessarily to be blamed because they are victims of their dysfunctional subculture or culture. They have the stand that once the culture of poverty has come into existence it tends to perpetuate itself (Bradshaw, 2006; Islam, 2005). According to Durlauf (2000), individual's socioeconomic prospects are strongly influenced by the group to which he is attached over the course of his life. According to him, such membership can exert causal influences on individual outcomes through peer group effect, role model effects, social learning and social complementarities.

The other school of thought that says poverty is caused by cumulative and cyclical interdependence states that the individual and their community are caught up in a spiral of opportunity and problems, and once problems dominate they close other opportunities and create a cumulative set of problems that make any effective response nearly impossible (Bradshaw, 2006). The cyclical explanation explicitly looks at individual situations and community resources as mutually dependent, with a faltering/wavering economy. These may also be related to the poverty trap hypothesis which states that agents in an economy are trapped in a situation in which their actions generate a situation of low income/productivity and at the same time the economy's low level of income has the consequence of generating incentives for agents not to change their actions (Rodrigue, 2008).

From the above discussions, it is possible to sum up that poverty is caused by a multiple of factors that range from individual characteristics to economic and political systems. Thus, any study that deals with poverty should examine these theories so as to recommend appropriate poverty reduction policy and strategy.

2.2.3. Methodological and analytical framework of poverty analysis

According to the World Bank (2005), the steps in measuring poverty include defining an indicator of welfare, establishing a minimum acceptable standard of that indicator to separate the poor from the non-poor (poverty line), and generating summary statistics to aggregate the information from the distribution of this welfare indicator relative to the poverty line. The concept of poverty line as being used by those income/consumption based poverty study is based on the utility theory. According to Ravallion (2003) the poverty line for a given individual can be defined as the money the individual needs to achieve the minimum level of welfare not to be deemed poor, given circumstances. Everyone at the poverty line is taken to be equally badly off, and all those below the line are worse off than all above it. Ravallion also states that poverty line is the cost of a bundle of goods, the vector utility-compensated (Hicksian) demand curve. Biancotti (2006) also defines poverty line as a quantity of a good at which there is a structural break in how utility is extracted from the consumption of a good.

In practice, poverty lines can be constructed based on the cost of basic needs, food energy intake or by subjective evaluations. In the cost of basic need approach one estimates the costs of acquiring enough food for adequate nutrition, usually 2100 calories per person per day, and then adding on the costs of other essentials such as clothing and shelter (World Bank, 2005; MOFED, 2008). When price information is lacking, one may use the food energy intake method, which graphs expenditure (or income) per capita against food consumption (in calorie per person per day); from this one may determine the expenditure (or income) level at which a household acquires enough food. Subjective poverty lines are based on asking people what minimum income level is needed in order to just make ends meet (World Bank, 2005).

According to Bidani *et al.* (2001), the food energy intake method of identifying the poor suffers from some limitations. The relationship between the food energy intake and total consumption expenditure is likely to be different according to differences in tastes, activity levels, relative prices or publicly provided goods. They explain with examples that urban people get access to goods with lower costs and the activities they do require lower energy than the rural ones resulting in lower food intake and lower total costs in the urban areas. This does not mean, according to their explanation that urban people are poorer than the rural ones.

The poverty lines for non-monetary poverty indicators are determined usually by setting a given optimum level based on experience or subjective judgment of the researcher. Gigler (2005), for example, define information and communication poverty line as the minimum capability to participate in the information society. He argues that there must be a minimum set of ICT materials (asset) for a given geographic location, it should be able to exchange (receive and provide) a minimum transparent information about political, institutional, economic processes (including those of production, commercialization and income distribution), about social protection mechanism; and it must be able to communicate, through the analysis and minimum level of exchange of ideas about political, institutional, technological and economic processes as well as social protection mechanisms.

In the case of poverty analysis, either we find a linear combination of all the components and find one poverty line or we find the poverty line for each component of the multidimensional poverty indicator. Bourguignon and Chakravarthy (2003) criticize the approach that determines the linear combination of the components and consider it to be the same as the one-dimensional income poverty indicator. The other approach that they support is, therefore, to define poverty as a shortfall from a threshold on each dimension of an individual's well being. They also show by some mathematical proofs that this second approach can help determine the share of different attributes to total poverty. Hence, they recommend identification of sub-group attribute combinations that are more susceptible to poverty. Isolation of such subgroup-attribute combinations becomes important in designing antipoverty policies when a society's limited resource does not enable it to eliminate poverty for an entire sub-group or for a specific attribute. Ravallion (2011) also supports the same idea arguing that one has to look into a country's attainments in various dimensions rather focusing on its performance with respect to a single composite index.

However, this study follows one dimensional poverty analysis in which the index is computed for income poverty based on household consumption expenditure in order to identify the households are or are not poor. A household is called income poor if households' adult equivalent annual expenditure is less than the national income poverty line, that is, if less than the minimum requirement (need) for healthy life. Income poverty was based on collecting the household consumption expenditure that is usually thought to

represent income. As this study is concerned, the determination of income poverty was based on computing the household expenditure on different sources on which the rural households are supposed to spend their expenditure. For the purpose of computing poverty head count, a household is called income poor if per adult equivalent annual expenditure falls below the poverty line determined for the zone based on the past national poverty line.

Actually, measurement of poverty involves specification of (a) the poverty line and (b) the indicator of well-being and standard of living such as income or expenditure. The standard of living varies not only from country to country but across regions/communities within a country. Considering these variations, there is no unique poverty line that can be applied to all systems. The international poverty line of US\$1.25/day has its own limitations, as it often tends to overestimate poverty. A poverty line estimated for a country/region or community should provide a more realistic estimate of poverty. Therefore, secondary estimates of poverty lines are commonly employed by the national/regional statistical agencies. These national poverty lines are based on per capita incomes or expenditures needed for required food and non food basic needs. There is also no consensus on whether household income or expenditure is a better measure to be used in estimating poverty. Each measure has its own limitations. Households usually tend to understate their incomes and overstate their expenditures. However, there are a large number of empirical studies that use either incomes or expenditures (Hussain and Wijerathna, 2004).

As far as the threshold setting is concerned, Rio Group (2006) states that some standard could be found based on legally established limits and some policies may establish certain goals that would be particularly useful as they reflect expert opinion. When no absolute criteria can be defined because of a lack of agreed standards or indicators of results, thresholds should reflect a clear break point in the usual practices of the society. This study, therefore, used standard thresholds found in the literature. Future studies can use this threshold or make improvements if they get sufficient evidences and justifications to do so. The method of identifying the poor is given as follows.

Rural households spend their income on different items. We can classify these items as food and non-food expenditures. According to Hussain and Wijerathna (2004) the total expenditure of a household will comprise expenses incurred on items in the following four categories, purchases from the market or the village shopkeeper on a loan basis. The items

that will be included in category (i) will be wheat flour, rice, pulses, maize flour, potato, vegetables, mutton, beef, chicken, fish, eggs, milk, fruit and bread. Category (ii) will include items such as tea, soft drinks, cooking oil, ghee, sugar, salt, and category (iii) will include items such as, soap, electricity charges, telephone charges, cow dung, lighting fuel and water charges. Category (iv) will include items such as clothing, shoes, medical care, treatment for sickness, education, recreation, and expenses for ceremonial occasions, transportation and communication, remittance to family members or relatives, house rent, loan payment, tax, charities, legal disputes, rent for a shop, salary of house servants and other similar expenses. The total expenditure of the household is therefore the sum of all these expenditure components.

According to MOFED (2013), the Ethiopian national absolute poverty line was 3781 birr per annum per adult equivalent in 2010/2011 and has not been revised yet. This makes the zonal absolute poverty line 3781 at the 2011 local prices, under the assumption of no change in the consumption level. MOFED (2013), on the other hand, shows that the real per adult equivalent consumption level changed by 18.94% between 2004/2005 and 2010/2011 for rural *Amhara*. Hence the “zonal poverty” line for the year 2011 was estimated to be 4497.12 Birr. This means that a household is called income poor if its total adult equivalent annual income is less than Birr 4497.12. This poverty line was used to compute poverty head count and related indices. According to Anderson *et al.* (2006), a binary variable base for dividing individuals as poor or non-poor would discard a lot of available information. Using a continuous variable like consumption expenditure per capita exploits more of the information in the data set, since it takes into account consumption differences below as well as above the poverty line. An added advantage, according to them, is that the properties of models focusing on continuous variables are more robust than those on binary variables.

Research works on poverty has tended to stress its multidimensional nature (Bevan and Sseweya, 1995). While this paper is limited to cross-sectional quantitative indicators, it provided as broad a perspective as the survey allows. The study uses consumption based measures of welfare to show direct impact of irrigation on rural households’ poverty. As long as data are reliable and of good quality, and there is consistency in estimation, use of either incomes or expenditures should not be of much concern (Hussain and Wijerathna, 2004). But, this study employed expenditure method as households are expected to more

understate their incomes compared to overstating their expenditure. These are arguably the single most comprehensive indicators of ability to meet wants. As such they are commonly used by the World Bank and others in making poverty assessments (Demery, 1993).

2.2.4. Empirical studies on poverty measurement and its determinants

Appleton (1996) used alternative welfare measures in making poverty assessments. By using descriptive statistics he compared economic and social welfare of men headed and women head households in Uganda. He found that mean private consumption per capita is virtually identical in men-headed households (MHHs) and women-headed households (WHHs). The same applies when consumption is assessed per adult equivalent (equivalence scales). By setting two relative poverty lines, the median and the lower quartile, he found that WHHs are poorer than MHHs on almost all poverty indicators. But the differences were often small. His comparisons of WHHs' and MHHs' food consumption, however, give broadly the same conclusions as comparisons of total consumption. Only in urban areas do WHHs have significantly lower real food consumption per adult equivalent. The Uganda data show women-headed households to be better off on income measures than on consumption measures. Indeed, income per capita is 6% higher for women headed households, a statistically significant difference. Cultivable land is the most important physical asset for the majority of Ugandans. Nonetheless, conditional upon having some land, greater holdings are associated with higher economic welfare.

The effect of social indicators such as education is not very large but it is statistically significant. About 64% of girls aged 7-14 years in WHHs were reported to be attending school at the time of the surveys compared to 67% in MHHs. Enrolment rates for boys were equal across WHHs and MHHs. He also found that women in WHHs are reported to lose more days through illness than those in MHHs, although this difference is not significant. Children in WHHs are reported to be ill for 9% more days than those in MHHs, although this difference is significant only at the 10% level. Women are more likely to be reported ill than men, but this effect is substantial only in WHHs.

Appleton (1996) also identified differences in household welfare by gender and marital status using multivariate analysis. Two different models were estimated. One was an Ordinary Least Squares (OLS) regression of the welfare measure (household consumption per adult equivalent) expressed in logs which provided insights into the determinants of average economic welfare. The second model focuses directly on poverty: that is to say

whether a household's economic welfare falls below the poverty line. Due to the dichotomous nature of the dependent variable (poor or non-poor), a logistic model was used. A priori, the two models are clearly related. The poverty variable is a non-linear transformation of economic welfare. Empirically, there is a reasonable correspondence between the two sets of results. The explanatory variables in both models included dummy variables for the different types of households defined according to the gender and marital status of the head. In addition, a number of other hypothesized determinants of welfare and poverty were included. The variables specifically include: land holdings, remittances, the age and education of the head, household size and dependency ratios, location and season. Households headed by married men were taken as the default group. The results show none of the dummy variables for households with heads of different gender and marital status are significant nor are they collectively significant, as measured by an F-test in the welfare model and a likelihood ratio test in the poverty model.

Ognonna *et al.* (2012) used the Ordinary Least Squares (OLS) and found that education, membership of farmers' group, and production experience affect poverty negatively while dependency ratio promotes poverty in yam farm households in south eastern Nigeria. Sakuhuni *et al.* (2011) using the regression model with method of OLS found that age squared, gender (male), widow, maximum level of education, attaining primary education, employment in any sector except working in the informal sector, migration status, engaged in secondary business, number of sources of income, credit availability and land area cultivated were positively correlated to per capita consumption in Zimbabwe. The same study identified that age and household size were negatively correlated to per capita consumption.

Riley (2008) reviewing different literature, states that the causes of poverty are embedded in the intersection of different inequalities in social relations, such as racism, gender, homophobia, religious, and cultural discrimination. Rose *et al.* (2011) in their study in Zimbabwe used the linear regression (OLS) and found that age squared, sex of household head (male), marital status (widow), maximum level of education, attainment of primary education, employment in any sector except in the informal sector, migration status, engagement in secondary business, number of sources of income, credit availability and cultivated land area positively determine household consumption; while age and household size determine household consumption negatively. El-Osta and Morehart (2008), using the binary probit regression, found that educational attainment of the farm operator is

significant in mitigating poverty when measured on relative basis. Ibrahim and Umar (2008) used the discriminant analysis and found that the most determinants of poverty (in terms of cost of calorie intake) among the farming households in Nasarawa State of Nigeria are household size, number of income sources, number of household members working outside agriculture, and the number of literate male and female members of the household.

Anderson *et al.* (2006), using linear regression model with natural logarithm of consumption as dependent variable, found that household size, dependency ratio, education, and access to agricultural inputs were among the main determinants of per capita consumption in Lao PDR. They found also that geography and ethnicity matters in a sense that the higher poverty incidence among minority households is due to their limited access to productive resources rather than lower efficiency of resource use. His research was based on the theory of production with the sense that what affects the productive capacity of the household affects the consumption too. Mehta and Shah (2006) indicated that the scheduled castes and scheduled tribes, female, old persons, the disabled, and the destitute are the chronically poor in India. Hopkins *et al.* (1999), using binary logistic regression, found that family educational attainment, distance to medical services, extent of agricultural landholdings, family size and reliance on fuel wood for cooking are the most important determinants of poverty in El Salvador.

Apata *et al.* (2010), in their study in rural Nigeria, used the probit model and found that access to micro-credit, education, participation in agricultural workshops/seminars, livestock asset, and access to extension services significantly influence the probability of households' exiting chronic poverty. They also found that female headed households and distance to the market increases the probability of persistence in chronic poverty. Their study was based on household expenditure and the universal poverty line of one US dollar a day.

Ayalneh *et al.* (2005), who made a study on rural poverty found that age of household head, sex of household head, number of oxen owned, land holding per adult equivalent, per-capita income and education of household head are significant in determining household poverty in rural Ethiopia. They concluded, based on the results of the logistic regression, that the probability of a household being poor tends to diminish as age of the

household head increases; and the probability of being poor is higher for male headed households than female headed households when per capita food energy consumption is considered.

Ayalneh *et al.* (2011), in their poverty analysis of eastern Hararghe highlands of Ethiopia, used the ordered probit model where expenditure was used to classify households as extremely poor, moderately poor, slightly non-poor and non-poor, found that poverty is location specific in a sense that it is significantly determined by access to irrigated land and access to non-farm income. They found also that involvement in governance, social and production related networks are strongly associated with the probability of a household being poor. Household size and age of the household were found to affect the household's wellbeing negatively, according to their study.

As it was stated in the section above, poverty is affected by multiple factors. Analyzing the impact of irrigation on farm household poverty based on consumption expenditure is one of the concerns of this study. As the theories of the causes of poverty indicates, this study assumes that individual, cultural, economic, political, geographical and other factors are responsible for the household being poor, but these factors are not expected to equally affect poverty.

2.3. Impact Evaluation

In this section review of theory of impact evaluation, methodological and analytical framework and empirical literature on the impact of irrigation are presented.

2.3.1. Concepts and definition

According to Rogers (2012) impact evaluation investigates the changes brought about by an intervention; and the expected results of an impact evaluation are important part of the evaluation. Thus, impact is defined as the intended and/or unintended, positive and/or negative, primary and/or secondary, direct and/or indirect effects produced by an intervention. Impact evaluation can be undertaken on interventions at any scale. It includes the comparison of a group who received intervention with a group who did not receive the intervention. The major reasons for doing impact evaluation are to learn how to scale up and successfully adapt a successful intervention to suit another context, to decide whether

or not to continue or expand an intervention, and to inform intended beneficiaries about the benefits of the intervention.

2.3.2. Theory of impact evaluation

Development program interventions are typically aimed at changing the behavior or knowledge of households, individuals, and organizations. Underlying the design of the intervention is a theory which is either explicit or implicit with social, behavioural, and institutional assumptions indicating why a particular policy intervention will work to address a given development challenge. Theories partly require reconstruction and articulation. After articulating the assumptions on the effect of an intervention on outcomes and impacts, these assumptions will need to be tested. This can be done by carefully constructing the causal story about the way the intervention has produced results or by formally testing the causal assumptions using appropriate methods (Leeuw and Vaessen, 2009).

According to Trochim (1989) and Rogers *et al.* (2000) interventions are embodiments of theories. They comprise an expectation that the introduction of a program or policy intervention will help ameliorate a recurring social problem; and also they involve an assumption or set of assumptions about how and why program activities and resources will bring about changes for the better. Program or intervention theory can be identified (articulated) and expressed in a graphic display of boxes and arrows, a table, a narrative description, and so on. The methodology for constructing intervention theory, as well as the level of detail and complexity, also varies significantly.

Leeuw (2003) states that methods for reconstructing the underlying assumptions of policy theories include a policy-scientific method, which focuses on interviews, documents, and argumentation analysis, strategic assessment method, which focuses on group dynamics and dialogue as well as elicitation method, which focuses on cognitive and organizational psychology. The overall aim is to reduce the uncertainty about the contribution the intervention is making to the observed results through an increased understanding of why the observed results have occurred (or not) and the roles played by the intervention and other factors. The central question is to what extent changes in outcomes of interest can be attributed to a particular intervention (Leeuw and Vaessen, 2009). Program impact evaluation studies the effect of an intervention on final welfare outcomes, rather than the

program implementation process. More generally, program impact evaluation establishes whether the intervention had a welfare effect on individuals, households, and communities, and whether this effect can be attributed to the concerned intervention.

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. However, two outcomes cannot be observed for the same individual. In other words, only the factual outcome can be observed. Thus, the fundamental problem in any intervention evaluation is the missing data problem (Bryson *et al.*, 2002; Ravallion, 2005). As Baker (2000) explained estimating the impact of a program requires separating its effect from intervening factors which may be correlated with the outcomes, but not caused by the program. To ensure methodological rigor, an impact evaluation must estimate the counterfactual in the absence of baseline data, that is, what would have happened had the intervention never taken place.

2.3.3. Methodological and analytical framework of impact evaluation

According to BIS (2011), impact evaluation seeks to prove that the intervention had an effect (outcome) that would not otherwise have been achieved without the intervention. A successful evaluation is required to take into considerations the objective(s) of the intervention, the target population, the treatment, and the treated and feasible impact evaluation models. It states also that successful impact evaluation methods is judged by its capability of proving causality, measuring the counterfactual and therefore estimate impact. The evaluation result should also be valid and reliable. Validity and reliability are also referred to as robustness. A robust evaluation is one where stringent research and/or statistical techniques have been followed to arrive at valid and reliable results or conclusions.

As far as statistical methods are concerned, the impact assessment methods can be classified as before-and-after and with-and-without. In the before-and-after case, outcomes are recorded before applying the treatment/intervention and after applying the treatment/intervention. The analysis is done by comparing the two results for changes. In the with-and-without case, a group to which a treatment/intervention is given is compared to the group from which the treatment/intervention is withheld. 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 also cases where the design involves matching program participants with a comparable group of individuals who did not participate in the program. This last alternative is called quasi-experimental method (Barnes and Sebstad, 1999). It can be used to carry out an evaluation when it is not possible to construct treatment and control groups through experimental design. These techniques generate comparison groups that resemble the treatment group, at least in observed characteristics.

According to Jalan and Ravallion (2003), a quasi-experimental method is the only alternative when neither a baseline survey nor randomizations are feasible options. The main benefit of quasi-experimental designs is that they can draw on existing data sources and are thus often quicker and cheaper to implement, and they can be performed after a project has been implemented, given sufficient existing data. It includes matching methods, double difference methods and reflexive comparisons. According to Becker and Ichino (2002) Difference in Difference (DID) method entails comparing observed changes in outcome before and after the project for a sample of participants and non-participants. Typically, one collects outcome data of both participants and non-participants using a baseline survey before the program and repeats this survey at some later point after the program is implemented. For this reason, this approach incurs higher costs and spends more time as compared to propensity score approach. Regression Discontinuity Design (RDD) method compares outcomes of a group of individuals just above the cut-off point for eligibility with a group of individuals just below it. 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 (Caliendo and Kopeining, 2005).

Propensity Score Matching (PSM) method is also one of quasi-experimental method to estimate causal treatment effects. PSM is a method to match program participants with non-participants typically using individual observable characteristics. Each program participant is paired with a small group of non-participants in the comparison group that are most similar in the probability of participating in the program (Becker and Ichino, 2002). It matches control groups to treatment groups on the basis of observed characteristics or by a propensity scores; the closer this score, the better the match. 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, e.g. 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. Results from the matching method are easy to explain to policy makers, since the idea of comparison of similar group is quite intuitive.

Becker and Ichino (2002) and Caliendo and Kopeining (2005) proposed that propensity score matching as a way to correct for the estimation effects of the program controlling for the existence of confounding factors based on the idea that the bias is reduced when the comparison is performed using participants and control subjects who are similar as possible.

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, but also imposes arbitrary functional form assumptions concerning the treatment effects and the control variables. PSM, however, does not require a parametric model linking outcomes to program participation (Ravallion, 2005). Thus, PSM allows estimation of mean impacts without arbitrary assumptions about functional forms and error distributions. In PSM one confines attention to the region of common support. Non-participants with a score lower than any participant are excluded but OLS uses the full sample. Research findings show also that impact estimates based on full (unmatched) samples are generally more biased, and less robust to misspecification of the regression function, than those based on matched samples (Ravallion, 2005). For the above aforementioned reasons, PSM was used in this study to measure the impact of irrigation intervention on potato production efficiency and farm household poverty.

2.3.4. Empirical studies on the impact of irrigation

Dillon (2008) explored the contribution of irrigation on welfare of households in Northern Mali. Using difference-in-differences, propensity score matching, and matched difference in differences with a small panel, the study estimated the impact of access to irrigation on poverty, production, and nutrient intakes. The findings suggest that gains in agricultural

production value do not transfer uniquely to household consumption. The study also provided that relying solely on household consumption, may underestimate the welfare gains of irrigation investment by ignoring the household's savings and informal insurance network. The results of their study implied that, while irrigation is an important contributor to poverty alleviation, the magnitude of antipoverty impacts of irrigation varies greatly depending on a range of factors. These include size and distribution of landholdings (equity in land), distribution of available water across farm households and across upstream-downstream locations (equity in water distribution) with proper maintenance of irrigation infrastructure (good infrastructural condition), cultivation/production technology (improved cultivation technology), cropping patterns, and level of crop diversification supported by market infrastructure to facilitate marketing of inputs and outputs.

They reported also that in the studied irrigation systems, where all these conditions prevailed, access to irrigation has strong direct antipoverty impacts. The antipoverty impact of irrigation decreases as one or more of these conditions do not hold. In short, investments in irrigation sectors may not reduce poverty directly in any significant way unless accompanied by other complementary interventions. Overall, the findings of the study implied that improving performance of irrigation systems by improving land and water productivity of crops, diversifying cropping patterns, improving infrastructure and water distribution across locations would help reduce poverty.

Hussain and Wijerathna (2004) undertook comparative assessments and analyses of antipoverty impact of irrigation in 26 selected large and medium-scale canal irrigation systems in six Asian countries: Bangladesh, China, India, Indonesia, Pakistan and Vietnam. Their analysis is based on primary household-level data collected for the 2001-2002 agricultural years from selected irrigation systems, and adjoining rain-fed areas. Their study used poverty head count and poverty gap indices. Their study findings suggested that irrigation has strong linkages with poverty. Irrigation impacts on poverty alleviation both directly and indirectly. Direct impacts are realized through land augmentation impacts of irrigation resulting in improved productivity, employment, incomes, consumption and other social aspects at micro or household level. Poverty incidence is 20-30 percent less in settings with irrigation compared to those without irrigation. Indirect impacts are realized through expansion in economic activities and welfare of population at wider regional or macro levels.

Tekana and Oladele (2011) examined the impact of *Taung* irrigation scheme on the household welfare among sixty sample farmers in the North West Province of South Africa. The relationship between the household welfare and the independent variables were estimated using an ordinary least square regression estimation procedure. The dependent variable used to capture household welfare is per capita expenditure. Per capita expenditure is used as a proxy for per capita income and employed as a measure of welfare. The results of the multiple regression analysis showed that the independent variables relate significantly to knowledge levels of the extension officers. The significant determinants of household welfare amongst farmers were age, gender, educational level, household head type, access to natural capital and socio-economic status. Finally, they concluded that the higher the age, educational, income and socioeconomic status of the farmers and the availability of males on the scheme, the higher the household welfare. The availability of financial and human capital also contributes to a higher household welfare. The male-headed household has a significant relationship to the household welfare while the female and child headed household lower household welfare. Unavailability of natural and physical capital lowers the household welfare of farmers on the irrigation scheme.

Similarly, Kimsum *et al.* (2011) conducted empirical study on the relationship between irrigation and household assets such as durable assets, livestock, farm equipment, cows and buffalo, and pull/plough animals based on data from 220 selected households surveyed during 2008-2010 in Cambodia. Since irrigation is widely seen as being an endogenous variable, the Instrumental Variable Regression Model is used to measure the effect of irrigation on household assets. Empirical results suggested that irrigation is unlikely to have a positive impact on the amount of durable assets, livestock, farm equipment, cows and buffalo and pull/plough animals. However, their analysis indicated that human capital does play a critical role in durable assets accumulation. These results could reflect the fact that irrigation systems in Cambodia do not function well enough to have a significant impact on household assets accumulation. Under these circumstances, they concluded that investment in irrigation should be focussed more on achieving a balance between the expansion of irrigation systems and improvements in irrigation system efficiency, i.e. ensuring the availability of water in both wet and dry seasons, establishing appropriate levels of water for effective irrigation and ensuring equitable water allocation across the regions. Their findings provided further support for the widely held view that increased investment in a combination of human capital and irrigation infrastructure could have a

stronger impact on the amount of household assets than investment in the development of infrastructure alone.

Abonesh *et al.* (2006) analysed the impact of small scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ada Liben district of east Shoa. She employed the Heckman two-step procedure to identify the impact of small scale irrigation on household food security from among possible other household food security influencing factors. The results showed that among the observable hypothesized variables, those that significantly influenced the probability of participating in irrigation farming include nearness to the water source, household size, size of cultivated land, livestock holding, the quality of land owned by a farmer and access to credit. Access to irrigation had significant impact on household food security. The other variables that significantly enhance household food security are experience (as indicated by farmer's age in years), access to extension service, and size of cultivated land.

Getaneh (2011) investigated the impact of selected small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia. He used the Logit model analysis. The results indicate that irrigation development has a profound impact in alleviating poverty. The poverty analysis indicates that a much higher proportion of those who are poor are non-irrigating rather than irrigating households. Thus, the poverty prevalence in non-irrigating households is by far greater than in irrigating households. This suggests that irrigation has an important influence on rural poverty alleviation. The logit model analysis indicates that use of irrigation reduces the probability of a household being poor, controlling for other factors.

In a nutshell, the above empirical studies used different impact evaluation methods to identify demographic, socio-economic, institutional, and marketing characteristics that impede the impact of a given intervention on farm productivity, rural poverty and welfare of households. But, PSM method takes high cumulative weight over the other methods of impact evaluation due to absence of baseline data and that randomization is unlikely.

2.4. Conceptual Framework of the Study

This section presents conceptual framework of the study. It examines the patterns of interrelationships between participation in irrigation, agricultural production efficiency and

farm households' rural poverty. Agricultural productivity in general may be increased in different ways. First, agricultural productivity may be improved through increased use of inputs, usually referred as horizontal expansion. Increasing agricultural productivity using this method requires raising the quantity of inputs used in the production. Though such activities have the potential for productivity enhancement, the method has little application in Ethiopia and other developing countries because of limited resources and restricted access to credit to increase the quantity of inputs. The second method of increasing agricultural productivity is through improving efficiency of resource utilization usually referred to as the improvement approach. This approach requires the improvement of conditions or the removal of some of the existing institutional constraints that hinder farmers from using resources efficiently. Such technique increases productivity by improving the overall efficiency of farmers using the current levels and existing technology. The third source of increasing agricultural productivity and hence economic growth is what is usually referred to as the transformation approach. It is economic growth attained through improvement in technologies (technical change), which includes the use of irrigation, technology packages, such as use of High Yielding Varieties (HYV), use of fertilizers, and the use of agro-chemicals such as herbicides and pesticides. Such technique results in shifting the production frontier upward. The fourth source of economic growth is the impact of the environment in which the production takes place. For example, good weather tends to increase output, but bad weather hinders it (Arega, 2003; Jema, 2006; Headey *et al.*, 2010).

Access to irrigation can contribute to agricultural growth and reduce poverty directly by: increasing farm outputs and incomes; agricultural wage employment; and reducing local food prices and hence improving real net incomes. It can also reduce poverty indirectly via increased rural and urban employment as a result of the multiplier effect on growth in rural and urban non-farm economies. Overall, irrigation water, like land, can have an important income-generating function in agriculture specifically, and in rural settings in general (Hussain and Wajiratina, 2004). This implies increasing agricultural productivity depends on improvement of efficiency in production, and making use of productivity-enhancing technologies such as irrigation, which leads to directly by raising production levels and indirectly by, for example, reducing poverty through raising incomes of farm households, raising employment, lowering the price of food and thereby affecting the food security and wellbeing status of rural households (De Janvry and Sadoulet, 2001). Therefore,

agricultural productivity affects food security directly by increasing the available supply of food, particularly for subsistence households, and indirectly by reducing the shortage of finance of farmers that can be used for the participation in utilization of improved agricultural technologies such as irrigation, increasing production inputs and enhancing efficiency in resource utilization processes.

Moreover, increasing agricultural productivity also has a number of advantages. First, facilitates the flow of resources from one sector to another and contributes to economic growth. Second, a higher level of agricultural productivity results in lower food prices for consumers and a rise in income of producers that increases the welfare of the society and thereby enhancing the economic growth of the country. Third, agricultural productivity growth also improves the competitive position of the sector (Jema, 2006).

However, irrigation utilization, efficiency in production and rural households' poverty are assumed to be affected by a wide range of factors. The various factors can be classified into the following broad categories: socioeconomic characteristics, demographic characteristics, farm characteristics, institutional factors and factors related to marketing characteristics. The factors related to the socioeconomic characteristics include livestock holding, off/non-farm income, education level and family education etc. The factors related to demographic characteristics include age, sex, family size and household size marital status etc. The factors related to farm characteristics include the size of farm, number of plots, and experience of farming, farm distance from home, etc. The institutional factors include use of credit, extension service, and membership in rural institutions. The factors related to the marketing characteristics include inputs and outputs prices, accessibility of market and availability of market information, etc. The detailed schematic description is provided in Figure 5.

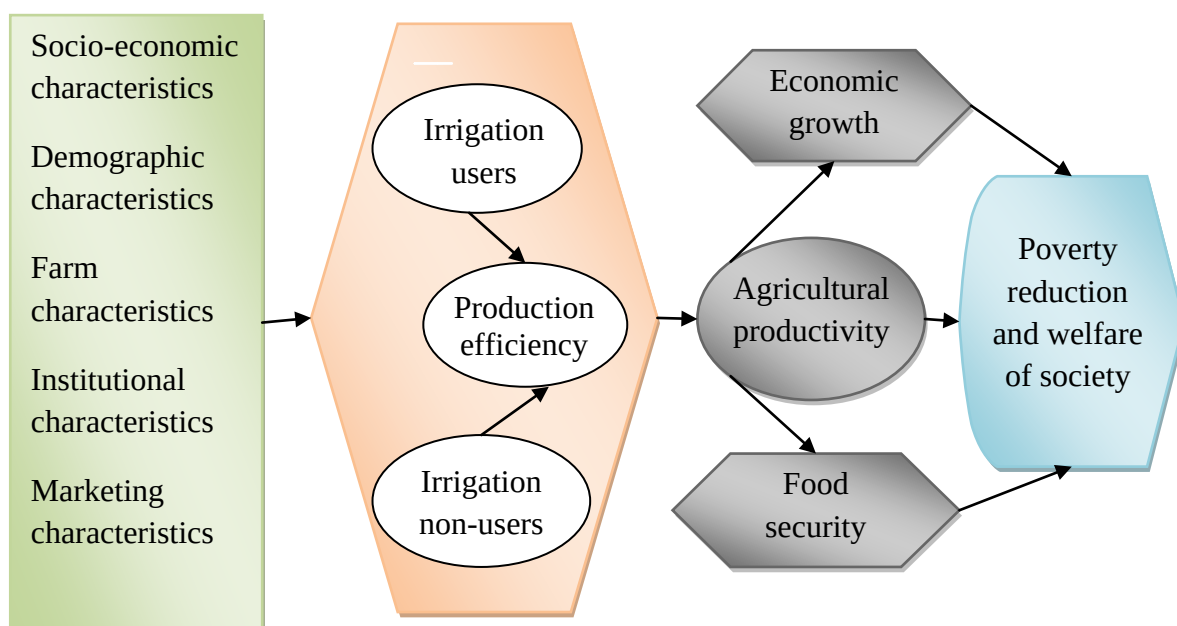


Figure 5. Conceptual framework of the study

Source: Adapted from Hussain and Wajiratina (2004)

3. RESEARCH METHODOLOGY

This chapter gives the details of the methodology used to meet the objectives of the study. It begins with the description of the study area and types and sources of data followed by sampling and the methods of data collection. Then, it describes the methods of data analysis in connection with the relevant literature. The most important variables selected for the study are also discussed in this chapter.

3.1. Description of the Study Area

The study was conducted in east Gojjam zone of the Amhara National Regional State (ANRS), Ethiopia. The administrative center of east Gojaam zone is Debre Markos town, which is located 299 kilometers (km) from Addis Ababa North West direction along the main road to Bahir Dar city, capital of the Regional State. It is one of eleven administrative zones of the ANRS with a total population of 2.153 million of which 90.12 percent live in rural areas and the remaining 9.87 percent are urban dwellers (CSA, 2008). It has also the projected population of 2.614 million for 2017 of which 1.292 million are male and the remaining 1.322 million are females (CSA, 2013). East Gojjam zone has 18 rural districts (woredas) and two town woredas with a total number of 424 administrative kebeles of which 387 are rural and 37 are urban Kebeles. The administrative kebeles are further divided into villages called 'Gott'. It is situated in the southern part of the region with an area of 14,009.75 km². The zone has asphalt and all weather roads which interconnect the entire 20 woredas with exits to Addis Ababa, Mota, and the regional capital, Bahir Dar. It is bordered with Oromia region in the south, with west Gojjam zone in the west, south Wollo zone in the east and with south Gonder in the north (EGZOFED, 2012). The zone is found approximately between 10° 15' and 11° 14' N and between 37° 3' and 38° 32' E. This area is specifically selected from the zones for the study on the basis of its high extent of cereals, vegetables and root crop production.

The mean annual rainfall ranges between 900 and 1800 mm and annual temperature of 8 to 27 °C. Large amount of rainfall occurs during months of June to August. The rainfall is of unimodal pattern and much of the rainfall occurs in the months of June, July, August and September (locally known as 'kiremt' season). The driest months are November, December, January and February (locally known as *bega* season). Livelihoods in the study

area are primarily agricultural. The study area is typical of the high-potential, intensively cultivated, mixed farming, and ox-plough cereal belt in the north-western Ethiopian highlands. That is, like other parts of the region, mixed farming is predominantly practiced by smallholders as a major source of livelihood. The overall farming system is strongly oriented towards grain production and is dependent on the use of oxen for land preparation and traditional grazing on communal lands. Its topography is estimated to be 48% mountainous, 12% rugged and 40% gentle slope. It has also four agro climatic zones namely low land (800-1500 masl) , midland (1500-2300 masl), highland (2300-3200 masl) and extreme highland (3200-4070 masl) covering 16%, 37%, 45% and 2% of the total area, respectively (EGZOFED, 2012).

The major crops vary and follow altitude zones. The major crops grown in the zone are cereals such as *teff*, wheat, barley, maize; pulses such as beans, peas, chickpea and lentils; root crops such as potatoes, onion and carrot, and vegetables such as green pepper, tomatoes and cabbage among others. Generally, the crop types are divided in to two: subsistence crops and cash crops. Wheat, *teff*, barley, oats, maize, peas, faba beans, root crops and vegetables are some of the subsistence crops where as *Neug* (*Guizotia sps*), flax, rapeseed etc. are some of the cash crops. In the study area, land preparation starts in October and continues up to April with two to three frequency of ploughing. Farmers have the tradition of repeatedly ploughing the land until the soil is fine and this facilitates moisture retention and seed emergence. 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 (EGZOARD, 2013).

In Ethiopia, close to half of the country's potato production comes from Amhara region. Potato is an important food security and a hunger reliever crop in Amhara region and in several other parts of the country by virtue of its ability to mature in advance of most other crops at the time of critical food need. In recent years, the production of this crop is expanding because of availability of improved technologies, expansion of irrigation, increased market value, and production systems diversification, produced under rainy season, irrigation, residual moisture, short rains and recessed land. To this end, the livelihood of thousands of highland farmers in the country/Amhara region in general and in east Gojjam zone in particular relies on potato production. But, in spite of its growing

importance to Ethiopia's food security, the introduction of new technologies and infrastructural development to increase the production and productivity of this crop remains very low. In Amhara region, potatoes are often grown in rotation with other crops such as maize, rapeseed, and faba beans during the *meher* (main cropping) season. Now, the crop is rapidly expanding to irrigable areas. For instance, in *Koga* irrigation project, out of the total 5,060 ha of land covered by different crops so far, 2042 ha (41%) was entirely covered by potatoes in 2012/13 production year (ARARI, 2013).

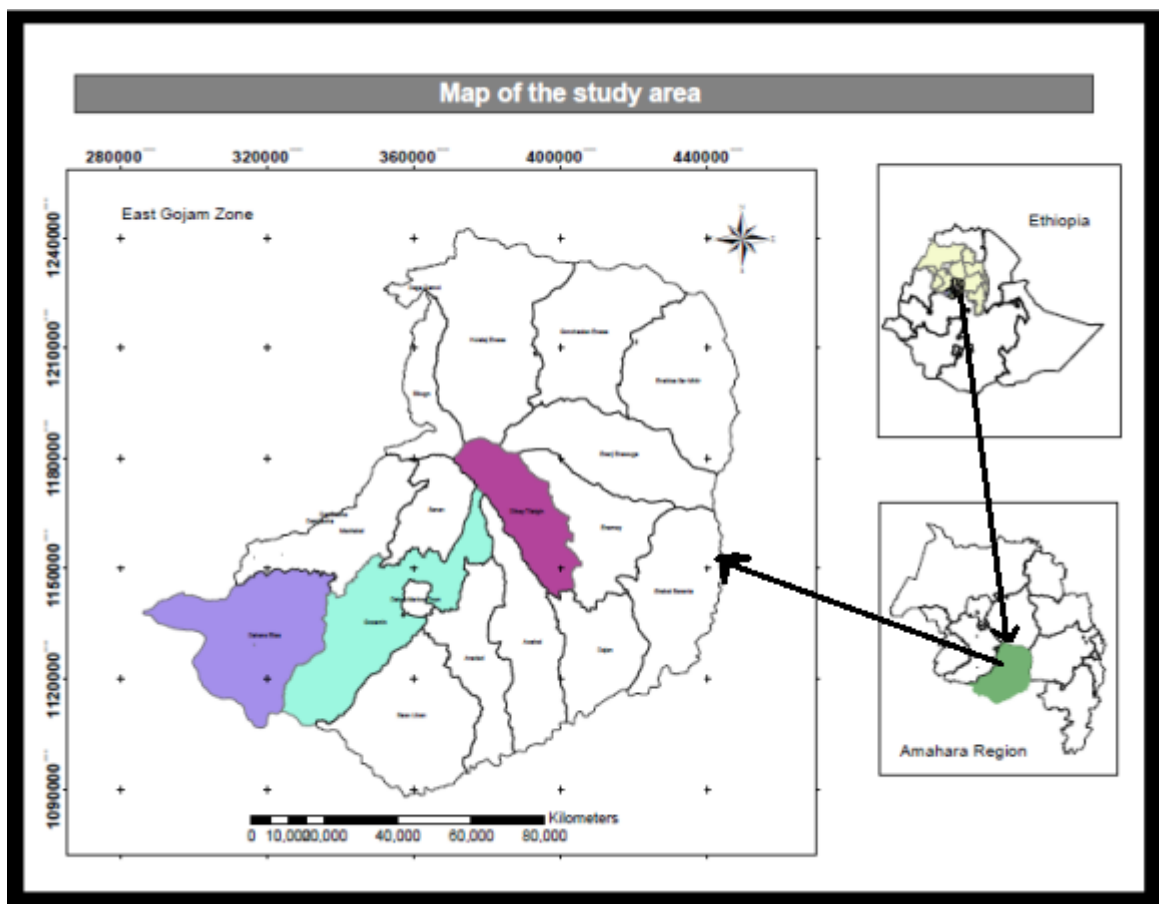


Figure 6. Physical map of the study area and districts

Source: EGZOFED (2012)

3.2. Data Types, Sources and Methods of Data Collection

In this study, both primary and secondary data were used. Secondary data were collected from official reports and documents of government and non-government organizations. These include annual, semi-annual and quarterly reports, and publications. Primary data were gathered from both irrigation users and non-user farm households in the study area.

In order to achieve the objectives of this study, data were collected at different levels using different approaches. First, background information was gathered in east Gojam zone for the preparation of the proposal. Different secondary data from Central Statistical Agency (CSA) publications, East Gojam Zone Finance and Economic Development and East Gojam zone Agricultural and Rural Department, selected irrigation schemes and their respective districts and related organizations were collected and used. These data include the general description of the zone and its irrigation schemes.

A cross sectional primary data were collected using a structured questionnaire during April- May, 2014 using face-to-face interview. Enumerators who know the local language (Amharic) with education levels of diploma up to first degree were recruited and trained on how to collect data. The enumerators were involved in pre-testing to reshape both the content and format of the questionnaire. Household level primary data were collected with the questionnaire prepared in the local language with its English version given in Appendix 7.1. The questionnaire was used to gather data on farm and household socio-economic characteristics. It includes data about the occupation, farm input use and output, participation in irrigated agriculture, work experience in agriculture, distance of residence and crop field from the nearest market center, number of visits by extension workers, housing/shelter conditions, accesses and uses of facilities by the households, farm credit, livestock ownership, crop production and food security, household food and non-food expenses, participation in off/non-farm activities, participation of the households in social organizations, household head sex, age, marital status, education of the household head, family size, fragmentation, total cultivated land, agro-ecology and eucalyptus tree.

3.3. Sampling Method and Sample Size

It is important to have a representative sample in order to be able to make proper inferences about the population of the study area. Thus, it is necessary to determine a representative sample size based on scientific criteria. Consequently, the following formula was applied to calculate the total sample size (n) needed following Yamane (1967).

$$n = \frac{N}{1+N(e)^2} \quad (7)$$

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 number of total households of selected *kebeles* with the irrigation schemes. Then, the minimum sample size (n) can be determined by choosing the value of $e = 0.05$ for the 95% level of significance.

The study used multi-stage sampling procedures for selecting sample households. In the first stage, lists of irrigating districts were prepared together with experts from the zone agricultural office. The criteria for inclusion in the list include availability of irrigation intervention programs embracing potato producers in the districts. At this stage, from ten irrigating districts three districts were randomly selected. The selected districts were, namely, Debay Tilat Gin, Gozamin and Debre Elias. In the second stage, a list of irrigating lower administrative divisions (*kebeles*) in which irrigation has been practiced was prepared. From a total of nine *Kebeles* having access to irrigation, four irrigating *kebeles* were selected using simple random sampling technique. The selected *kebeles* were, namely, Wodeb Eyesus and Arajo Kulkual from Debay Tilat Gin district, Asam Abo from Gozamin district and Yeguarat from Debre Elias district. The respective irrigation schemes from these selected irrigating *kebeles* were Muga-Wodeb Eyesus (medium scale irrigation scheme) which was developed by CIDA in 2006 and Muga-Arajo Kulkual which was developed by SEARAR (Sustainable Environmental and Agricultural Rehabilitation for Amhara Region) in 1998, Kulech which was developed by Ethiopian Aid in 2007 and Tied which was developed by CIDA in 2007 are small scale irrigation schemes (EGZOARD, 2013).

In the final stage, lists of potato producing households using irrigation and potato producers who do not have access to irrigation or not using irrigation at all were prepared for each selected irrigated *kebele*. Sample households were selected using systematic random sampling based on probability proportional to size. Accordingly, a total of 288 sample households of which 129 households producing potato using irrigation and 159 households producing potato without using irrigation were selected on which primary data were collected for this study. Allocation of sample size by districts and *Kebeles* is presented in Table 1.

Table 1. Frequency distribution of the sample in districts and *kebeles*

District (<i>Kebele</i>)	Total household			Number of potato producer households			Sample size		
	Irrigating	Non- irrigating	Total	Irrigating	Non- irrigating	Total	Irrigating	Non- irrigating	Total
Gozamin (Asam Abo)	255	901	1156	71	207	278	35	43	78
Debre Elias (Yeguarat)	212	829	1041	60	190	250	32	39	71
Debay/Tilat (WodebEyesus)	333	952	1285	93	219	312	39	49	88
(Arajo Kulkual)	153	603	756	43	139	182	23	28	51
Total	953	3285	4238	267	755	1022	129	159	288

3.4. Methods of Data Analysis

In this study, both descriptive statistics and econometric models were used. Descriptive statistics analysis makes use of mean, variance, standard deviation, proportion, t and χ^2 -tests. Descriptive statistics analysis was employed to describe and compare participant and non-participant farm households in terms of farm characteristics, socio-economic and poverty status. Analyses of efficiency and its determinants, impact of irrigation farming on potato production efficiency and improvements in welfare of households were carried out using econometric methods. Stochastic Frontier Cobb-Douglas Production and Cost Functions, tobit model and Propensity Score Matching analytical techniques were employed to analyze efficiency, determinants of efficiency and impact of irrigation farming on potato production efficiency and households' rural poverty, respectively.

3.4.1. Efficiency analysis

3.4.1.1. Specification of the stochastic frontier model

The analysis of production function was carried out following the economic concept depicted by Coelli *et al.* (2005). A production function is a model that relates output to a set of inputs and conditioners; it is output explained by the use of variable inputs (such as, labor, land, fertilizer, seed, oxen, etc.), and other conditioning factors as productivity shifters. Therefore, a production function model is specified as:

$$\text{Output} = f(\text{Land, Labor, Capital, Productivity shifters}) \quad (8)$$

That is, a household uses amounts of N inputs (in this case land, labor, seed, fertilizer, oxen power) to produce output. The technological possibilities of such a household can be summarized using the production function $Y = f(\mathbf{X}, \mathbf{Z})$, where Y represents output, $\mathbf{X} = (X_1, X_2, \dots, X_N)$ is an $N \times 1$ vector of inputs and $\mathbf{Z} = (Z_1, Z_2, \dots, Z_M)$ is an $M \times 1$ vector of productivity shifter variables including household characteristics, socioeconomic and institutional support services.

Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function model of the form:

$$Y_i = f(X_i; \beta) + v_i - u_i \quad (9)$$

Where Y_i measures the quantity of potato output of the i^{th} household, X_i is a vector of the inputs used by i^{th} household β is a vector of unknown parameters, $f(X_i, \beta)$ is a suitable production function. The random error v_i can be positive or negative and so the stochastic frontier outputs vary about the deterministic part of the model, $\exp(X; \beta)$. v_i s are assumed to be independently and identically distributed $N(0, \sigma_v^2)$ random errors, independent of the u_i s; and the u_i s are non negative random variables, associated with technical inefficiency in production, and are assumed to be independently and identically distributed as half-normal, $u \sim N(0, \sigma_u^2)$. The maximum likelihood estimation of the equation nine yields estimators for β and λ which measures the effect of technical inefficiency in the variation of observed output, $\gamma = \frac{\lambda^2}{1 + \lambda^2} = \frac{\sigma_u^2}{\sigma^2}$ where

$$\lambda = \frac{\sigma_u}{\sigma_v} \geq 0 \text{ and } \sigma^2 = \sigma_u^2 + \sigma_v^2.$$

The λ parameter has a value between 0 and 1. A value of zero for λ indicates that the deviations from the frontier are due entirely to noise, while a value of one would indicate that all deviations are due to technical inefficiency. The parameter σ_u^2 is the variance parameter that denotes deviation from the frontier due to inefficiency; σ_v^2 is the variance

parameter that denotes deviation from the frontier due to noise; and σ^2 is the variance parameter that denotes the total deviation from the frontier. The parameters of Stochastic Frontier Analysis (SFA) can be estimated using the maximum likelihood estimation techniques and the measure of technical efficiency (TE) must have a value between zero and one. The maximum likelihood estimation of the assumptions made on the statistical distributions of v and u , make it possible to calculate the conditional mean of u_i given:

$$\varepsilon_i = v_i - u_i$$

This method helps to decompose deviation of the actual observed potato output from the estimated frontier into random variations and inefficiency. Hence,

$$u_i = Z_i\delta + w_i \quad (10)$$

Where,

Z_i is a vector of variables that explain inefficiency of i^{th} household. δ is a vector of unknown coefficients that are to be estimated in the model, and $w_i \geq -Z_i\delta$ to ensure that $u_i \geq 0$ (Battese and Coelli, 1995).

The most common output-oriented measure of technical efficiency (TE) is the ratio of observed output (Y_i) to the corresponding stochastic frontier (potential) output (Y_i^f) (Coelli, 2005):

$$TE = \frac{Y_i}{\exp(X_i'\beta + v_i)} = \frac{\exp(X_i'\beta + v_i - u_i)}{f(X_i'\beta) \exp v_i} = \exp(-u_i) \quad (11)$$

The production relationship can be expressed in several functional forms such as linear, polynomial, Cobb-Douglas and translog functional forms. A production function $Y = f(X_1; X_2, \dots, X_n)$ is a Cobb-Douglas production function if it can be written in the form:

$$Y = AX_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} \dots X_n^{\beta_n} \quad (12)$$

Where, Y = Total output, X_i 's are physical inputs, β_i 's are the output elasticities of physical inputs and A is total factor productivity.

The analysis of efficiency was carried out following the Aigner *et al.* (1977) method of estimating the stochastic frontier production function provided in equation (9). In this

study, the parametric specification of frontier in the Cobb-Douglas form for one output and five inputs is given by:

$$\log Y_i = \beta_0 + \sum_{j=1}^5 \beta_j \ln X_{ji} + v_i - u_i \quad (13)$$

$$= \ln Y_i = \beta_0 + \beta_1 \ln land + \beta_2 \ln labor + \beta_3 \ln fertilizer + \beta_4 \ln seed + \beta_5 \ln oxen + v_i - u_i$$

Where,

Y_i is the total quantity of potato produced in kilogram by the i^{th} household;

X_1 represents the area under potato (in hectares) by the i^{th} household;

X_2 represents amount of labor (family, hired and exchange labor) used for potato production (person-days) by the i^{th} household;

X_3 denotes the amount of fertilizer (in kilogram) applied by i^{th} household for potato production;

X_4 denotes the amount of seed (in kilogram) used by i^{th} household on land allocated for potato production of the i^{th} household;

X_5 denotes oxen power used by the i^{th} household for potato production (oxen-day):

β_0 is intercept

β_i is vector of production function parameters to be estimated.

v_i 's are assumed to be independently and identically distributed $N(0, \sigma_v^2)$ random errors, independent of the u_i s; and

u_i 's are non-negative random variables, associated with technical inefficiency in production, and are assumed to be independently and identically distributed as half-normal,

$$u \sim |N(0, \sigma_u^2)|.$$

Then, estimation of TE for individual household is predicted by obtaining the ratio of the observed production values to the corresponding estimated frontier values. The value achieves its maximum feasible value if and only if $TE_i = 1$ otherwise, $TE_i < 1$. The TE for the i^{th} farmer can be computed as:

$$TE = \left[\frac{\log Y_i = \beta_0 + \sum_{j=1}^5 \beta_j \ln X_{ji} + (v_i - u_i)}{\log Y_i = \beta_0 + \sum_{j=1}^5 \beta_j \ln X_{ji} + v_i} \right] \quad (14)$$

Before fitting the Cobb-Douglas stochastic production function, all data on each variable were transformed into natural logarithms (Table 2).

3.4.1.2. Variables definition and hypotheses for technical efficiency analysis

The dependent variable: The dependent variable in production function model is total potato output in kilogram. It is influenced by a number of farm inputs. The effects of independent variables or inputs have been hypothesized as follows:

Land size: This refers to the area of land in hectare planted with potato by the i^{th} household. It is one of the important fixed inputs in agricultural production, and scarce commodity in Ethiopia. The higher the land size is the better the household's ability to produce sufficient amount of crop output to support family (Hopkins *et al.*, 1999; Ayalneh *et al.*, 2005).

Labour: Aggregated family, hired and exchange labour used in potato production was measured in man-days. A person-day refers to an average man working for eight hours per day. Labour asset includes terms for the number of adults in a household and the number of days of labor paid. The number of adults is of particular importance, because farm households rely primarily on family labor, especially for key tasks such as clearing farm, planting and harvesting crops. The hired labor variable is included to account for the effects of labor market, which can offset household labor scarcity, particularly at times when labor demand peaks during clearing, planting and harvesting. As a substitute or complement to family labor, optimal days of labor hired should lead to potato output (Stephen, 2004).

Seed: Potato tuber that is used by the i^{th} household was measured using kilogram. Case study by Reardon *et al.* (1997) describes seed as one of the most important determinant of production. Thus, the level of use of seed was expected to be positively correlated to potato output.

Fertilizer: The use of fertilizer for potato production measured in kilogram is regarded as a key factor for increasing potato output. A positive association was expected between potato output and fertilizer use (Otitoju and Arenne, 2010).

Oxen power: The amount of draught power used for potato production was taken by considering the number of oxen-days per hectare used. Animal traction has historically been associated with potential benefits of increasing area cultivated, increasing land yield through improved seed bed preparation, deeper ploughing, more timely planting and weeding, moisture conservation, and reducing drudgery (Pingali *et al.*, 1989). In this study, animal traction has been measured by the number of oxen-days used for potato production. It is hypothesized to have a positive effect on potato output.

Table 2. Definitions of variables included in technical efficiency estimation

Variable	Description
Dependent variable	
Ln (Potato output)	Log of total potato output (in kilogram) obtained from inputs used
Independent variables	
ln(Land)	Log of land used for potato production (in hectares)
ln(Labor)	Log of labor used in potato production in person-days*
ln(Fertilizer)	Log of fertilizer used in potato production in kilogram
ln(Seed)	Log of potato tuber seed used (in kilogram)
ln(Oxen)	Log of oxen power used in potato production in oxen-days*

Note: *A person-day and oxen-day are equivalent to 8 working hours in the study area

3.4.1.3. Specification of model for allocative efficiency analysis

For the farmer to realize allocative efficiency there should be an optimal combination of inputs so that output is produced at minimal cost and profit could be increased by simply reallocating resources. Therefore, the farmer has to choose a combination of inputs to be used in right proportions and technically efficient at low prices so that output is produced at minimal costs. The objective of the producer is to maximize profit either by increasing the quantity of output Y produced or by reducing the cost of producing Y. This study followed the assumptions to maximize profit as farmers choose the best combination (low costs) of inputs to produce profit maximizing output level. If a firm is technically and allocatively efficient, it is said to be cost effective (Coelli *et al.*, 2005).

The estimation of allocative efficiency was achieved using the Cobb-Douglas cost function analysis. To maximize profit from potato production, famers have to choose the best

combination of inputs given the prices of inputs and output. For this study, allocative efficiency was measured or estimated from single output (potato) and five inputs Cobb-Douglas cost function. The five inputs were land, labor, chemical fertilizers, seed and oxen used in potato production. These are the conventional inputs commonly used in stochastic frontier production function analysis. It is standard practice to include only the conventional inputs (land, labor and capital) in frontier analysis (Arega *et al.*, 2006).

The above stochastic frontier production function estimated using equation (9) is only appropriate for measuring TE. The measurement of allocative and economic efficiencies can be investigated through applying Efficiency Decomposition Techniques. The technique that work under the framework of SFA was first proposed by Kopp and Diewert (1982) and latter developed by Bravo-Ureta and Rieger (1991). The method is used to decompose the overall efficiency into technical and allocative efficiencies and is generally based on the duality between production and cost functions. The parameters of the stochastic frontier production function are actually used to derive the parameters of the duality cost function. Let the stochastic frontier production function is redefined into original form in Equation (9) above as:

$$Y_i = f(X_i; \beta) + v_i - u_i \quad (15)$$

If v_i is now subtracted from both sides of Equation (9), we obtain

$$Y_i^* = f(X_i; \beta) - u_i = Y_i - v_i \quad (16)$$

Where Y_i^* is the i^{th} households's observed output adjusted for the statistical noise captured by v_i . $f(\cdot)$ is the deterministic frontier output, and u and v are, respectively, the inefficiency and random component of overall deviation from the frontier. Adjusted output Y^* is used to derive the technically efficient input vector, X^* . The technically efficient input vectors form the basis for deriving the technical efficiency measures by taking the ratio of vector of the norms of the efficient and observed input quantities while the adjusted output is used to derive allocative and economic efficiencies employing the dual cost frontier function that is analytically derived from the stochastic frontier production function. Assuming that the production function in Equation (9) is self-dual (i.e. Cobb-Douglas Production Function), the corresponding parameter of the dual cost frontier can be derived algebraically and written in a general form as:

$$\ln C_i = C(W_i, Y_i^*; \alpha) \quad (17)$$

where C_i is the minimum cost of the i^{th} household associated with output, Y_i^* , W_i is a vector of input prices for the i^{th} household, and α is a vector of parameters to be estimated. The economically efficient input vector for the i^{th} household, X_i^e , is derived by applying Shephard's Lemma and substituting the households' input prices and adjusted output level into the resulting system of input demand equations:

$$\frac{\partial C_i}{\partial W_n} = X_i^e(W_i, Y_i^*; \alpha) \quad (18)$$

where α is a vector of parameters, $n = 1, 2, \dots, N$ are inputs. The observed, technically efficient, and economically efficient costs of production of the i^{th} household are equal to $W_i^t X_i$, $W_i^t X_i^t$ and $W_i^t X_i^e$, respectively. These cost measures are used to compute (TE) and overall productive or economic efficiency (EE) indices for the i^{th} household as follows:

$$TE_i = \frac{w_i^t X_i^t}{w_i^t X_i} \quad (19)$$

$$EE_i = \frac{w_i^t X_i^e}{w_i^t X_i} \quad (20)$$

Following Farrell (1957) the allocative efficiency (AE) index can be derived from equations (19) and (20) as:

$$AE_i = \frac{w_i^t X_i^e}{w_i^t X_i^t} \quad (21)$$

Since Cobb-Douglas production function is self dual, the dual cost frontier for the farm households can be estimated. Following Bravo-Ureta and Rieger (1991), using efficiency decomposition technique shown in Equation (9), the study computed the dual cost frontier in Equation (21) based on the estimated production frontier in Equation (13) and this forms the basis for computing the EE and AE of potato production. Thus, to estimate allocative efficiency, the following Stochastic Frontier Cobb-Douglas Dual Cost Function was applied:

$$\begin{aligned} \ln C_i &= \beta_0 + \sum_{i=1}^n \beta_i \ln W_i + v_i + u_i \\ &= \ln C_i = \beta_0 + \beta_1 \ln w_R + \beta_2 \ln w_L + \beta_3 \ln w_F + \beta_4 \ln w_S + \beta_5 \ln w_O + \beta_6 \ln Y_i^* + (v_i + u_i) \end{aligned} \quad (22)$$

Where C_i is minimum cost of potato production of the i^{th} household in Birr; Y_i^* is total potato output in kilogram which is also represented in X_i ; W_i 's are prices of inputs: W_R is seasonal rental value of a hectare of land estimated at market price; W_L is wage rate at market price in Birr, W_F is price of fertilizer at market price in Birr, W_S is price of potato seed at market in Birr, and W_O is price of oxen day estimated at market price in Birr. β_o and β_i are parameters to be estimated. v_i and u_i are as specified earlier but with positive sign of the inefficiency term since inefficiency factors raise the cost of production. Before fitting the Cobb-Douglas cost function, all data on each variable were transformed into natural logarithms (Table 3).

Table 3. Definition of variables included in cost frontier function

Variable	Description
Dependent variable	
ln (total cost of production)	Log of total input cost for the i^{th} household in Birr
Independent variables	
ln (price of land)	Log of the seasonal average rental price of a hectare of land used in potato production in Birr of the i^{th} household
ln (price of labor)	Log of the wage rate per person day in Birr for labor used in potato production of the i^{th} household
ln (price of fertilizer)	Log of price of fertilizer per kilogram in Birr used on potato farm of the i^{th} household
ln (price of potato seed)	Log of price of potato seed used in kilogram in Birr of the i^{th} household
ln (price of oxen)	Log of price of oxen used for potato production per oxen days in Birr of the i^{th} household
ln (total output)	Total potato output in kilogram of the i^{th} household

Economic efficiency was found by multiplying technical efficiency by allocative efficiency of potato production.

3.4.2. Factors affecting production efficiency

3.4.2.1. Specification of tobit regression model

To identify the factors affecting efficiency in Equation (9), tobit model was separately estimated from the coefficients of farm input variables. Given the level of technical and allocative efficiencies derived from Equations (14) and (21), respectively and the specified X vector efficiency explanatory variables (Table 4), the coefficients of efficiency variables were separately estimated from the coefficients of input variables. That is, a second stage procedure was used where the estimated efficiency scores are regressed on selected

explanatory variables using tobit model with non-zero censoring point. Following Battese and Coelli (1995) as given in Equation (10), the linear form of the equation is given as:

$$U_i = Z_i\delta + w_i \quad (23)$$

Where, Z_i is a vector of variables that explain efficiency of i^{th} household. δ is a vector of unknown coefficients that are to be estimated in the model, and $w_i \geq -Z_i\delta$ to ensure that $U_i \geq 0$.

The dependent variable (efficiencies) in this case assumed minimum non-zero efficiency index as lower limit and maximum efficiency index as upper limit (censored). Thus, the investigation of factors influencing technical, allocative and economic efficiencies of irrigation user and non-user households is carried out by estimating tobit model and the tobit model is formulated as:

$$y_i^* = \beta_o + \sum \beta_m X_{jm} + \mu_j \quad (24)$$

Denoting y_i as the observed variables:

$$y_i = \begin{cases} 1 & \text{if } y_i^* \geq 1 \\ y^* & \text{if } 0 < y_i^* < 1 \end{cases} \quad (25)$$

Where, y_i^* is latent variable representing the efficiency of household j , β is a vector of unknown parameters, X_{jm} is a vector of explanatory variables m ($m = 1, 2, \dots, k$) for household j and μ_j is an error term that is independently and normally distributed with mean zero and variance σ^2 (Maddala, 1999).

The distribution of dependent variable in Equation (25) is not normal distribution because values of TE, AE and EE vary between 0.22 to 0.92, 0.29 to 0.95 and 0.06 to 0.87, respectively (Table 15). The ordinary least squares (OLS) estimation will give biased estimates (Maddala, 1999). Therefore, the alternative approach is using the maximum likelihood estimation which can yield the consistent estimates for unknown parameters vector. Following Maddala (1999), the likelihood function of this model is given by:

$$L\left(\beta, \frac{\sigma}{y_j}, X_j L_{1j}, L_{2j}\right) = \prod_{y=L_{1j}} \varphi\left(\frac{L_{1j} - \beta' X_j}{\sigma}\right) \prod_{y_j=y_j^*} \frac{1}{\sigma} \phi\left(\frac{y_j - \beta' X_j}{\sigma}\right) \prod_{y_j=L_{2j}} 1 - \varphi\left(\frac{L_{2j} - \beta' X_j}{\sigma}\right) \quad (26)$$

where L_{1j} is lower limit and L_{2j} is upper limit and where $\phi(\cdot)$ and $\varphi(\cdot)$ are normal and standard density functions. In practice, since the log function is monotonically increasing function, it is simpler to work with log of likelihood function rather than likelihood function and the maximum values of these two functions are the same (Greene, 2003).

The regression coefficients of the tobit model cannot be interpreted like traditional regression coefficients that give the magnitude of the marginal effects of change in the explanatory variables on the expected value of the dependent variable. In a tobit model, each marginal effect includes both the influence of explanatory variables on the probability of dependent variable to fall in the uncensored part of the distribution and on the expected value of the dependent variable conditional on it being larger than the lower bound. Thus, the total marginal effect takes into account that a change in explanatory variable will have a simultaneous effect on probability of being efficient and value of efficiency score.

McDonald and Moffitt (1980) proposed a useful decomposition of marginal effects that was extended by Gould *et al.* (1989). From the likelihood function of the model stated in equation (26), Gould *et al.* (1989) indicated the equations of three marginal effects as follows:

- i) The unconditional expected value of the dependent variable

$$\frac{\partial E(y)}{\partial X_j} = [\varphi(Z_U) - \varphi(Z_L)] \frac{\partial E(y^*)}{\partial X_j} + \partial \left[\frac{\varphi(Z_U) - \varphi(Z_L)}{\partial X_j} \right] + \frac{\partial(1 - \varphi(Z_U))}{\partial X_j} \quad (27)$$

- ii) The expected value of the dependent variable conditional upon being between the limits

$$\frac{\partial E(y^*)}{\partial X_j} = \beta_m \cdot \left[1 + \frac{\{Z_L \phi(Z_L) - Z_U \phi(Z_U)\}}{\{\{\varphi(Z_U) - \varphi(Z_L)\}\}} \right] - \left[\frac{\{\phi(Z_L) - \phi(Z_U)\}^2}{\{\varphi(Z_U) - \varphi(Z_L)\}^2} \right] \quad (28)$$

- iii) The probability of being between the limits

$$\frac{\partial[\varphi(Z_U) - \varphi(Z_L)]}{\partial X_j} = \beta_m \cdot [\phi(Z_L) - \phi(Z_U)] \quad (29)$$

where $\varphi(.)$ = the cumulative normal distribution

$\phi(.)$ = the normal distribution function

$Z_L = \beta' X / \sigma$ and $Z_U = (1 - \beta' X) / \sigma$ are standardized variables that came from the likelihood function given the limits of y^*

σ = standard deviation of the model

3.4.2.2. Specification of efficiency model variables

Dependent variable: Dependent variable in tobit model is potato production efficiency. This study used efficiency scores as a dependent variable in the tobit model to identify factors that determine it. The socio-economic, demographic and institutional support service variables hypothesized to influence potato production efficiency and explanation for their expected effects is presented as follows.

Agro-ecology: The agro-ecological variable takes values 1 and 0 for *dega* (highland) and *woynadega* (mid-altitude area), respectively. *Dega* refers to area with altitude range of 2, 300 - 3, 200 masl and *woynadega* ranges from 1, 500- 2, 300 masl (EGZOARD, 2012). The households in *dega* are expected to have relatively small and more degraded landholdings than those in *woynadega*. Therefore, this variable was expected to have a negative or positive effect on potato production efficiency.

Access to irrigation: It is an opportunity to make use of irrigation water. It refers to households that use irrigation water only to produce potato in dry seasons. It is a dummy variable which assumes value 1 if the household head has access to potato irrigation and zero otherwise. Efficiency is expected to be high due to irrigation. That is, access to irrigation can positively contribute to potato production efficiency (Arega and Reshid, 2005).

Household head sex: Dummy variable that takes a value 0 for female headed and 1 for male headed households. Female headed households are poorer than the male headed households for various reasons. Female headed households might have socio-economic, cultural and other forms of dominations that make them inefficient in potato production.

Farm credit: It measures the amount of credit obtained from the lending institutions in Birr per year. Credit injects additional funds into a farming system, which should raise incomes to pay for loans. There is farm credit packages designed to promote crop production including potato in the study area. Credit is often used for buying cattle and farm inputs. Since credit obtained is an important source of financing the agricultural activities of farm households, it is expected that households who have obtained credit sources are more efficient than others (Stephen, 2004; Heady *et al.*, 2010).

Education of the household head: Refers to the household head's years of schooling completed. This variable is included in order to capture the effect of human capital on potato production efficiency. In general, education will have a positive effect on efficiency because households who attended some level of education are expected to be active in looking for updated agricultural information (Arega and Rashid, 2005; Wambui, 2005).

Family size: This continuous variable represents the total number of adult equivalent family members. Family size might have positive effect in raising the efficiency of the household in potato production. Since labor is the main input in crop production as the household has large family size, it would manage potato plots on time. Thus, family size is expected to have a positive influence on efficiency of the households in potato production (Aye and Mungatana, 2011).

Frequency of extension contact: Refers to number of days an advice was given to farm households by local extension agents. In other words, it refers to number of days the household received advice from extension agents in a year. Farm households with more number of contacts with extension agents are expected to score high efficiency (Khudu and Ahmed, 2006).

Livestock holding: This variable was measured in terms of tropical livestock unit (TLU) and it reflects the total livestock the farmer owns. Zingore *et al.* (2009) indicated that livestock significantly contributes to crop productivity through provision of manure and traction power is a major factor in determining households' choice of crops and production methods. Efficiency is expected to increase with the number of livestock holding.

Farming experience: Refers to whether the head of a household had previous agricultural experience. Length of farming experience in farming is included to capture the effects of learning locally appropriate agricultural techniques by experimentation and experience. Farming experience of the household head measured in years is a continuous variable used to capture the general experience (managerial ability) that increases efficiency (Fernandez and Nuthall, 2009). Experience can also reflect the capacity the farm operator has to engage in farming activities. Over time, households experiment with different farming techniques. In this regard, it is assumed that experienced households are more efficient.

Off/non-farm income: This is treated as earnings in Birr households receive per year other than their own potato farm activities. Being involved in off/non-farm activities may have both negative and positive effect on the production efficiency of households. This is because households may allocate more of their time to off/non-farm activities and thus may lag in agricultural activities. In other words, off/non-farm activities compete with farm activities for labor in the rainy season, for weeding, for ploughing, or for harvesting (Reardon *et al.*, 1997). Thus, off/non-farm income was expected to have a negative influence on allocative and economic efficiency of potato production. On the other hand, incomes from off/non-farm activities may be used as extra cash to buy potato farm inputs and also be a supplement for home use and will influence technical efficiency positively.

Fragmentation: This is the number of crop plots the farm household owns. Fragmented lands are difficult for effective management of potato production. For households, who use mainly labor for field management, the movement from one field to the other may reduce their efficient utilization of the resources. Msuya (2008) identified that land fragmentation had significant impact on the level of households' potato production efficiency. Thus, those households with more number of crop fields are less efficient compared to those who have less number of plots despite its risk aversion strategy of farmers.

Participation in social organizations: It refers to households' relationship with rural institutions in the village, defined as whether the household is a member of rural institutions or associations such as *idir*, *equb* etc. It is a dummy variable which assumes value 1 if the household head is participated in social organizations and 0 otherwise. Participation in social organizations was expected to increase household's potato production efficiency.

Table 4. Definition of variables hypothesized to influence efficiency

Variable	Description	Expected effect
Dependent variable		
Efficiency	Technical, allocative and economic efficiency scores	
Independent variables		
Access to irrigation	1= accessed irrigation and utilized it and 0 otherwise	
Agro-ecology	1= highland and midland = 0	+(-)
Sex	1 = male and 0 otherwise	+
Participation in social organizations	1= has membership in rural institution and 0 otherwise	(+)
Family size	Number of members of the family in adult equivalent	+ (-)
Education	Education of the household head in grade completed	+
Ln (Farm credit)	Amount of credit obtained in Birr per year	+
Extension contact	Number of extension contact in a year	+
Livestock	Amount of livestock owned in TLU	+
Ln (Experience)	Years of participation in agriculture	+
Ln (Off/non-farm income)	Amount of earnings received in Birr per year other than on farm income	+ (-)
Fragmentation	Number of farm plots in different places	-

Source: Computed from survey data (2014)

3.4.3. Poverty analysis

In this study, poverty index was determined for income poverty to show the direct impact of irrigation on farm household income. That is, the impact of irrigation on other indicators of poverty is through income gained from use of irrigation. In other words, income/consumption poverty can be adopted for non-income poverty indicators as income/consumption was supposed to determine the fulfilment of other indicators. A household is called income poor if the households' adult equivalent annual expenditure is less than the national income poverty line. Once the poverty line is determined, one has to determine the number of people falling below that line in a form of some indices. Poverty indices are the descriptive statistics that are used to aggregate poverty over households/individuals (Bidani *et al.*, 2001; World Bank, 2005). The most commonly used ones are head count index, poverty gap index, and poverty severity index. These three indices are summarized under the formula called FGT (after Foster, Greer and Thorbecke) (1984) which is given as:

$$P_{\alpha}(Y_i, Z) = \frac{1}{n} \sum_{i=1}^q \left(\frac{Z - Y_i}{Z} \right)^{\alpha}, \quad (\alpha \geq 0) \quad (30)$$

where, y_i is the household mean adult equivalent annual expenditure, n is the sample size, z is the poverty line and q is the number of poor, α is the poverty aversion parameter (a measure of the sensitivity of the index to poverty). The poverty aversion parameter (α) reflects the concern attached to the proportionate shortfall from the poverty line. When α is equal to zero, the FGT measure corresponds to the head count index (incidence of poverty) in which no concern for the depth of the shortfall is shown. The head count ratio is the share of the poor people in the total population. When α is equal to unity, the FGT measure is called the poverty gap ratio or depth of poverty index. It is the sum of individual deprivations divided by the total population times the poverty line. Poverty gap ratio measures how far are the poor on average below the poverty line. When α is greater than unity (1), the poverty measure becomes more sensitive to the poorest of the poor. It measures the inequality among the poor as not all poor are equally poor. The most commonly used value of α (greater than 1) is 2, which is called squared poverty gap or poverty severity index, which measures the severity of poverty. In this case, FGT measure is simply the weighted sum of poverty gaps, as a proportion of the poverty line, where the weights are the poverty gaps themselves.

3.4.4. Impact of irrigation farming on production efficiency and poverty

3.4.4.1. Specification of the PSM model

Rosenbaum and Rubin (1983) have developed the PSM statistical tool as a method to reduce bias in the estimation of treatment effects with observational data sets. Based on Rosenbaum and Rubin (1983), propensity score can be defined as the conditional probability of receiving a treatment given pre-treatment characteristics. Let Y_i^T and Y_i^C are the outcome variable for participant (irrigation user) and non-participant (irrigation non-user) farm households, respectively. The difference in the outcome between treated and control groups can be seen from the following mathematical equation (Caliendo and Kopeinig, 2008).

$$\Delta_i = Y_i^T - Y_i^C \quad (31)$$

Y_i^T : Outcome of treatment (annual adult equivalent expenditure in Birr or production efficiency of the i^{th} household, when the household is participant); Y_i^C : Outcome of the

non-participant individuals (i.e., annual adult equivalent expenditure or efficiency of the i -th household when the household is non-participant in irrigation); Δ_i : Change in the outcome as a result of participation in irrigation for the i -th household. Let the above equation be expressed in causal effect notational form, by assigning $D_i = 1$ as a treatment variable taking the value 1 if the individual received the treatment and zero otherwise. Then the Average Treatment Effect of an individual i can be written as:

$$ATE = E(Y_i^T | D_i=1) - E(Y_i^C | D_i=0) \quad (32)$$

Where ATE, Average Treatment Effect, which is the effect of treatment on the outcome variables:

$E(Y_i^T | D_i=1)$: Average outcomes for household, with treatment, if the household would irrigate ($D_i=1$). $E(Y_i^C | D_i=0)$: Average outcome of untreated, when the household would not irrigate, or absence of treatment ($D_i=0$). The Average Effect of Treatment on the Treated (ATT) for the sample households is given by:

$$ATT = E(Y_i^T - Y_i^C | D_i=1) = E(Y_i^T | D_i=1) - E(Y_i^C | D_i=1) \quad (33)$$

The fundamental evaluation problem in estimation of impact is that it is impossible to observe a person's outcome for with and without treatment at the same time. While the post-intervention outcome $E(Y_i^T | D_i=1)$ is possible to observe, however, the counterfactual outcome of the i -th household when the household does not use the treatment is not observable in the data. Thus, estimation of ATE can give a seriously biased result, due to the fact that the population can differ among the comparison group, not only in terms of treatment status, but even in terms of other characteristics: this problem is often referred to as the "fundamental problem of causal inference". Thus, simple mean comparison between the treated and non-treated can be misleading, yet taking the mean outcome of non-participants as an approximation is not advisable, since participants and non-participants usually differ even in the absence of treatment (Holland, 1986; Macro and Sabine, 2008). A solution to this problem is to construct the unobserved outcome which is called the counterfactual outcome that households would have experienced, on average, had they not participated (Rosenbaum and Rubin, 1983), and this is the central idea of matching.

The basic idea of PSM is to find treated and non-treated cases that are similar with respect to a set of observed pre-treatment characteristics and match them to each other. Rosenbaum and Rubin (1983) show that under the assumption of strong ignorability, the propensity score, i.e., the conditional probability of assignment to a certain treatment, is a suitable single-index balancing score to identify matching partners. Strong ignorability comprises two central assumptions. First, Conditional Independence Assumption (CIA) states that for a given set of observable covariates, participation assignment is independent of potential outcomes (Caliendo and Kopeinig, 2008). According to Rosenbaum and Rubin (1983), the effectiveness of matching estimators as a feasible estimator for impact evaluation depends on CIA which states that treatment assignment (D_i) conditional on attributes, X is independent of the post program outcome (Y_i^T, Y_i^C). In formal notation, this assumption corresponds to:

$$(Y_i^T, Y_i^C) \perp (D_i | X_i) \quad (34)$$

This assumption imposes a restriction that choosing to participate in a program is purely random for similar individuals. As a consequence, this assumption excludes the familiar dependence between outcomes and participation that lead to a self selection problem (Heckman *et al.*, 1998). The conditional average effect of treatment on the treated has a problem, if the number of the set of conditioning variables (X 's) is high, and thus the degree of complexity for finding identical households both from program users and non-users becomes difficult. To reduce the dimensionality problem in computing the conditional expectation, Rosenbaum and Rubin (1983) showed that instead of matching on the base of X 's one can equivalently match treated and control units on the basis of the “propensity score” defined as the conditional probability of receiving the treatment given the values of X 's, notationally expressed as:

$$P(X_i) = \Pr (D_i = 1 | X_i) \quad (35)$$

Where $\Pr$ is the probability or the logistic cumulative distribution, $D_i = 1$ if the subject was treated, X_i is a vector of pre-treatment characteristics. In estimating the propensity scores, all variables that simultaneously affect participation in the program and outcome variables were included. Thus, the average treatment effect on the treated conditional on propensity score $P(X)$ can then be written as:

$$ATT = E(Y_i^T | P(X), D_i=1) - E(Y_i^C | P(X), D_i=1) \quad (36)$$

The second assumption is assumption of common support, there needs to be a region of common support where households with the same characteristics have a positive probability of being both participants and nonparticipants (Heckman *et al.*, 1998). That is, the propensity scores for the comparison groups need to overlap sufficiently:

$$0 < P(X) < 1 \quad (37)$$

The assumption is that $P(X)$ lies between 0 and 1. This restriction implies that the test of the balancing property is performed only on the observations whose propensity score belongs to the common support region of the propensity score of treated and control groups (Becker and Ichino, 2002). Individuals that fall outside the common support region would be excluded in the treatment effect estimation. This is an important condition to guarantee improving the quality of the matching used to estimate the ATT. Moreover, implementing the common support condition ensures that a person with the same X values (explanatory variables) have a positive probability of being both participant and non participants (Heckman *et al.*, 1999). Rubin (1983) describes assumption one and two together as strong ignoreability assumption. According to Caliendo and Kopeinig (2008), there are steps in implementing PSM. These are estimation of the propensity scores, choosing a matching algorithm, checking the common support condition, testing the matching quality and sensitivity analysis. The steps used in PSM implementation are discussed as follows:

(i) Propensity score estimation: The first step in PSM method is to estimate the propensity scores. Thus, the propensity scores, $P(X)$ were estimated in PSM method and matching was performed using propensity score (p-score) of each observation. In this process, a probit model is estimated for participation in irrigation as a function of all variables in the data that are likely to determine participation and the outcome variables. That is, in estimating the probit model, the dependent variable was participation, which takes the value of 1 if a household participated in the irrigation and 0 otherwise.

(ii) Choice of matching algorithm: Estimation of the propensity score is not enough to estimate the ATT of interest. This is due to the fact that propensity score is a continuous variable and the probability of observing two units with exactly the same propensity score

is, in principle, zero. Various matching algorithms have been proposed in the literature to overcome this problem. The methods differ from each other with respect to the way they select the control units that are matched to the treated, and with respect to the weights they attribute to the selected controls when estimating the counterfactual outcome of the treated. However, they all provide consistent estimates of the ATT under the CIA and the overlap condition (Caliendo and Kopeining, 2008). A good matching estimator is the one that provides low pseudo- R^2 value (Sianesi, 2004), statistically insignificant likelihood ratio test of all regressors after matching (a matching estimator which balances all explanatory variables between both groups) (Smith and Todd, 2005) and also expected to retain relatively larger observations for evaluating the impact of an intervention (i.e; relatively large matched sample size is preferable).

The most commonly applied matching estimators include the nearest neighbor matching, caliper or radius matching and kernel matching (Caliendo and Kopeinig, 2008).

Nearest Neighbour matching: In nearest neighbour (NN) matching the individual household from the comparison is chosen as a matching partner for a treated individual that is closest in terms of propensity score. NN matching with replacement indicates that untreated individual can be used more than once as a match, which would result in increased quality of matches and decreased precision of estimates. On the other hand, NN matching without replacement can be used only once.

Radius or Caliper matching: In radius matching those individual from the comparison group is chosen as a matching partner for a treated individual that lies within the specified radius in terms of propensity score (Owuor, 2009).

Kernel matching: It is among the non-parametric matching estimators that use weighted averages of all individuals in the control group to construct the counterfactual outcome. This implies each participant is matched with a weighted average of all controls with weights that are inversely proportional to the distance between the propensity scores of participants and controls (Owuor, 2009).

Among these matching algorithms the matching method that will provide low pseudo- R^2 value (Sianesi, 2004), statistically insignificant likelihood ratio test of all repressors after matching (Smith and Todd, 2005), retain relatively larger observations for evaluating the impact of an intervention and have low mean standard bias would be chosen.

(iii) Checking overlap and region of common support: Checking overlapping region and common support is needed in using PSM. Propensity scores outside the range (too low) for non-participant and too high for participants are excluded. Imposing a common support condition ensures that any combination of characteristics observed in the treatment group can also be observed among the control group (Bryson *et al.*, 2002). No matches can be made to estimate the average treatment effects on the ATT parameter when there is no overlap between the treatment and non-treatment groups. The common support region is the area which contains the minimum and maximum propensity scores of treatment and control group households, respectively. Only the subset of the comparison group that is comparable to the treatment group should be used in the analysis i.e., observations which lie outside this region are discarded from analysis (Caliendo and Kopeinig, 2008). Hence, an important step is to check the overlap and the region of common support between treatment and comparison group. One means to determine the region of common support more precisely is by comparing the minima and maxima of the propensity score in both groups.

(iv) Testing the matching quality: Balancing test should be taken care of in using PSM because main purpose of the PSM is that it serves as a balancing method for covariates between the irrigation users and non-user farm households. Consequently, the main target of balancing tests is to check whether the propensity score is adequately balanced. In other words, a balancing test seeks to examine if at each value of the propensity score, a given characteristic has the same distribution for the irrigation user and non-user farm households. The basic idea of all approaches is to compare the situation before and after matching and check if there remain any differences after conditioning on the propensity score (Caliendo and Kopeinig, 2008). The propensity scores themselves serve only as devices to balance the observed distribution of covariates between the treated and comparison groups. The success of propensity score estimation is therefore assessed by the resultant balance rather than by the fit of the models used to create the estimated propensity scores (Dehejia and Wahba, 2002). The parameter of interest is the average treatment effect on the treated (ATT) (Krasuaythong, 2008). In this case, the ATT indicates the mean difference in adult equivalent annual consumption expenditure and potato production efficiencies between irrigation users and non-user farm households, who are identical in observable characteristics and adequately weighted by a balanced probability of participation.

(v) Sensitivity analysis: Matching has become a popular method to estimate average treatment effects. It is based on the conditional independence or unconfoundedness assumption which states that we should observe all variables simultaneously influencing the participation decision and outcome variables. Hence, checking the sensitivity of the estimated results with respect to deviations from this identifying assumption becomes an increasingly important in the applied treatment evaluation. If there are unobserved variables which simultaneously affect assignment into treatment and the outcome variable, a hidden bias might arise to which matching estimators are not robust (Rosenbaum, 2002). Clearly, if the study is free of hidden bias, the effect of unobserved variable will be zero and the participation probability will solely be determined by observed characteristics. However, if there is hidden bias, two individuals with the same observed covariates have differing chances of receiving treatment. Sensitivity analysis helps to know whether the final evaluation results are sensitive with respect to the choice of the balancing score. To test the sensitivity of matching estimators, either t-test or F test can be used (Caliendo and Kopeinig, 2005).

Finally, in this study, the main pillars of PSM were households producing potato, the treatment (participation in irrigation) and potential outcome (adult equivalent annual consumption expenditure and potato production efficiencies). The idea was to match those households that participated in irrigation and produced potato using irrigation water only in dry season with that of non-participants (non-users) who do not have access to irrigation at all but sharing similar observable characteristics. Then, mean effect of participation in irrigation was calculated as the average difference in adult equivalent consumption expenditure and production efficiency between irrigation users and non-users.

3.4.4.2. Specification of impact evaluation model variables

Dependent variable: Participation in irrigation is the dependent variable in PSM model. It is a dummy variable which assumes value one if the household head has access and participated in irrigated potato farming and zero otherwise. Participant households in this study are those who produce potato using irrigation water only during winter (Bega) season (February to May). The non-participant households are those who do not have access to irrigation and produce potato using rain water only during summer (Kiremt) season (May to August).

Outcome variables: In this study potato production efficiencies and households' adult equivalent annual expenditure are the outcome variables.

Adult equivalent expenditure: Mean adult equivalent annual expense or spending of a household on food and non-food items. Income poverty was based on collecting the household consumption expenditure that is thought to represent income. This variable is included in PSM model as an outcome variable.

Efficiencies: The study used technical, allocative and economic efficiency scores of potato production variables as outcome variables in PSM model.

Explanatory variables: Description of explanatory variables hypothesized to influence outcome variables (consumption expenditure and efficiencies) with explanation of their expected effects are presented as follows.

Age: This is the number of years lived by the household head. The age of the household was expected to have a negative effect on production efficiency and welfare of households. That is, younger farmers were expected to have greater access to knowledge on productivity enhancing technologies than older farmers.

Household head sex: It takes a value 1 for male headed and 0 for female headed households. The female headed households are poorer than the male headed households for various reasons. That is, female headed households might have socio-economic, cultural and other forms of dominations that make them unable to improve their production efficiency and welfare. So, positive effect of sex on participation in irrigation was expected for male headed sample households.

Marital status: This variable takes the value of 1 if the household head is married and 0 otherwise. Marital status was expected to affect both the ways in which resources are created and they are being used. It also affects the households' plan for different activities. Thus, it is among the demographic characteristics identified to affect production efficiency and welfare of households positively.

Family size: The number of members of family in adult equivalent is of particular importance, because farm households rely primarily on adult family labor, especially for key tasks such as clearing farm, planting and harvesting crops. Obviously a family with more number of adult labourers is more likely to be efficient and wellbeing and positive effect was expected.

Education of the household head: Education was taken to be the number of years of grade completed for each of the respondents. This variable is included in order to capture the effect of human capital on efficiency and welfare of the households. In general, literature indicated that education would have a positive effect on potato production efficiency and welfare of households because households who attended some level of education are expected to be active in looking for updated agricultural information.

Total cultivated land size: It refers to area allocated to potato in hectare. It was expected that households with larger cultivated land size are more likely to be efficient and wellbeing because more cultivated land size increases their output and income base which enables them to buy farm inputs; and enhances the risk bearing ability of farmers (Andreu, 2008). Hence farm size would have a positive effect on participation in irrigation.

Livestock holding: It refers to the total livestock in TLU the household owns. Number of livestock contributes income, plough animals and manure, and would have positive effect on participation in irrigation.

Eucalyptus tree: This variable refers to the number of eucalyptus trees owned by farm households. On the one hand, it would increase financial capacity of farm households and would have positive effect on production efficiency and welfare of households. On the other hand, it would shift away labor power from potato production activities to eucalyptus tree marketing activities such as carrying firewood for sale and influences potato production efficiency and welfare of households negatively.

Frequency of extension contact: This is a continuous variable which is measured in terms of the number of visit to the household by the extension agents in a year. Households who have had frequent extension contact were expected to have more potato production

efficiency and welfare than others. Thus extension measured in contact made during the cropping season was expected to influence efficiency and welfare of households positively.

Farm credit: There is farm credit packages designed to promote crop production in the study area. Credit is in cash from the lending institutions. In this case, it measures the amount of credit obtained in Birr. Since amount of credit is an important factor for financing the agricultural activities of smallholder farmers, it was expected that households who have received high credit would be more efficient and wellbeing than others.

Table 5. Definitions of variables included in propensity score matching

Variable	Description	Expected effect
Dependent variable		
Participation	1 = The household has access to irrigation and used irrigation water only to produce potato and 0 otherwise	
Outcome variables		
Expenditure	Mean adult equivalent annual consumption expenditure in Birr	
Efficiency	Technical, allocative and economic efficiency scores	
Explanatory variables		
Age	Age of household head in years	-
Total cultivated land	Total cultivated land owned in hectare	+
Family size	Number of members of the family in adult equivalent	+
Education	Education of the household head in years of grade completed	+
Farm credit	Amount of credit obtained in Ethiopian Birr	+
Eucalyptus tree	Number of eucalyptus tree owned	+(-)
Extension contact	Number of extension contact in a year	+
Livestock	Amount of livestock owned in TLU	+
Sex	1 = male and 0 otherwise	+
Marital status	1 = married and 0 otherwise	+

Source: Computed from survey data (2014)

4. RESULTS AND DISCUSSION

This chapter presents the findings of the study and discusses them in comparison with the findings of earlier studies. It is organized into four sections. The first section presents demographic, institutional and socioeconomic attributes of the sample households. The remaining three sections deal with the results of the analytical models specified in chapter three.

4.1. Socio-economic Characteristics of the Sample Households

A set of key variables describing the socio-economic, demographic and institutional characteristics of the sample households are presented. Socioeconomic characteristics described under this section include household and farm characteristics. The frequency distribution of the categorical variables and descriptive statistics of continuous variables is presented.

4.1.1. Descriptive statistics of categorical variables

About 30.6 % of sample households live in highland whilst 69.4% of them live in midland agro-ecological areas. About 92.71 % and 7.29% of the households were male and female headed households, respectively. This is probably due to low participation of female headed households in irrigation. About 38% of female headed household have participated in irrigation and the remaining 62% of female headed households were non-participants. About 45.32 % of male headed households did participate in irrigation whilst 54.68% of male headed households were non-participants. About 45.28% of irrigated and 54.72% non-irrigated household heads were married while about 39.1% of irrigated and 60.87% of non irrigated households were not married (Table 6).

About 41.24% of irrigated and 58.76% of non-irrigated households was participating in the local institutions whilst 46.6 % of irrigated and 53.94 % of non-irrigated households was not participating in local institutions. From the total sample, 33.68 % households were participating in the local institutions whilst 66.32% households were not participating in local institutions. Such participation is believed to enhance the information exchange and experience sharing among households about the use of new farm technologies and farming practices (Table 6).

Many of the sample households live in houses with corrugated iron sheet roof (98.61%), some in the traditional thatch-roofed huts (1.39%). From the total sample households living in corrugated iron sheet roof, irrigation user and non-user sample households living in houses with corrugated iron sheet roof were 45.07 % and 54.93 %, respectively. This could be due to deterioration of grasslands resulting from expansion of crop land and human and animal population pressure. Moreover, living in the corrugated iron-sheet roofed house in these rural areas is considered as a prestige, better living standard and wealth. About 93.75% of the total households cooked in the kitchen and about 95.14% used toilet facility (pit latrine). Irrigated households using kitchen and toilet facility were 42.2%, 44.53%, whereas non-irrigated farm households using kitchen and toilet facility were 57.8%, 55.47%, respectively. This could be due to awareness created by health extension workers in rural areas of the country (Table 6). The χ^2 -test for percentage difference in cooking place between the irrigation users and non-user sample households gave significant value (p-value = 0.001), indicating that there is a significant difference in cooking place between irrigation users and non-user sample households (Table 6).

Table 6. Frequency distribution of categorical household characteristics

Characteristics	Irrigation						χ^2 -test (p-value)
	Irrigation user		Non-user		Total		
	Number	%	Number	%	Number	%	
Agro-ecology							0.915
High-land	39	44.32	49	55.68	88	30.6	
Mid-land	90	45	110	55	200	69.4	
Sex							0.522
Female	8	38.1	13	62.0	21	7.29	
Male	121	45.32	146	54.62	267	92.71	
Marital status							0.290
Married	120	45.28	145	54.72	265	92.01	
Not married	9	39.1	14	60.87	23	7.99	
Social institutions							0.387
Member	40	41.24	57	58.76	97	33.68	
Non-member	89	46.6	102	53.4	191	66.32	
Roof of housing							0.423
Corrugated iron	128	45.07	156	54.93	284	98.61	
Non-corrugated iron	1	25	3	75	4	1.39	
Cooking place							0.001
In the kitchen	114	42.2	156	57.8	270	93.75	
In the house	15	83.3	3	16.7	18	6.25	
Toilet facility							0.688
Has toilet	122	44.53	152	55.47	274	95.14	
Does not have toilet	7	50	7	50	14	4.86	

Source: Computed from survey data (2014)

4.1.2. Descriptive statistics of continuous variables

In total sample, the average age of the sample household heads was found to be 45.17 years with standard deviation of 9.18. The average ages of irrigation user and non-user sample households were 45.2 and 45.16 years with standard deviation of 7.97 and 10.08, respectively. This indicates that most of the household heads were in the productive age group. The mean family size for the whole sample was found to be 4.28 persons with standard deviation of 1.27. The average family size of irrigation user and non-user sample households was 4.3 and 4.24 with standard deviation of 1.17 and 1.36, respectively. In total sample, the average number of years of farming experience was about 24.27 with standard deviation of 8.66. The average farming experience of irrigation user and non-user sample households were 24.28 and 24.26 years with standard deviation of 7.79 and 9.33, respectively. This shows that the households have rich experience of farming. The years of formal education was about 0.61 on average with maximum of preparatory school certificate. Mean of ratio of literate adult members in the household was 0.22 with standard

deviation of 0.24. This low ratio of literate adult members indicates that average households in the sample were not able to read and write as well as easily understand technical recommendations provided by the extension agents (Table 7).

Land holding size, Livestock holding, eucalyptus trees owned and the residential house structure were identified as key indicators of the wealth of the households. The total livestock holding measured in terms of Tropical Livestock Unit (TLU) was found to be 4.29 with standard deviation of 2.27. Livestock holding in irrigation user and non-user sample households was 4.27 and 4.32 with standard deviation of 2.27 and 2.28, respectively. This is relatively large number in the crop-livestock mixed farming system, where land holdings are small and grazing areas are continuously converted into crop land. The average number of oxen owned by the households was about 2.36 with standard deviation of 1.06, which sufficed the required oxen for farm operation. Another key indicator of the wealth of the farm households is the availability of perennial trees. The eucalyptus tree is identified as source of income in the study area. Average eucalyptus tree owned by households were 924.02 with a standard deviation of 1450.64 which also financially supported the farm operation. The t-test result for eucalyptus tree between households shows the significant value (p -value = 0.029), indicating that there is a difference in eucalyptus tree owned by households (Table 7).

The average cultivated land size of the sample households was about 1.6 hectares with standard deviation of 0.65. This indicates that there was an egalitarian landholding for the majority of the sample households due to the continuous sub-divisions as the population increases. The mean number of plots was 3.6, with standard deviation of 1.38 but some households had a single farming plot connected to their houses. The average area covered with potato under irrigation and rain-fed farming system was about 0.23 hectare and 0.24 ha with standard deviation of 0.12 and 0.13, respectively. The respective yield of potato was 1.38 t and 1.4 t/ per average unit area given (Table 7) under irrigated and non-irrigated farming systems respectively which is below the national average potato productivity of 8 t to 10 t/ha (Haverkort *et al.*, 2012; CSA, 2011; Abay *et al.*, 2011) which indicates a very low level of productivity per unit area (Table 7).

The average frequency of extension contact during the cropping season was found to be about 3.28 with standard deviation of 1.35. In irrigated and non-irrigated farming, the average frequency of extension contact during the cropping season was found to be about

3.47 and 3.12 with standard deviation of 1.39 and 1.30. This shows that there was still limited access to the institutional support services of extension advice. The walking distance measured in km from households' residence to the farm and local market center was found to be about 1.41 and 8.96 km on average with standard deviation of 5.49 and 1.17, respectively. The t-test result for farm distance to home between households shows the significant value (p-value = 0.046), indicating that there is a difference in farm distance to home (Table 7). The average annual off/non-farm income of the sample households was found to be about Birr 43.33, with standard deviation of about 276.62. The t-test result for off/non-farm income between households shows the significant value (p-value = 0.086) indicating that there is a difference in off/non-farm income (Table 7).

Table 7. Descriptive statistics of continuous variables

Characteristics	Irrigation user		Non-user		Total		t-test (p-value)
	Mean	Std	Mean	Std	Mean	Std	
Age	45.2	7.97	45.16	10.08	45.17	9.18	0.51
Experience	24.28	7.79	24.26	9.33	24.27	8.66	0.50
Family size	4.3	1.17	4.24	1.36	4.28	1.27	0.67
Education	0.65	2.0	0.572	1.62	0.61	1.79	0.64
Share of literate adult members	0.24	0.25	0.20	0.23	0.22	0.24	0.92
Livestock holding	4.27	2.27	4.32	2.28	4.29	2.27	0.99
Farm credit	248.06	838.8	422.01	1215.70	344.09	1065.3	0.08
Oxen owned	2.4	1.02	2.34	1.10	2.36	1.06	0.68
Eucalyptus tree	744.68	1382.14	1069.51	1492.42	924.02	1450.64	0.029
Cultivated land	1.69	0.67	1.54	0.63	1.6	0.65	0.97
Potato planted area	0.23	0.12	0.24	0.13	0.23	0.13	0.36
Number of plots	3.81	1.79	3.88	2.03	3.6	1.38	0.400
Yield of potato	20.79	9.38	21.2	10.02	21.04	9.72	0.35
Extension contact	3.47	1.39	3.12	1.30	3.28	1.35	0.98
Distance to market center	9.17	5.59	8.79	5.43	8.96	5.49	0.715
Off/ non-farm income	18.60	211.308	63.39	319.25	43.33	276.62	0.086
		2					
Farm distance to home	1.29	1.13	1.52	1.19	1.41	1.17	0.046

Source: Computed from survey data (2014)

4.1.3. Food self sufficiency status of sample households

About 86.82% of sample households in irrigated and 81.76% of the sample households in non-irrigated farming had secured food self sufficiency. In total sample, 84.03% of the

sample households in study area had food self sufficiency. This implies that most of the sample households could feed their family throughout all months of the year. But in total sample, irrigated and non-irrigated farming systems there are still about 13.97%, 13.18% and 18.24% sample households, respectively who could not feed their family throughout all months of the year (Table 8).

Table 8. Food self sufficiency of sample farmers

Months of food self sufficiency	Irrigation users	%	Irrigation non-users	%	Total	%
0.5	0	0	1	0.63	1	0.35
0.66	4	3.10	7	4.40	11	3.82
0.75	7	5.43	8	5.03	15	5.2
0.83	1	0.77	11	6.92	12	4.2
0.92	5	3.88	2	1.26	7	2.4
1	112	86.82	130	81.76	242	84.03
Total	129	100	159	100	288	100

Source: Computed from survey data (2014)

4.1.4. Consumption pattern and expenditure of sample households

The total average number of times adult and child fed per day were 2.86 and 3.4 with standard deviation of 0.38 and 1.03, respectively. Average number of times adult and child fed in irrigated farming system was 2.89 and 3.47 per day with standard deviation of 0.35 and 0.98, respectively. Average number of times adult and child fed in non-irrigated farming system was 2.83 and 3.38 per day with standard deviation of 0.39 and 1.06, respectively. This shows the sample households and their children fed below 4 times per day. Average ratio of food self sufficiency months to total months of a year was 0.96 with standard deviation of 0.09. In irrigated and non-irrigated farming system, average ratio of food self sufficiency months to total months of a year was 0.97 and 0.95 with standard deviation of 0.08 and 0.10, respectively. This is the indication of food self insufficiency of some of the sample households (Table 9).

Expenditure is one of the most commonly used measures of welfare of a household. Rural households in the study area spend their income on food and non-food items. The survey results show that the mean adult equivalent annual expenditure on all items in total sample was 5020.3 Birr with standard deviation of 2666.7. In irrigated and non-irrigated farming

systems the mean adult equivalent annual expenditure on all items was 5238.15 Birr and 4843.5 Birr with standard deviations of 2764.9 and 2579.6, respectively (Table 9).

Table 9. Consumption pattern and adult equivalent expenditure of sample households

Consumption pattern	Irrigated		Non-irrigated		Total		t-test (p-value)
	Mean	Std	Mean	Std	Mean	Std	
Number of times adult fed per day	2.89	0.35	2.83	0.39	2.86	0.38	0.9396
Number of times child fed per day	3.47	0.98	3.38	1.06	3.4	1.03	0.7679
Ratio of months of food self sufficiency	0.97	0.08	0.95	0.10	0.96	0.09	0.9130
Adult equivalent annual expenditure	5238.153	2764.9	4843.5	2579.6	5020.3	2666.7	0.8938

Source: Computed from survey data (2014)

4.1.5. Measurements of poverty indices

It was found that 73.3% of the sample households generated annual per adult equivalent income which is higher than the income poverty line of 4497.12 birr determined in the methodology part. In irrigated and non-irrigated farming system 74.4% and 72.3% of the sample households generated annual per adult equivalent income higher than the income poverty line of 4497.12 Birr, respectively. This poverty head count is equivalent to the national level rural poverty head count index (26% in 2010/11) which was based on consumption expenditure. The income poverty gap and severity indices were also found to be 0.21 and 0.16, respectively, implying that 944.39 birr per adult equivalent is needed to bring the life out of poverty. But, lower inequality among the poor was observed as most of the households below the poverty line did not have high difference in their income. The income poverty gap indices for irrigation user and non-user farm households were also found to be 0.19 and 0.22 implying that 854.45 Birr and 989.37 Birr per adult equivalent are needed respectively to bring the life out of poverty. The poverty severity indices for irrigated and non-irrigated farming system were 0.14 and 0.17, respectively (Table 10).

Table 10. Poverty indices

Characteristics	Irrigated	Non-irrigated	Total sample
Poverty head count index	0.256	0.277	0.267
Poverty gap index	0.19	0.22	0.21
Poverty severity index	0.14	0.17	0.16

Source: Computed from survey data (2014)

4.2. Potato Production Efficiencies

This section presents the results of stochastic frontier analysis and the tobit model with non-zero censoring point. First, the technical efficiency of households was estimated from the stochastic frontier model and using efficiency decomposition technique from the dual cost frontier, the study decomposed economic efficiency into technical and allocative efficiencies. In the second stage, the tobit model with non-zero censoring point was employed to identify factors influencing the efficiencies of sample households.

4.2.1. Production function parameter estimates

The likelihood ratio test was used to identify the functional form of production function which properly fit the data. The test result revealed that Cobb-Douglas Stochastic Frontier model best fit the data compared to the OLS. The ratio of the standard error of $\mu(\delta_\mu)$ to the standard error of $v(\delta_v)$, known as λ is 2.14, which measures the effect of technical inefficiency in the variation of observed output, $\gamma = \lambda^2 / [1 + \lambda^2] = \sigma_\mu^2 / \sigma_\epsilon^2$. The estimated value of (γ) is 0.82, which is an estimate of the variance parameter and significant at one percent level of significance implying that 82 percent of the total variation in output is due to existence of production inefficiency. This result is confirmed by conducting a likelihood ratio test to compare OLS model versus frontier model in representing the surveyed data. Likelihood ratio test statistic provides a statistic of 11.9 distributed chi-square with five degrees of freedom, which is significant at one percent level of significance thus rejecting the adequacy of the OLS model in representing the data.

The existence of inefficiency factor was also tested by Wald test. The null hypothesis was that no systematic inefficiency in the distribution. However, the test result showed significant chi-squared statistic for the study area (wald chi2 = 150.78, prob > chi2 = 0.0000), implying rejection of the null hypothesis (Table 11). This means that there was systematic inefficiency in the distribution. Based on this, the parameters of Cobb-Douglas

parametric stochastic frontier production function was estimated with the maximum likelihood estimates. It measured the physical relationship between output and inputs used in potato production at the given level of technology. The variables were transformed into natural logarithms for efficiency analysis.

The coefficients of land, labor, fertilizer, seed and oxen of stochastic frontier model of Cobb-Douglas frontier production function is presented in Table 11. The signs of all the slope coefficients of the production function are positive. The inputs (land, seed and oxen) have turned out to be significant in determining potato output; that is, potato output is responsive to inputs utilization. The coefficients associated with the inputs measure the partial elasticity of potato output with respect to the respective inputs. The results of the model indicate that the use of variable inputs such as land, seed and oxen power significantly and positively determined potato output under the total farming system. All results were consistent with the hypotheses formulated regarding the relationship between potato output and physical input variables under the total farming system. That is, potato output is responsive to inputs utilization.

The use of land had a significant and positive effect on potato output at less than one percent level of significance under total farming systems suggests that increasing land utilization in potato production would significantly increase potato output. That is, further increase in the level of utilization of land for potato production would contribute to increased level of potato output. But, other researchers found the inverse relationship between land size and farm output (Masterson, 2007). The elasticity of oxen was the highest (0.31) for the study area, indicating that there was relatively more proportionate change in output due to proportionate change in amount of oxen-day used to cultivate potato land (Table 11).

The potato seed had significant and positive influence on potato output at less than one percent level of significance under the total farming system. This shows that households who used optimal amount of seed receive higher potato yields. On the other hand, suboptimal use of seed contributes to lower output of potato. Therefore, improving the level of use of seed would significantly increase potato output. Using oxen for farm operation and optimal seed amount enhances potato output and are key inputs in potato production. This is revealed from the result that the effects of seed and oxen were significant at less than one percent levels of significance under the total farming system.

The elasticities in Table 11 indicate the magnitude of changes on potato output resulting from a percentage change in a significant farm input variable, keeping all other variables constant. A 1% increase in land, seed and oxen inputs would result in 22%, 16% and 31% increase in total output of potato under total farming system, respectively. This indicates that the optimal use of these inputs is an important contributor to potato output. This might be due to the fact that draft power enables repeated cultivation of the land which facilitates soil moisture retention (Table 11).

Table 11. The ML and OLS estimates of production function for total sample

Variables	ML estimates				OLS estimates	
	Coefficient	Standard error	z-value	P> z	Coefficient	Standard error
Constant	6.52***	0.51	12.72	0.000	5.940	0.550
ln (Land)	0.22***	0.07	3.26	0.001	0.210	0.073
ln (Labor)	0.02	0.11	0.18	0.859	0.071	0.120
ln (Fertilizer)	0.006	0.004	1.35	0.178	0.006	0.005
ln (Seed)	0.16***	0.05	3.26	0.001	0.160	0.054
ln (Oxen)	0.31***	0.06	4.97	0.000	0.290	0.065
Log likelihood	-133.76					
Wald chi2(5)	150.78***					
Prob > chi2	0.0000					
lnsig2v	-2.846	0.292	-9.75	0.000		
lnsig2u	-1.326	0.231	-5.74	0.000		
sigma_v	0.241	0.0352				
sigma_u	0.515	0.0595				
sigma2	0.323	0.0492				
lambda	2.138	0.0896				

*** indicate the level of significance at 1 percent

Source: Computed from survey data (2014)

The maximum likelihood estimate of the model also shows that potato output elasticities associated with seed and oxen inputs were positive and significant in the irrigated farming (Table 12). The elasticity of output due to oxen input was the highest (0.36), followed by elasticity of output due to seed (0.27) in the irrigated farming. In non-irrigated farming, elasticities of output due to land (0.33) and oxen (0.35) were positive and significant, with the highest being elasticity of output due to oxen. That is, a 1% increase in seed and oxen would result in 27 and 36 percent increase in total output of potato under irrigated farming, respectively. Under non-irrigated farming a 1% increase in land and oxen would bring about a 33 and 35 percent improvement in output of smallholder potato production,

respectively. The sum of elasticities of the five inputs (land, labor, fertilizer, seed and oxen) in total farming system is 0.806, i.e. scale elasticity is less than one. This indicates that the potato production function exhibits decreasing returns to scale that represents the second stage of a production function. It means that proportionate increase in all inputs results in a less than proportionate increase in potato output.

Table 12. Regression results of Cobb-Douglas frontier for each farming systems

Variables	Irrigation users			Non-users		
	Coefficient	Standard error	P> z	Coefficient	Standard error	P> z
Constant	5.04***	0.63	0.000	8.03***	0.72	0.000
Ln (Land) (ha)	0.10	0.09	0.260	0.33***	0.09	0.000
Ln (Labor) (man-day/ha)	0.23	0.14	0.100	-0.23	0.16	0.140
Ln (Fertilizer) (kg/ha)	0.008	0.006	0.133	0.004	0.006	0.535
Ln (Seed) (kg/ha)	0.27***	0.06	0.000	0.04	0.07	0.533
Ln (Oxen) (oxen-day/ha)	0.36***	0.09	0.000	0.35***	0.099	0.000
Log likelihood	-31.66			-89.39		
Wald chi2(5)	143.93***			53.89		
Prob > chi2	0.000			0.0000		
Lnsig2v	-2.948***	0.481	0.000	-3.18***	0.566	0.000
Lnsig2u	-2.094***	0.626	0.001	-0.85***	0.252	0.001
Sigma_v	0.2289	0.055		0.204	0.058	
Sigma_u	0.351	0.109		0.654	0.083	
Sigma2	0.175	0.056		0.469	0.091	
Lambda	1.533	0.161		3.202	0.133	

*** indicates the level of significance at 1 percent

Source: Computed from survey data (2014)

4.2.2. Cost function parameter estimates

To attain allocative efficiency, a household should choose the optimal combination of inputs so that output is produced at a minimal cost. To maximize profit from potato production, households have to choose the best combination of inputs given the prices of inputs and output. The existence of cost inefficiency factor was tested by Wald test. The null hypothesis was that no systematic cost inefficiency in the distribution. However, the test result showed significant chi-squared statistic for the study area (wald chi2 = 239.66, prob > chi2 = 0.000), implying rejection of the null hypothesis. This means that there was systematic cost inefficiency in the distribution. Based on this, the parameters of Cobb-Douglas stochastic cost frontier function was estimated with the maximum likelihood estimates.

In this study, allocative efficiency was estimated from a single output and five inputs (Equation 21). The five inputs were land, labor, oxen, chemical fertilizer and seed used in potato production. The cost of production was measured in Birr; price of land was estimated based on the rental value of land in Birr per hectare; and the value varied from farm to farm based on the fertility of land and demand for rental land. Daily wage rate for labor and rent for oxen per day were used to value labor and oxen, and price of chemical fertilizer was in Birr per kilogram. Average price of seed was per kilogram. All the data on each variable were transformed into natural logarithms. Stochastic Frontier Cobb-Douglas cost function was estimated using maximum likelihood method.

Table 13 gives the maximum likelihood estimates of the coefficients of Cobb-Douglas stochastic frontier cost function. Land and fertilizer prices are positive and statistically significant at less than one percent significance level. The effects of prices of all inputs were positive on the cost of potato production.

Table 13. Regression results of Cobb-Douglas cost frontier for total sample

Variables	Coefficient	Standard error	z-value	P> z
Constant	2.09*	1.12	1.87	0.061
Ln (pland) per ha	0.28***	0.026	11.17	0.000
Ln (plabor) per man-day	0.12	0.09	1.28	0.199
Ln (pfertilizer) pe kilogram	0.012***	0.004	2.72	0.007
Ln (pseed) per kilogram	0.27	0.30	0.93	0.353
Ln (poxen) per oxen-day	0.16	0.12	1.34	0.179
Ln (output)	0.36***	0.034	9.10	0.000
Log likelihood	-77.171			
Wald chi2(6)	239.66***			
Prob > chi2	0.0000			
Sigma_v	0.32	0.01		
Sigma_u	0.0036	0.3		
Sigma2	0.10	0.008		
Lambda	0.011	0.28		

*** and * indicate the level of significance at 1 and 10 percent, respectively

Source: Computed from survey data (2014)

The maximum likelihood estimation of the coefficients of Cobb-Douglas stochastic cost function shows that the coefficients (elasticities) of costs due to change in prices of land and oxen were statistically significant in their effects on the cost of production in irrigated households. That is, proportionate change in cost of production increases due to proportionate change in prices and quantities of land and oxen in irrigated households. In

non-irrigated households, prices of land and fertilizer were statistically significant. All significant input prices had positive effects on the level of cost of potato production in non-irrigated farm households (Table 14).

Table 14. Regression results of Cobb-Douglas cost frontier for each farming systems

Variables	Irrigated			Non-irrigated		
	Coefficient	Standard error	P> z	Coefficient	Standard error	P> z
Constant	0.25**	1.33	0.851	4.06**	1.8	0.022
Ln (pland) per ha	0.37 ***	0.029	0.000	0.22***	0.04	0.000
Ln (plabor) per person-day	0.062	0.10	0.541	0.14	0.14	0.295
Ln (pfertilizer) per kilogram	0.007	0.004	0.147	0.018***	0.006	0.004
Ln (pseed) per kilogram	0.25	0.34	0.455	0.26	0.4	0.557
Ln (poxen) per oxen-day	0.36 ***	0.14	0.008	-0.039	0.18	0.831
Ln (output)	0.45 ***	0.047	0.000	0.27***	0.058	0.000
Log likelihood	2.268			-58.786		
Wald chi2(6)	319.54			62.36		
Prob > chi2	0.0000			0.0000		
Sigma_v	0.24	0.015		0.35	0.02	
Sigma_u	0.0012	0.58		0.004	0.84	
Sigma2	0.056	0.0071		0.12	0.014	
Lambda	0.0052	0.58		0.011	0.84	

*** and ** indicate the level of significance at 1 and 5 percent, respectively

Source: Computed from survey data (2014)

4.2.3. Efficiency estimates

This section presents the results of technical, allocative and economic efficiencies which were estimated using Cobb-Douglas stochastic frontier model separately from factors that influence efficiency of households in potato production which was estimated using tobit model. Based on the estimated parameters of the Cobb-Douglas production function shown in Table 11, the parameters of the corresponding dual cost function were derived, Equation (22) and formed the basis for computing AE and EE indices.

Technical efficiency was calculated by taking physical inputs of potato production and total potato output. The results of SFA indicated that technical efficiency of households in

potato production ranged between 22% and 92%. The frequency distribution of technical efficiency scores of the total sample households indicated that the majority of the households lie below efficiency score of 80% compared to other efficiency ranges. This shows that there was a technical inefficiency in potato production. The efficiency scores also show that only 1.74% of the farmers operated at greater than 90% technical efficiency level in total farming system. The average technical efficiency was found to be about 69% with minimum and maximum technical efficiency of 22% and 92%, respectively, in the total farming system indicating that households that lie below 80% are highly technically inefficient. This indicates that if the average farmer in the sample was to achieve the technical efficiency level of its most efficient counterpart, then the average farmer could realize 31 percent output increments. The result reveals that the average farmer in the study area could realize 31 percent output increment without any increment in inputs used if the household operates at the efficiency level achieved by its most efficient counterpart (Table 15).

Allocative efficiency was calculated by taking total cost of production, input prices and adjusted total output reflected in inputs. The results of SFA indicated that the allocative efficiency of households in potato production ranged between 29.5% and 95% (Table 15). The frequency distribution of allocative efficiency scores of the sample households indicated that the majority of the sample households also lie below efficiency score of 80%. This shows that there was an allocative inefficiency in potato production. The efficiency scores also showed that only 5.21 percent of the households operated at greater than 90 percent allocative efficiency level in potato production in the total farming system. The average allocative efficiency was found to be about 67 percent with minimum and maximum allocative efficiency of 29.5 and 95.3 percent in the total farming system, respectively. This indicates that if the average household in the sample was to achieve the allocative efficiency level of its most efficient counterpart, then the average household could realize 33 percent cost reduction. The result reveals that the average household in the study area could realize 33 percent cost reduction if the household operates at the efficiency level achieved by its most efficient counterpart. Economic efficiency is the product of technical and allocative efficiencies. That is, economic efficiency is determined by multiplying the technical and allocative efficiencies of a given household. The mean economic efficiency result in the total farming system is 46 percent with minimum and maximum efficiency scores of 6.8% and 88%.

Table 15. Potato production efficiency distributions for total sample households

Efficiency ranges	TE		AE		EE	
	Number of households	%	Number of households	%	Number of households	%
0.068-0.40	14	4.86	13	4.51	83	28.82
0.41-0.50	21	7.29	20	6.95	55	19.09
0.51-0.60	42	14.58	32	11.11	71	24.65
0.61-0.70	61	21.18	50	17.36	48	16.7
0.71-0.80	71	24.65	75	26.04	24	8.33
0.81-0.90	74	25.69	83	28.82	7	2.43
0.91-1.00	5	1.74	15	5.21		
Total	288	100	288	100	288	100
Mean	0.69		0.67		0.46	
Min.	0.22		0.295		0.068	
Max.	0.92		0.95		0.879	

Source: Computed based on model output (2014)

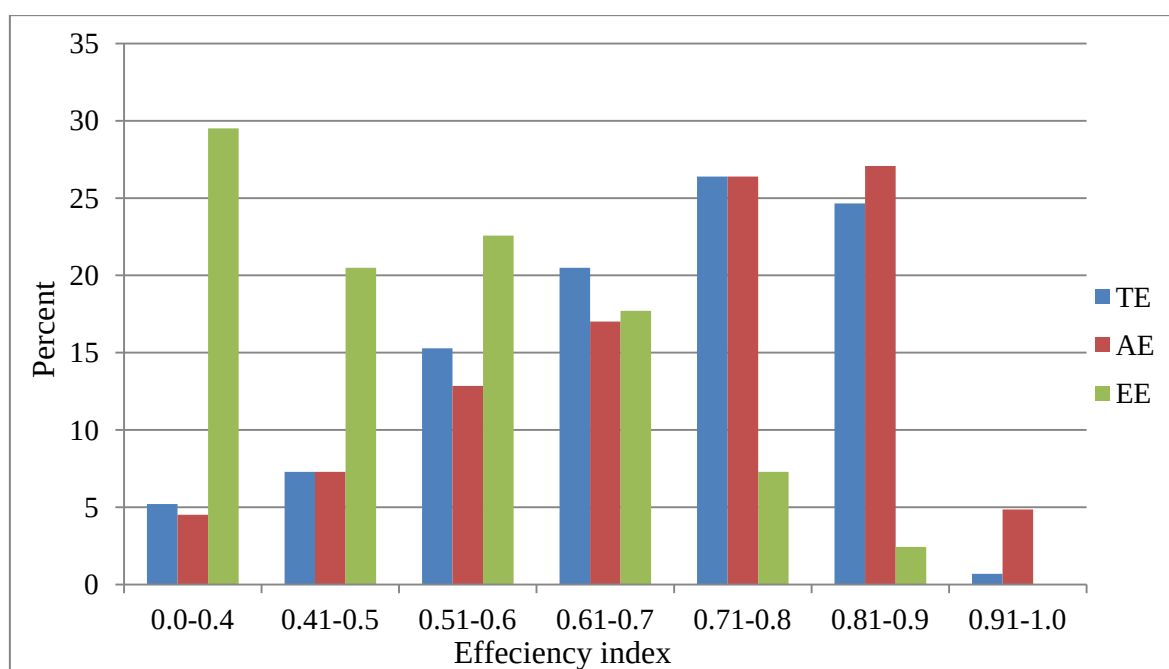


Figure 7. Frequency distribution and estimates of efficiencies

Source: Computed from survey data (2014)

For irrigation user households, the estimated mean technical and allocative efficiency scores are 77% and 74.5%, whereas the corresponding results for non-user households are 63% and 63%, respectively. The results indicate that non-user households exhibit higher mean economic inefficiencies due to their higher mean technical and allocative inefficiencies in potato production compared to irrigation users. Therefore, irrigation user

and non-user households can gain respectively, an average potato output growth of 23 and 37 percent through improvements in technical efficiency and 25.5% and 37% cost reduction through improvements in allocative efficiency. The results are consistent with what have been found by Arega and Zeller (2005), Arega (2006) and Mesay *et al.* (2013) in their smallholder or commercial farms production efficiency analyses carried out in the country. The economic efficiency results in the irrigated and non-irrigated potato farming are 57% and 40%, respectively. Thus, potato producers can gain 43% and 60% increment in overall economic efficiency with their existing technologies (Table 16).

Table 16. Production efficiency distributions of irrigation user and non-user households

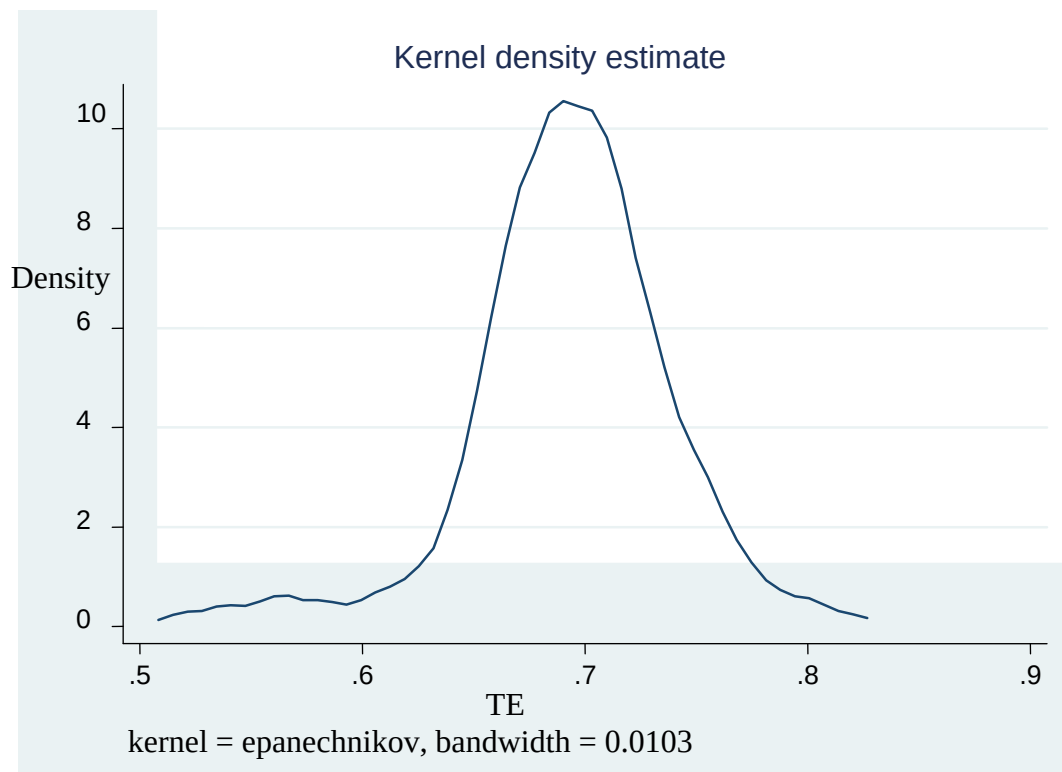
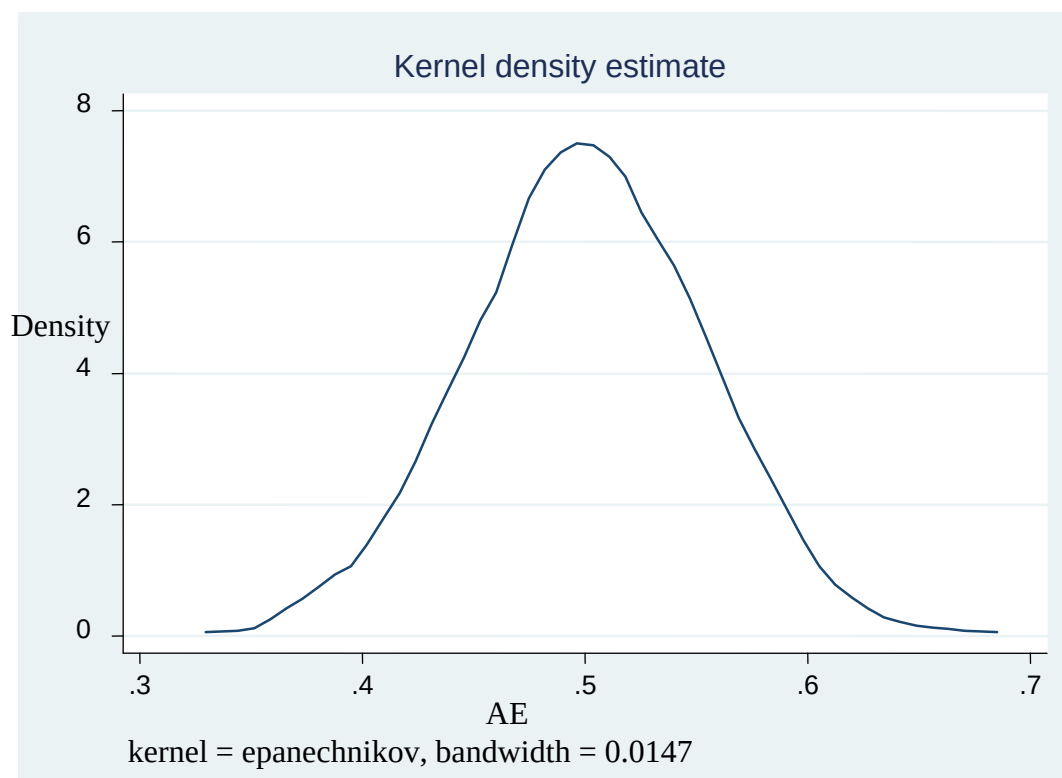
Efficiency range	TE		AE		EE	
	Number of irrigation user (%)	Number of non-user (%)	Number of irrigation user (%)	Number of non-user (%)	Number of irrigation user (%)	Number of non-user (%)
0.068-0.40		24 (15.1)		15 (9.4)	25 (19.4)	58 (36.5)
0.41-0.50	2 (1.6)	19 (11.95)	4 (3.1)	15 (9.43)	30 (23.26)	25 (15.72)
0.51-0.60	16 (12.4)	25 (15.72)	15 (11.63)	13 (8.18)	35 (27.13)	36 (22.64)
0.61-0.70	14 (10.8)	25 (15.72)	18 (13.95)	37 (23.27)	28 (21.71)	20 (12.59)
0.71-0.80	39 (30.23)	30 (18.87)	31 (24.03)	37 (23.27)	9 (6.97)	15 (9.43)
0.81-0.90	55 (42.64)	33 (20.76)	47 (36.43)	35 (22.01)	2 (1.55)	5 (3.14)
0.91-1.00	3 (2.33)	3 (1.89)	14 (10.85)	7 (4.40)		
Total	129 (100)	159 (100)	129 (100)	159 (100)	129 (100)	159 (100)
Mean	0.77	0.63	0.745	0.63	0.57	0.40
Min.	0.47	0.19	0.47	0.27	0.216	0.068
Max.	0.92	0.92	0.95	0.97	0.82	0.879

Source: Computed based on model output (2014)

4.3. Determinants of Efficiencies of Potato Production

After measuring the level of technical, allocative and economic efficiency indices, it was necessary to identify which demographic, socioeconomic, farm specific attributes, marketing and institutional factors influence the level of TE, AE and EE in potato production. Using tobit model with non-zero censoring point, the coefficients of factors affecting efficiency were estimated separately from the elasticities of potato output with respect to inputs. The variables included in the model were tested for the problems of multicollinearity. The problem of multicollinearity was checked using VIF. The maximum value of VIF obtained for these variables in this case was found to be 1.18 (Appendix Table 3). In addition, a test for normality of TE, AE and EE of plot residuals was made

using Kernel density plot residuals. The estimated graph resembles normally distributed curve that shows normality assumption is not violated (Figure 8).



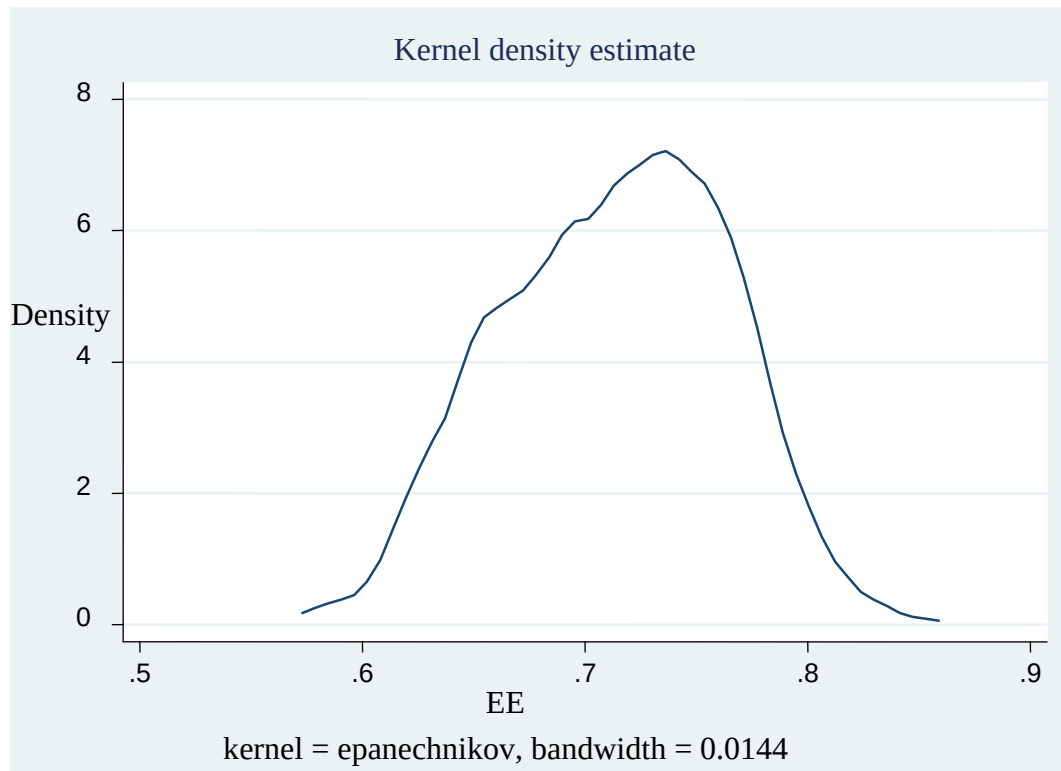


Figure 8. Kernel density estimate for efficiencies

Source: Computed from survey data (2014)

4.3.1. Factors affecting technical efficiency of potato production

The technical efficiency scores of the sample households generated by the frontier model were used in the tobit model with non-zero censoring point as a dependent variable on a number of farmer, farm and policy related explanatory variables to identify those factors that determine the technical efficiency of the sample households in potato production. That is, two stages of analysis were carried out to determine the efficiency and identify determinant of efficiency. First, the efficiency of sample households was analyzed using SFA. Then, the tobit model was applied to identify factors that affect the technical efficiency of households. The effects of change in these variables on the technical efficiency of households in potato production were examined. Details of variable descriptions and their hypothesized effects on the efficiency of production have been given under methodology chapter in section 3.4.2., Table 4.

According to the results of tobit model, technical efficiency was significantly and positively influenced by loan size at less than one percent level of significance. Farm credit significantly and positively affected technical efficiency of potato production because access to credit is an important source of finance for the agricultural activities. It was also

significantly and positively influenced by frequency of extension contact at one percent level of significance. This implies that households who had more number of contacts with extension agents improved their access to improved inputs and farming management practices thereby increased their production efficiencies. Arega and Reshid (2005) and Aye and Mungatana (2011) found extension contact as a factor that affects technical efficiency positively and significantly. The fact that technical efficiency was positively and significantly related to extension contact and loan size variables suggest that there is a room to increase potato productive efficiency in the study area. This shows that households who have frequent contact and accessed loan are more efficient than those who lack extension contact and farm credit services. Technical efficiency was significantly and negatively influenced by off/non-farm income. The significant and negative influence of off/non-farm income on technical efficiency might be due to the shift of labor from potato production activities to off/non-farm activities (Table 17). The results of tobit model show that access to irrigation had no significant effect on technical efficiency but indicates there is positive relationship between them.

Table 17. Determinants of technical efficiency of potato production

Variable	Coefficient	Standard error	t-value	P> t
Family size	0.0010	0.0076	0.14	0.891
Education	-0.0016	0.0049	-0.32	0.748
ln (experience)	-0.016	0.022	-0.75	0.454
ln (Farm credit)	0.0058***	0.0021	2.76	0.006
Extension contact	0.017***	0.0067	2.46	0.014
Fragmentation	0.0028	0.0067	0.41	0.681
ln (off/non-farm income)	-0.010***	0.0037	-2.72	0.007
Livestock holding	0.0038	0.0038	0.99	0.324
Access to irrigation	0.025	0.017	1.48	0.141
Agro-ecology	-0.0075	0.021	-0.36	0.719
Sex	0.029	0.033	0.88	0.380
Participation in social organizations	0.0059	0.019	0.31	0.758
Constant	0.61***	0.079	7.74	0.000
Log likelihood	159.848			
LR chi2(12)	29.68***			
Prob > chi2	0.0031			
Pseudo R ²	-0.1023			

*** indicates the level of significance at 1 percent

Source: Model output (2014)

4.3.2. Marginal effects on technical efficiency

The marginal effects of changes in explanatory variables included in tobit model were computed following the procedure proposed by McDonald and Moffitt (1980) and Maddala (1999). The derived values for the significant explanatory variables indicate the effects of a unit change in explanatory variables on the unconditional expected value of technical efficiency, expected value of technical efficiency conditional upon being between minimum and maximum values of technical efficiency and the probability of being between these values (Table 18).

A unit increase in the value of extension contact would increase the expected value of TE by about 1.5 percent with an overall increase in the probability and the level of efficiencies by 1.6 percent. A unit increase in the value of farm credit would increase the expected value of TE by about 0.53 percent with an overall increase in the probability and the level of efficiency by 0.57 percent. A unit increase in the value of off/non-farm income would decrease the expected value of TE by about 0.94 percent with an overall decrease in the probability and the level of efficiencies by 0.1 percent (Table 18).

Table 18. Marginal effects of explanatory variables on technical efficiency

Variable	$\frac{\partial E(y)}{\partial X_j}$	$\frac{\partial E(y^*)}{\partial X_j}$	$\frac{\partial [\varphi(Z_U) - \varphi(Z_L)]}{\partial X_j}$
Family size	0.0010	0.00096	-0.00026
Education	-0.0016	-0.0015	0.00039
ln (experience)	-0.016	-0.015	0.0041
ln (Farm credit)	0.0057	0.0053	-0.0014
Extension contact	0.016	0.015	-0.0041
Fragmentation	0.0027	0.0025	-0.00069
ln (off/non-farm income)	-0.010	-0.0094	0.0025
Livestock holding	0.0037	0.0035	-0.00095
Access to irrigation	0.025	0.023	-0.0065
Agro-ecology	-0.0074	-0.0069	0.0019
Sex	0.028	0.027	-0.0059
Participation in social organizations	0.0058	0.0054	-0.0015

Source: computed based on model output (2014)

4.3.3. Determinants of allocative efficiency of potato production

The allocative efficiency scores of the sample households generated by the frontier model were used in the tobit model as a dependent variable on a number of farmer, farm and policy related explanatory variables to identify those factors that determine the allocative efficiency of the sample households in potato production. That is, two stages of analysis were carried out to determine the efficiency and identify determinant factors of efficiency. First, the efficiency of the households was analyzed using SFA. Then, tobit model was applied to identify factors that affect the allocative efficiency of sample households. The effects of change in these variables on the allocative efficiency of households in potato production were examined. Details of variable descriptions and their effects on efficiency have been given under methodology chapter in section 3.4.2., Table 4.

According to the results of tobit regression model, important variables affecting the allocative efficiency were access to irrigation, livestock holding, sex of household head and agro-ecology. Irrigation access and sex of household head were significant and positively affecting the allocative efficiency of sample households at 10 percent level of significance. This is in agreement with the aforementioned hypothesis formulated regarding the relationship between allocative efficiency and irrigation access (Table 19). That is, access to irrigation enhances farm productivity which leads to directly by raising production levels and indirectly by, for example, reducing poverty through raising incomes of farm households, and thereby affecting wellbeing status of rural households (de janvry and Sadoulet, 2001).

Agro-ecology was highly significant and positively affecting the allocative efficiency of smallholder potato producers at less than one percent level of significance. Livestock holding was highly significant and positively affecting the allocative efficiency of sample households at one percent level of significance. This is in agreement with the aforementioned hypothesis formulated regarding the relationship between allocative efficiency and livestock holding.

Table 19. Determinants of allocative efficiency of potato production

Variable	Coefficient	Standard error	t-value	P> t
Family size	-0.0079	0.0077	-1.03	0.304
Education	0.0015	0.0050	0.30	0.765
ln (experience)	0.0046	0.022	0.21	0.837
ln (farm credit)	0.0029	0.0021	1.34	0.182
Extension contact	0.0044	0.0068	0.64	0.521
Fragmentation	0.0025	0.0067	0.37	0.714
ln (off/non-farm income)	0.00055	0.0038	0.14	0.885
Livestock holding	0.0097***	0.0039	2.47	0.014
Access to irrigation	0.032*	0.017	1.82	0.070
Agro-ecology	0.063***	0.021	2.99	0.003
Sex	0.060*	0.033	1.81	0.071
Participation in social organizations	0.0018	0.019	0.0	0.927
Constant	0.501***	0.080	6.23	0.000
Log likelihood	153.9202			
LR chi2(12)	32.95***			
Prob > chi2	0.0010			
Pseudo R ²	-0.1199			

*** and * indicate the level of significance at 1 and 10 percent, respectively

Source: Model output (2014)

4.3.4. Marginal effects on allocative efficiency

The derived values for the significant explanatory variables indicate the effects of a unit change in those variables on the unconditional expected value of allocative efficiency, expected value of allocative efficiency conditional upon being between minimum and maximum values of allocative efficiency, and the probability of being between minimum and maximum values.

The computed marginal effect of livestock showed that a unit change in livestock ownership would increase the expected value of AE by about 0.86 percent with an overall increase in the probability and the level of efficiency by 0.95 percent. The computed marginal effect of agro-ecology showed that a change in dummy variable representing agro-ecology from high-land (*dega*) to mid-land (*weynedega*) increases the mean level of allocative efficiency by about 5.6 percent with an overall increase in the probability and level of allocative efficiency by 6.2 percent. That is, a change in the agro-ecology in ordered direction brings about 6.2 percent increases in the expected value of unconditional allocative efficiency. A change in the dummy variables representing irrigation access and

the sex of household head from 0 to 1 would increase the mean level of allocative efficiency by about 2.8 and 5.5 percent with an overall increase in the probability and level of allocative efficiency by 3.1 and 5.9 percent, respectively (Table 20).

Table 20. Marginal effects on allocative efficiency of potato production

Variable	$\frac{\partial E(y)}{\partial X_j}$	$\frac{\partial E(y^*)}{\partial X_j}$	$\frac{\partial [\varphi(Z_U) - \varphi(Z_L)]}{\partial X_j}$
Family size	-0.0078	-0.0071	0.0029
Education	0.0015	0.0013	-0.00055
ln (experience)	0.0045	0.0041	-0.0017
ln (Farm credit)	0.0028	0.0026	-0.001
Extension contact	0.0043	0.0039	-0.0016
Fragmentation	0.0025	0.0022	-0.00092
ln (off/non-farm income)	0.00054	0.00049	-0.0002
Livestock holding	0.0095	0.0086	-0.0035
Access to irrigation	0.031	0.028	-0.012
Agro-ecology	0.062	0.056	-0.023
Sex	0.059	0.055	-0.015
Participation in social organizations	0.0018	0.0016	-0.0007

Source: computed based on model output (2014)

4.3.5. Determinants of economic efficiency of potato production

The determinants of economic efficiency were assessed using the tobit model. According to the results of tobit model, important variables affecting the economic efficiency were access to irrigation, livestock holding, frequency of extension contact, loan size and sex of household head. Irrigation access and sex of household head were significant and positively affecting the economic efficiency of sample households at 10 percent level of significance. This is in agreement with the aforementioned hypothesis formulated regarding the relationship between economic efficiency and irrigation access (Table 21).

Livestock holding and extension contact were significant and positively affecting the economic efficiency of sample households at five percent level of significance. This is in agreement with the aforementioned hypothesis formulated regarding the relationship between economic efficiency and livestock holding. Extension service was significant at positively affecting the economic efficiency of sample households due to updated agricultural information gained by farmers from frequent extension contact. Farm credit was significant at positively affecting the economic efficiency of sample households at ten

percent level of significance. This is because access to credit is an important source of finance for agricultural activities of sample households.

Table 21. Determinants of economic efficiency of potato production

Variable	Coefficient	Std. Err.	t-value	P> t
Family size (number)	-0.0039	0.0085	-0.46	0.644
Education (year)	-0.00081	0.0056	-0.15	0.884
ln (experience) (year)	-0.012	0.025	-0.47	0.638
ln (Farm credit) (Birr)	0.0062***	0.0024	2.61	0.010
Extension contact (number)	0.015**	0.0075	1.98	0.049
Fragmentation	0.0041	0.0076	0.54	0.589
ln (off/non-farm income) (Birr)	-0.0069	0.0042	-1.63	0.104
Livestock holding in TLU	0.0096**	0.0043	2.21	0.028
Access to irrigation (dummy)	0.034*	0.019	1.75	0.081
Agro-ecology (dummy)	0.037	0.023	1.57	0.117
Sex (dummy)	0.061*	0.037	1.66	0.099
Participation in social organizations (dummy)	0.0049	0.022	0.23	0.821
Constant	0.31***	0.087	3.45	0.001
Log likelihood	125.761			
LR chi2(12)	30.45***			
Prob > chi2	0.0024			
Pseudo R ²	-0.1377			

***, ** and * indicate the level of significance at 1, 5 and 10 percent, respectively

Source: Model output (2014)

4.3.6. Marginal effects on economic efficiency

The derived values for the significant explanatory variables indicate the effects of a change in those variables on the unconditional expected value of economic efficiency, expected value of economic efficiency conditional upon being between minimum and maximum economic efficiency values, and the probability of being between these values .

A change in the dummy variables representing irrigation access and the sex of household head from 0 to 1 would increase the mean level of economic efficiency by about 3.3 and 5.9 percent with an overall increase in the probability and level of economic efficiency by 3.4 and 6.1 percent, respectively. The marginal effect of extension contact showed that a unit change in extension contact would increase the expected value of EE by about 1.5 percent with an overall increase in the probability and the level of efficiencies by 1.5 percent. A unit increase in the value of TLU would increase the expected value of EE by about 0.94 percent with an overall increase in the probability and the level of efficiencies

by 0.96 percent. A unit increase in the value of farm credit would increase the expected value of EE by about 0.61 percent with an overall increase in the probability and the level of efficiencies by 0.62 percent (Table 22).

Table 22 Marginal effects on economic efficiency of potato production

Variable	$\frac{\partial E(y)}{\partial X_j}$	$\frac{\partial E(y^*)}{\partial X_j}$	$\frac{\partial [\varphi(Z_U) - \varphi(Z_L)]}{\partial X_j}$
Family size	-0.004	-0.004	0.000002
Education	-0.001	-0.001	0.0000004
ln (experience)	-0.012	-0.011	0.000006
ln (Farm credit)	0.006	0.0061	-0.000003
Extension contact	0.015	0.015	-0.000008
Fragmentation	0.004	0.004	-0.000002
ln (off/non-farm income)	-0.007	-0.007	0.000004
Livestock holding	0.009	0.010	-0.000005
Access to irrigation	0.034	0.033	-0.000055
Agro-ecology	0.037	0.036	-0.000019
Sex	0.061	0.059	0.001036
Participation in social organizations	0.005	0.005	-0.00005

Source: computed based on model output (2014)

4.4. Impact of Irrigation on Production Efficiency and Poverty

Poverty alleviation has attracted a considerable degree of policy attention in recent years both at national and international levels. Poverty is no longer accepted as a way of life and coordinated attempts are being made to address the challenge. However, it takes concerted and deliberate economic policy efforts to generate robust and sustainable economic growth and fair distribution to an increasing share of the population to address the problems of poverty in the long term perspective.

This section deals with impact of irrigation on rural households' potato production efficiency and poverty in east Gojjam zone of Amhara region, Ethiopia. Irrigation program is one of the means of helping the farm households in the rural areas in the country to escape poverty by improving farm production efficiency. As the current study deals with rural households' efficiency and poverty, it also aims at assessing the impact of irrigation program on the potato production efficiency and rural poverty of the irrigators using PSM method. One of the problems encountered in this study was that there were no baseline data to assess the level of efficiency and welfare improvements brought by irrigation

program. The possible option available was to compare this group with the irrigation non-users which were supposed to be similar with the irrigation users in some common variables. In order to reach at such a conclusion, the irrigation-users were compared with all the non-users. The irrigation-users were found to have a better status than the non-users in terms of welfare and efficiency except the insignificant positive impact of irrigation on technical efficiency.

4.4.1. Estimation of propensity score

Propensity Score Matching (PSM) method was used for estimating the impact of irrigation on potato production efficiency and mean adult equivalent annual consumption expenditure using `psmatch2` command and STATA version 11 software. Covariates included in PSM model to estimate propensity score are presented in table Table 23.

Table 23. Estimation of propensity score

Variable	Coefficient	Standard error	z	P> z
Age	-0.002	0.009	-0.22	0.825
Family size	-0.021	0.067	-0.32	0.748
Education	0.024	0.043	0.56	0.578
Loan size	-0.0001	0.0001	-1.05	0.293
Extension contact	0.15	0.060	2.52	0.012
Total cultivated land	0.28	0.131	2.12	0.034
Livestock	0.087	0.034	2.54	0.011
Eucalyptus	-.00002	0.00006	-2.55	0.011
Sex	-0.11	0.62	-0.18	0.856
Marital status	-0.14	0.22	-0.64	0.520
Constant	-0.86	0.97	-0.89	0.375
Log likelihood	-185.719			
LR chi ² (10)	24.68			
Prob > chi2	0.0060			
Pseudo R ²	0.0623			

Source: Model output (2014)

4.4.2. Choice of matching algorithm

For choosing the best matching algorithm the most widely used ones, namely nearest neighbor, radius caliper and kernel matching estimators were compared. The choice of the best estimator was based on four criteria; namely, balancing test, pseudo R², matched zsample size and mean standard bias (Caliendo and Kopeinig, 2008). The matching estimator which balances more independent variables, has low mean standard bias and results in large matched sample size was chosen as the best estimator of the data at hand.

Accordingly, radius calliper matching method with bandwidth of 0.15 was found to be the best estimator of the data at hand. As depicted in Table 24, relatively, this estimator resulted in high number of matched covariates (10), large number of matched sample size (286) and low means standard bias (4.4); which is in a range of 3-5% acceptable threshold for the bias remaining after matching although it has higher pseudo R^2 compared to kernel matching with 0.1 bad with. Thus, radius calliper with band width 0.15 was selected as the best matching estimator. Thus, in what follows estimation results and discussions are the direct outcomes of the radius calliper matching algorithm with a band width of 0.15.

Table 24. Criteria for choosing matching method

Matching method	Number of insignificant variables	Pseudo R^2	Matched sample size	MeanB
NN matching with-out replacement (1)	9	0.018	254	6.8
NN matching with replacement (1)	6	0.050	285	13.4
RC (D= 0.01)	9	0.027	278	10.5
RC(D= 0.15)	10	0.010	286	4.4
RC(D= 0.2)	10	0.018	286	4.4
RC (D= 0.25)	10	0.028	286	8.4
RC (D= 0.5)	7	0.055	286	13
KM (BW = 0.1)	10	0.007	286	4.7
KM (BW = 0.25)	10	0.016	286	5.5
KM (BW = 0.5)	6	0.049	286	13.3

Source: Computed based on survey data (2014)

Note: BW = band width; KM = kernel matching; NN = nearest neighbour; RC = radius caliper

4.4.3. Common support

Matching of participant and non-participant households was carried out to determine the common support region. The basic criterion for determining the common support region is to delete all observations whose propensity score (the conditional treatment probability) is smaller than the minimum propensity scores of participants and larger than the maximum in the control group (Caliendo and Kopeining, 2008). That is, deleting all observations out of the overlapping region. The summary statistics of propensity scores of households depicts that the common support region lies within the range of 0.046 to 0.93 propensity scores for both participant and non participant households in study area with mean of 0.45. The propensity scores range from 0.092 to 0.93 for irrigation user households with mean of

0.49 and 0.046 to 0.84 for irrigation non-user households with mean of 0.41. Therefore, the propensity scores for the common support region (overlapping region) range from 0.092 to 0.84 (Table 25). The distribution of the estimated propensity scores and the overlap between the groups are displayed in Fig.8. For each pairwise comparison, the figure illustrates the balanced distribution between the irrigation user and non-user households.

Table 25. Common support and distribution of propensity scores (PS)

Treatment assignment	Common Support		Total	Distribution of PS		
	Off support	On support		Mean	Minimum	Maximum
Untreated	0	159	159	0.41	0.046	0.84
Treated	2	127	129	0.49	0.092	0.93
Total	2	286	288	0.45	0.046	0.93

Source: Computed based on survey data (2014)

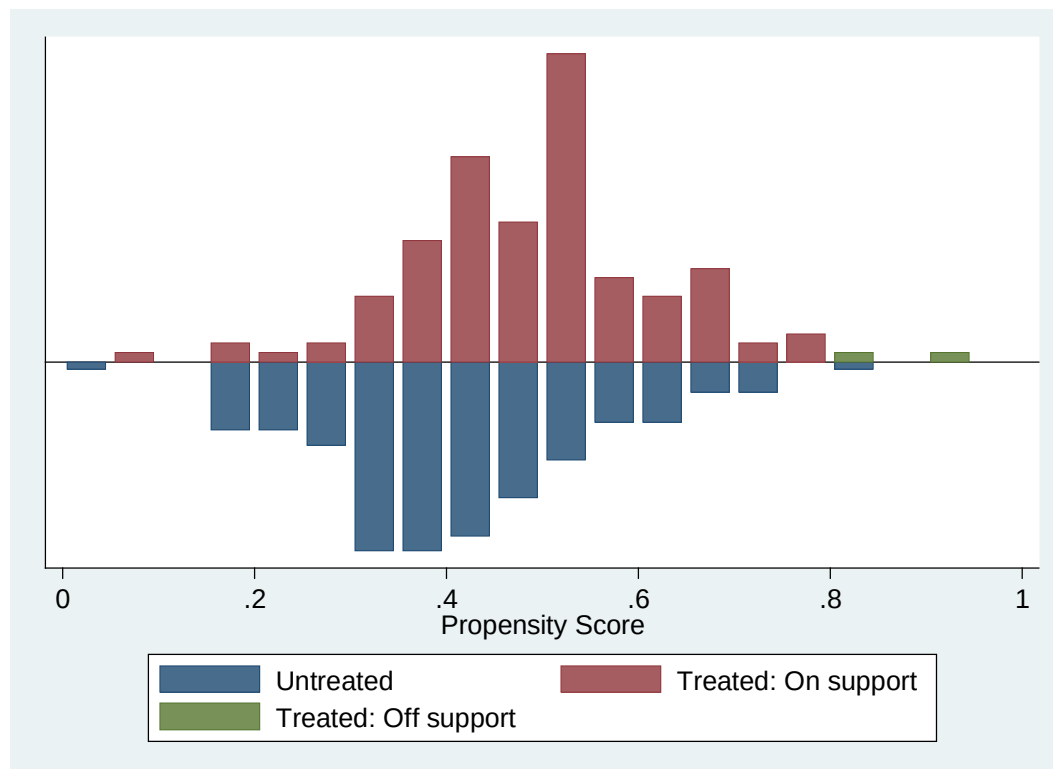


Figure 9. Propensity score distribution and common support area

Source: Own data, plotted using *psgraph*

4.4.4. Covariates imbalance test

Covariates imbalance test shows no significant difference between the two groups or irrigation users and non-users after matching in all explanatory variables proving the appropriateness of the matching estimator chosen. P-value shows that before matching

almost half of chosen variables exhibited statistically significant differences while after matching all of the covariates are balanced and become statistically insignificant. That is, the process of matching thus created a high degree of covariate balance between irrigation users and non- users that are ready to be used in the estimation procedure (Table 26).

Table 26. Covariates imbalance test

Variable	Before matching				After matching			
	Mean		%bias	p> t	Mean		%bias	p> t
	Treated	Control			Treated	Control		
Age	45.19	45.157	0.4	0.973	45.22	45.14	0.8	0.950
Famliy size	4.31	4.24	5.5	0.648	4.28	4.29	-0.3	0.980
Education	0.65	0.57	4.3	0.712	0.64	0.56	4.1	0.746
Loan size	248.06	422.01	-16.7	0.169	251.97	225.02	2.6	0.801
Extension contact	3.47	3.12	26.3	0.027	3.45	3.29	11.9	0.335
Total cultivated land	1.69	1.54	23.4	0.048	1.65	1.61	6.9	0.56
Livestock	4.65	4.003	29.0	0.015	4.61	4.49	5.4	0.676
Eucalyptus	744.69	1069.5	-22.6	0.059	754.06	876.87	-8.5	0.441
Sex	0.94	0.92	7.6	0.523	0.94	0.94	-2.4	0.833
Marital status	1.17	1.24	-10.2	0.396	1.17	1.16	1.3	0.911

Source: Computed based on survey data (2014)

The pseudo- R^2 indicates how well the regressors explain the participation probability. The low pseudo- R^2 (0.010) and the insignificant likelihood ratio tests indicated by the higher p-value (0.970) support the hypothesis that both irrigation users and non-users have the same distribution in covariates after matching. In order to evaluate how well the PSM performed, this study also compared the mean SB after matching, i.e., reduction of the bias in the covariates included in the PSM model to estimate the propensity score. Looking at matching irrigation users and non-users, it appears that an extremely good matching quality was attained. The mean standard bias (SB) of 14.6% before matching was reduced to 4.4% after matching (Table 27). This figure is within the range of 3–5%, which is considered as an acceptable threshold for the remaining bias after matching (Caliendo and Kopeinig, 2008).

Table 27. Mean standard bias

Sample	Pseudo R ²	LR chi ²	p>chi ²	MeanBias	MedBias
Unmatched	0.062	24.68	0.006	14.6	13.4
Matched	0.010	3.42	0.970	4.4	3.3

Source: Computed based on survey data (2014)

4.4.5. Sensitivity analysis

The sensitivity analysis of the model was conducted to check whether PSM is robust or not against unobserved or omitted variables which may lead to hidden bias. If the study is free of hidden bias, the effect of unobserved variable will be zero and the participation probability will solely be determined by observed characteristics. However, if there is hidden bias, two individuals with the same observed covariates have differing chances of receiving treatment (Rosenbaum, 2002). Rosenbaum bounds show how changing the unobserved factor by γ will not make the confidence interval of the impact of the observed variables on the outcome variable include zero. The model has passed sensitivity test (Appendix Tables 4 and 5) in the sense that the changes with less than factor of 2.5 in the unobserved variable(s) would not make the impact of irrigation on efficiency and income insignificant.

4.4.6. Average treatment effect on treated (ATT)

Results of ATT analyses shows irrigation have a significant positive impact on the adult equivalent annual consumption expenditure of the households. After controlling for pre-intervention differences in socio-economic, demographic, and institutional characteristics of the irrigation user and non-user households, it has been found that, on average, participation in irrigation has increased total annual expenditure by 459.05 birr (11.7%) compared to non-participants. This result is in line with the findings of Hussain and Wijerathna (2004) and Dillon (2008). Similarly, results of ATT analyses also show that irrigation have a significant and positive impact on participating households' technical, allocative and economic efficiencies. That is, participation in irrigation has increased technical, allocative and economic efficiencies of irrigation user households by 0.035 (4.92%), 0.030 (4.08%) and 0.039 (7.4%), respectively compared to irrigation non-user households indicating the efficiency improvement due to irrigation (Table 28).

Table 28. Average treatment effect on treated (ATT)

Variable	Sample	Treated	Controls	Difference	S.E	T-stat
Adult equivalent annual expenditure	Unmatched	3898.01	3442.57	455.43	191.40	2.38**
	ATT	3866.69	3407.64	459.05	202.12	2.27**
Technical efficiency	Unmatched	0.714	0.676	0.037	0.017	2.17**
	ATT	0.712	0.677	0.035	0.018	1.97*
Alocative efficiency	Unmatched	0.734	0.696	0.038	0.017	2.19**
	ATT	0.735	0.705	0.030	0.018	1.66*
Economic efficiency	Unmatched	0.527	0.479	0.047	0.019	2.44**
	ATT	0.526	0.486	0.039	0.020	2.00**

Source: Computed based on survey data (2014)

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

This section summarizes the key findings of the study. It then puts forward concluding remarks and gives important policy implications of the results of the study.

5.1. Summary

Limited access to irrigation, and production inefficiencies are among the most pressing problems responsible for an increasing gap between demand for and supply of food. One of the important strategies to meet increasing food demand and reduce rural households' poverty is to boost crop production and productivity through the use of irrigation.

Potato is the major root crop that has been produced using irrigation by the majority of households in Ethiopia, but less effort has been made to boost its production and productivity. Little attention has been given to irrigated farming and the various socioeconomic, demographic and institutional factors that determine the contribution of irrigation towards improvement in potato production efficiency and welfare of the households.

The objective of this study was to examine the impact of irrigation access in enhancing production efficiency and alleviating rural households' poverty in east Gojjam zone of Amhara region, Ethiopia. For this study, both primary and secondary data were used. The primary data were gathered from 288 sample households (129 irrigation users and 159 non-users who do not have access to irrigation), using personal interview. Secondary data were collected from different sources to support primary data. Subsequently, the technical, allocative and economic efficiencies of the sample households in potato production were assessed and the factors that affect these were identified. Moreover, poverty indices were determined and the impact of irrigation on rural households' poverty and potato production efficiency were evaluated. The relative importance of the factors that influence potato output and the efficiency of the households were determined using advanced and rigorous econometric tools. Poverty indices were determined using FGT formula and impact of irrigation on potato production efficiency and rural households' poverty were evaluated using PSM method.

The results of descriptive statistics show that size of land holding, livestock holding, the extent of eucalyptus trees owned and the residential house structure were identified as key indicators of the wealth of the households. Expenditure is one of the most commonly used measures of welfare of a household. Rural households in the study area spend their income on food and non-food items. It was examined that most of the households generated per adult equivalent annual income more than the income poverty line. The income poverty gap and severity indices were also determined but lower inequality among the poor as the poor households that fall below the poverty line did not have high income difference. It was also found that less number of the irrigation user households generated per adult equivalent annual income less than the income poverty line compared to irrigation non-user households. The sources of poverty and food insecurity were mainly related to small land size, lack of oxen, pests, crop disease, not working hard, and disability (over agedness and illness).

The econometric analysis conducted to assess the production of potato indicated that potato output was significantly determined by a number of factors. The SFA results revealed that land, seed and oxen had a significant and positive effect on potato production under the total farming system. This suggests that increasing land utilization in potato production would significantly increase potato output. That is, further increase in the level of utilization of land for potato production would contribute to increased level of potato output. Households who used optimal or recommended amount of seed receive higher potato yields. Using oxen for farm operation enhances potato production and is a key input in potato production, particularly if farmers have to use improved seeds and fertilizers. This is revealed from the result that the effects of seed and oxen were highly significant under the total farming system.

The maximum likelihood estimate of the model shows that potato output elasticities associated with seed and oxen inputs were positive and significant in the irrigated potato farming. The elasticity of output due to oxen input was highest followed by elasticity of output due to seed in the irrigated farming. In non-irrigated farming system, elasticity of output due to land was positive and significant, with the highest being elasticity of output due to oxen.

The technical efficiency of sample households indicated that the average level of technical efficiency was 69 percent. This shows that there was a significant technical inefficiency in

potato production. The analysis of potato production efficiency resulted in mean technical and allocative efficiency estimates higher for the irrigated (77, 74.5 percent) than for non-irrigated potato farming (63, 63 percent), respectively. This shows overall economic efficiency estimates for irrigated, non-irrigated and the total potato farming were 57, 40 and 46 percents, respectively. This indicates that non-irrigated households were more inefficient in potato production than irrigated households in the study area even though irrigation did not have significant impact on technical efficiency.

The tobit model was used to identify the determinants of efficiency. The determinants of efficiency were mainly related to access to irrigation, loan size, extension contact, livestock holding, agro-ecology, off/non-farm income and sex of household head. The efficiency ranges among all households imply that there is more scope for increasing potato output with the existing technology and input levels. Farm credit, extension contact and off/non-farm income were significant factors that influenced potato production technical efficiency whereas access to irrigation, livestock holding, agro-ecology, and sex of household head were significant factors that influenced potato production allocative efficiency. Overall economic efficiency was determined by access to irrigation, livestock holding and extension contact, sex of household head and loan size of households.

This study also evaluated impact of irrigation on rural households' poverty and potato production efficiency in irrigated and non-irrigated farming systems. Results of PSM estimation indicate that there are significant differences in adult equivalent annual consumption expenditure and potato production efficiencies between irrigation users and non-user households, which could be attributable to the irrigation utilization. The results revealed that households that participate in irrigation practice have got an improvement of 11.7% in consumption expenditure and 4.92%, 4.08% and 7.4% in technical, allocative and economic efficiencies, respectively compared to households that had no irrigation access to participate in irrigation practice.

In general, this study analyzed potato production efficiency, its determinants and impact of irrigation access on potato production efficiency and rural households' poverty under irrigated and non-irrigated farming systems in east Gojjam zone of *Amhara* region, Ethiopia. It was found out that access to irrigation can bring about a significant improvement in allocative and economic efficiency of potato production and welfare of households.

5.2. Conclusion and Recommendations

Based on the findings of this study, the following conclusions and recommendations or policy implications are made: Farm size was a key variable that influenced the output of potato. This is consistent with a priori hypothesis about the relationship between potato production and land size. Since it is not possible to increase land size, creating the means by which rural children who fail to pass exam get training and employment (self or others) can help reducing the pressure of further subdivisions of the current land owned by the rural households. Thus, policies that can increase or maintain the existing farm size per household can be taken as an alternative to attain gains in crop production in general and potato production in particular.

The use of oxen power in farm operations such as land preparation, planting and weeding was highly significant in influencing potato output. This can be through its effect on better utilization of other inputs such as labor and fertilizer. In other words, oxen-power augments labor input and enhances its productivity by reducing the time and drudgery needed to accomplish farm operations such as land preparation, sowing and weeding. However, the oxen holding of farmers in the study areas were found to be inadequate. As a result, initiatives that improve oxen holding of the farmers such as targeted credit and improved animal health service have to be looked for. Again, initiatives that enhance the traction power of the existing oxen such as improved feeding and management practices as well as improved farm implements have to be introduced to improve potato production.

The tobit model results indicated that farm credit, extension contact and off/non-farm income were significant factors that influenced potato production technical efficiency whereas access to irrigation, livestock holding, agro-ecology, and sex of household head were significant factors that influenced potato production allocative efficiency. Overall economic efficiency was determined by access to irrigation, livestock holding, sex of household head, frequent extension contact, and loan size of sample households.

Irrigation access was found to be one of the most important variables in increasing allocative and economic efficiencies. As the description of the study area shows, the zone has the potential both for traditional and modern irrigation. Government and other

concerned bodies have to work on developing irrigation facilities and support the households to develop by their own too.

Availability of credit opportunities is known to enhance the use of technologies and alleviate the difficulty that households face in getting access to these technologies. The findings of this study were in line with this general fact that technical efficiency increases with availability of credit. Therefore, improving households' access to easy and affordable credit sources should be given policy attention to increase technical efficiency.

It was examined that frequent extension contact was found to be one of the most important variables in increasing technical efficiency. In line with the hypothesis extension measured in number of contact influenced technical efficiency positively. Thus, government extension service program should provide more and longer contact with the farmers to increase technical efficiency.

Livestock holding was found to be one of the most important variables in determining allocative and economic efficiencies of smallholder potato producers. This is in agreement with the aforementioned hypothesis formulated regarding the relationship between efficiency and livestock holding. From this it can be inferred that livestock holding enhances efficiency of households. Households should, therefore, be financially supported to have optimal and/or productive heads of livestock through financial supports.

Off/non-farm income had negatively affected the technical efficiency of potato under smallholder production system. This is because increased off/non-farm opportunities reduce the amount of inputs allocated for farm operation. Furthermore, off/non-farm activities located at distant places from farms can cause the absence of farm operator at critical periods, for example during the time of weeding and harvesting, as outflow of labor is common in these areas. Therefore, creating off/non-farm employment opportunities in nearby places and during off seasons can be taken as a policy measure to achieve a sustained improvement in technical efficiency.

Being male-headed had positively affected both allocative and economic efficiencies of potato production. This can be attributed to more financial access that male-headed households get to buy farm inputs compared to female-headed sample households. Thus, the problem of finance to access the purchased inputs by female-headed households could

be alleviated through availability of credit and empowering women by giving special provisions to them in income generating schemes like the community development activities promoted by the government projects.

The poverty headcount, gap and severity indices show that some of the sample households were below the poverty line, some others were very far from the poverty line and the poor below the poverty line were not equally poor indicating that the welfare was found to be different among the households. Thus, investigations should be made into the irrigation access, extension and credit services, land possession, livestock holding, work habits and other related issues that brought such a differential nature of rural household poverty and act on the problems. Different development activities should also be designed and implemented for land less people.

Results of ATT analyses show that access to irrigation made the households to incur adult equivalent annual income more than that of the non-users of irrigation who were selected to be counterfactual of the irrigation users. Results of ATT analyses also show that irrigation had significant and positive impact on households' allocative and economic efficiencies. This implies irrigation access was found to be one of the most important variables in increasing allocative and economic efficiencies. Thus, government and other concerned bodies have to work on developing irrigation facilities and support the households to develop by their own too.

It is important to note that by improving the overall economic efficiency of both irrigated and non-irrigated farming more gains in production could be achieved. This means, additional efforts should be devoted to examining the impact of irrigation on efficiencies of potato production in each farming systems. Finally, studies that base irrigation impact on all the components of multidimensional poverty are recommended so as to monitor poverty dynamism in the future. It can also be concluded that participation in irrigation is crucial in increasing the rural households' allocative and economic efficiencies and could improve their welfare. Therefore, governmental and non-governmental organizations and other stakeholders should encourage the current effort of irrigation development program which improves household level income and agricultural productivity of the country in general and the study area in particular.

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7. APPENDICES

I. Survey Questionnaire

Haramaya University

Post Graduate Program

PhD Dissertation Project in Agricultural Economics

Prepared By Assefa Delesho (PhD candidate, Haramaya University)

Instructions for Enumerators

1. Politely introduce yourself to the respondent and explain the objective or purpose of the study as follows:

Dear respondent, the purpose of this questionnaire is to collect household level primary data from rural farmers of East Gojjam zone on farm production activities, production inputs and outputs, farm attributes, household composition and characteristics, household income and consumption expenditure. The objective of the survey is to secure first-hand data for PhD dissertation research titled as: *'Impact of Irrigation Access on Households' potato Productivity and Rural Poverty in East Gojjam zone of Ethiopia'*.

Dear respondent, the result of this study will help different stakeholders and policy makers to make appropriate measures on irrigation development, farm productivity and poverty reduction in the future. Your responses are confidential and only used for research purpose. Therefore, you are kindly requested to provide genuine responses.

Thank you in advance for your time and cooperation!

2. Ask the respondents exactly in the way the questions are written.
3. For multiple choice questions encircle the codes and for close-ended and open-ended questions clearly write the responses of the household.
4. Make sure that all of the questions are neatly and correctly filled or answered.
5. Please, contact the researcher if there is something not clear.

1. General Information on the Study Irrigation Project and Household

1.1. Name of the respondent household head _____

1.2. Code _____ Woreda _____ Kebele _____ Gott _____

1.3. Marital status: 1. Live with spouse 0. Live without spouse

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

1.5. Name of the irrigation scheme _____

1.6. Agro-ecology: 1. Dega 2. Weyna Dega 3. Kola

2. Household Composition and Characteristics

2.1. Name of all family members, their sex, age and education status

No.	Name	Sex (M, F)	Age in years	Education in grade attended
1				

3. Farm Inputs and Output

3.1. Crops cultivated and inputs used in rain-fed agriculture in 2013/14 production year

No.	Crops cultivated	Land area in hectare	Man days used (both family and hired)	Oxen days used	Fertilizer used in kg	Seed used in kg	Output produced in quintal
1	Barley						
	Wheat						
	Teff						
	Maize						
	Sorgum						
	Bean						
	Pea						
	Chick pea						
	Lentil						
	Potato						
	Onion						
	Pepper						
	Cabbage						
	Other specify						

3.2. Labour Input

3.2.1. Family time allocated to own farm activities for potato production

Crop cultivated	Area in hectare	Ploughing				
		Days used to finish it	Number of adult members involved		Total number of hours worked	
			Male	Female	Male hrs	Female hrs
For rain-fed potato						
For irrigated potato						
			Weeding			
For rain-fed potato						
For irrigated potato						
			Harvesting			
For rain-fed potato						
For irrigated potato						
			Threshing			
For rain-fed potato						
For irrigated potato						

3.2.2. Hired farm labor use of the household for farm activities

3.2.2.1. Have you used hired labor on the family farm for different agricultural activities?

0. No 1. Yes

3.2.2.2. Use the following table to fill number of hired labor hours and days used in each agricultural activity for potato production

Crops cultivated	Area in hectares	Ploughing					
		Number of Days employed		Number of hired laborers used		Total hours worked by hired laborers	
		Male	Female	Male	Female	Male hrs	Female hrs
rain-fed potato							
irrigated potato							
				Weeding			
rain-fed potato							
irrigated potato							
				Harvesting			
rain-fed potato							
For irrigated potato							
				Threshing			
rain-fed potato							
irrigated potato							

3.3. Farm land ownership by a household

3.3.1. Total land owned in hectare _____

3.3.2. How many number of cultivated farm plots do you have owned in different areas? _

3.3.3. Ownership status and amount of cultivated farm land in hectare:

1. Owned _____ 2. Rented in _____ 3. Share cropping _____ 4. Other, specify _

3.3.4. Distance from home to farm _____ km

3.3.5. The percentage of soil fertility on plots of land owned by the household

Plot of land allocated	% fertile	% not fertile	% not suitable for farming	Type of soil according to local classification
Annual crop				
Perennial crop				
Trees				

4. Participation in Irrigated Agriculture

4.1. Have you participated in irrigation in this cropping season? 0. No 1. Yes

4.2. Number of years of your participation is _____ year

4.3. Did you get adequate irrigation water in this cropping season? 0. No 2. Yes

4.4. What is the type of land ownership and amount of land of your irrigated crop field in hectare? 1. Owned _____ hectare 2. Rented _____ hectare 3. Shared _____ hectare

4.5 Crops cultivated and inputs used in irrigated agriculture in 2014 E. C. production year

No.	Crops cultivated	Land area in hectare	Man days used both family and hired	Oxen days used	Fertilizer used in kg	Seed used in kg	Output produced in quintal
1	Potato						
2	Maize						
3	Onion						
4	pepper						
5	Chick pea						
6	Lentil						
7	Cabbage						
	Other, specify						

5. Inputs used and Value of inputs in Rain fed Potato Production

5.1. Value of farm land used (Rental value for cultivated land) in rain-fed potato production

Total area rented in hectare	Rental value in Birr per hectare	Total rental value in Birr		Previous year rental value in Birr	

5.2. Hired wage rate paid per day per person for main agricultural activities in rain fed potato production

Hired wage paid for each agricultural activities				
Types of farm activities	Hired wage rate per day		Total wage paid to hired labor	
	Male	Female	Male	Female
Ploughing				
Weeding				
Harvesting				
Thershing				

5.3.Type and value of farm equipment used (rental value of agricultural tools) in-rain fed potato production

No.	Type of farm equipment used	Hours used	Rental value Birr per hour		Total rental value in Birr	
1						
2						
3						
	Other specify					

5.4. Farm animal used in production

5.4.1. Have you used animals in farm production this year? 0. No 1. Yes

5.4.2. How much is total estimated rental value of each farm animals used in rain-fed potato production?

No .	Type of farm animal	Service days used	Rental value in Birr per day		Total purchase value in Birr	
1	Oxen					
2	Horses					
3	Mules					
	Other, specify					

5.5. Use of chemical fertilizers

5.5.1. Have you used chemical fertilizer in this agricultural season? 0. No 1. Yes

5.5.2. If yes to 5.5.1. indicate the quantity and value of fertilizers used in rain-fed potato production

No	Type of chemical fertilizer	Quantity used in Kgs	Value in Birr	
1	UREA			
2	DAP			
3	Both			

5.6. Use of Seed

5.6.1. Local potato seed used: Type _____ quantity _____Kg price _____ per kg.

5.6.2. Have you used improved potato seed in this agricultural season? 0. No 1. Yes

5.6.3. If yes to 5.6.2, indicate the quantity and value of improved potato seed used in rain-fed agriculture

No.	Type of improved seed	Quantity used in Kgs	Value in Birr	
	Other specify			

6. Inputs Used and Value of inputs in Irrigated Potato Production

6.1. Value of farm land used (Rental value for cultivated land) in irrigated potato production

Total area rented in hectare	Rental value in Birr per hectare	Total rental value in Birr		Previous year rental value in Birr	

6.2. Hired wage rate paid per day per person for main agricultural activities in irrigated potato production

Hired wage paid for each agricultural activities				
Types of farm activities	Hired wage rate per day		Total wage paid to hired labor	
	Male	Female	Male	Female
Ploughing				
Weeding				
Harvesting				
Threshing				

6.3. Type and value of farm equipment or agricultural tools used in irrigated potato production

No.	Type of farm equipment used	Hours used	Rental value Birr per hour		Total rental value in Birr	
1						
2						
3						
	Other specify					

6.4. How much is total estimated rental value of farm animals used in irrigated potato production?

No.	Type of farm animal	Service days used	Rental value in Birr per day		Total purchase value in Birr	
1	Oxen					
2	Horse					
3	Mule					
	Other specify					

6.5. Indicate the quantity and value of fertilizers used in irrigated potato production

No.	Type of chemical fertilizer	Quantity used in Kgs	Value in Birr	
1	UREA			
2	DAP			
3	Both			

6.6. Indicate the quantity and value of potato seed used in irrigated agriculture

No.	Type of potato seed	Quantity used in Kgs	Value in Birr	

7. Extension Program

7.1. How much is your work experience in rain fed agriculture : _____ year

7.2. How many times do you plough your land before sowing? _____

7.3. Frequency of potato weeding is _____ times

7.4. Did you harvest your crop on time? 0. No 1. Yes

7.5. Have you ever exercised potato row planting this cropping season? 0. No 1. Yes.

7.6. Did you get advisory services on your farm activities this year? 0. No 1. Yes

7.7. Did extension workers visit your crop field in cropping seasons? 0. No 1. Yes

7.8. If yes to 7.7, would you state the number of visits for past cropping seasons? _____

7.9. Generally, what were the problems you encountered related to crop production last year? 1. Input unavailability 2. Small land size 3. Poor soil fertility 4. High input price 5. Other, specify _____

8. Input Prices During Ploughing and Weeding Seasons

8.1. Average local daily wage rate for hired labor _____ Birr

8.2. Average local daily non-farm wage rate _____ Birr

8.3. Average rental price of a pair of oxen a day _____ Birr

8.4. Average cost of chemical fertilizer used in farm production: UREA _____ Birr
DAP _____ Birr

8.5. Estimated cost of manure if used in farm production? _____ Birr.

8.6. Estimated cost of compost if used in farm production? _____ Birr.

8.7. The price of improved potato seed used _____ Birr

8.8. Average rental value of land per hectare _____ Birr

9. Infrastructure/Local Grain Prices and Market services

9.1. How far is the nearest market center from your residence? _____ Km.

9.2. How far is the nearest local market from your residence? _____ Km.

9.3. Indicate the average price of each of the following main crops during the specified agricultural seasons (Birr in quintal)

Type of crop	Planting time	Weeding time	Harvesting	Threshing
<i>Teff</i>				
Wheat				
Barely				
Maize				
Beans				
Peas				
Haricot bean				
Potato				
Onion				
pepper				
Chick pea				
Lentil				
Cabbage				
Other, specify				

10. Measures of poverty

10.1. Housing units and facilities

10.1.1. What is the major material used for the construction of *the roof* of the housing unit?

1. Corrugated iron 2. Cement 3. Thatch 4. Wood and mud 5. Bamboo 6. Other _____

10.1.2. What is the major material used for the construction of *the wall* of the housing unit?

1. Wood and mud 2. Wood and thatch 3. Stone and mud 4. Stone and cement 5. Bamboo 6. Other, specify _____

10.1.3. What type of toilet facility does the housing unit have?

1. Has no toilet 2. Pit, private 3. Pit, shared 4. Other specify _____

10.1.4. What type of kitchen does the housing unit have?

1. Has no kitchen 2. Traditional kitchen, private 3. Traditional kitchen, shared

10.1.5. What is the main source of drinking water for the members of this housing unit?

1. Tap water 2. Protected well/spring 3. Un protected well/spring/river 4. Other

10.1.6. What types of fuel does the resident of the housing unit mostly used for cooking?

1. Uses no fuel 2. Electricity 3. Gas 4. Kerosene 5. Fire wood/Charcoal

10.1.7. Do you have the following?

Item	Types (write 'No' if not having)	Quantity (if yes)	Approximate buying price in Birr
Bed			
Radio			
Tape recorder			
Television			
Telephone			
Watch/clock			
Tables			
Chairs			
Sofa			
Kerosene lamp			
Electric stove			
Blanket			
Drinking utensils			
Eating utensils			
Milk container			
Mill			
Car			
Motor pump			
Others			

10.2. Education

10.2.1. Do you have access and used educational facilities?

Name of family member attending education	Grade attended	Distance from the school in Km

10.2.2. Were there family members dropping out of school (this includes even the parents)

Name of family member	Sex	Grade	Year	Reason

For reason select: 1. Being married 2. Could not pay for education 3. Health problem 4. Underperformance 5. Other specify_____

10.3. Health facilities

10.3.1. Do you have access and used health facilities?

Name of family member attending medical care	Frequency of attendance	Distance from the facility in Km

10.3.2. Episode of illness by family members in the last 12 months

Name of the household member	Sex	Age	Type of illness	Went to clinic? (Yes, No)	Approximate cost	Cured? ('yes' or 'No')

10.4. Credit service

10.4.1. Have you ever borrowed money in the last 12 months? 0. No 1. Yes

10.4.2. If yes to 10.4.1, how much is the amount of credit received? _____ Birr

10.5. Food security

10.5.1. Frequency of feeding per day: adult _____ children _____

10.5.2. Do your family take the appropriate amount during each meal? 0. No 1. Yes

10.5.3. If "No" to 10.5.2, what is the possible reason? _____

10.5.4. How many days you eat meat or milk in a month? Meat _____ milk _____ days

10.5.5. Do your babies get milk to drink? 0. No 1. Yes

10.5.6. If Yes to 10.5.5, what is the source? 1. Own cow(s) 2. Buying from outside

3. Temporary transfer of cow from relatives 4. Gift of milk from relatives in some containers 5. Other please specify _____

10.5.7. Seasonality in food problem: Make a tick (✓) in front of the months where he/she faced food shortage in the past 12 months to show food sufficiency

Month	Food Shortage	Reason for the shortage	Percentage of food sufficiency
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

10.5.8. What are the problems you encountered related to crop production last year?

1. Small land size 2. Poor soil fertility 3. Input unavailability 4. High input price

Other please specify _____

10.6. Clothing: Do you face any problem related to clothing? 0. No 1. Yes

11. Household Expenditure

11.1. Household consumption of food and non-food items including durable goods

11.1.1. Household food consumption expenses in a week

List of consumption items	Source	Unit	Weekly consumption	Unit price	Total expenditure
Teff		Kg			
Wheat		Kg			
Barely		Kg			
Rice		Kg			
Maize		Kg			
Beans		Kg			
Peas		Kg			
Chick pea		Kg			
Onion		Kg			
Potato		Kg			
Sweet potato		Kg			
Milk		Litre			
Butter		Kg			
Mutton		Kg			
Beef		Kg			
Chicken		No.			
Fish		No.			
Eggs		No.			
Food oil		Litre			
Salt		Kg			
Fruit		Kg			
Bread		No.			
Tea		Cup			
Sugar		Kg			
Soft drinks		Bottle			
Tella		Litre			
Areke		Litre			
Total					

Note: for source write 1. if own produced 2. if purchased 3. if gift

11.1.2. Household non-food consumption expenses in 2013/14 for the past 12 months

List of consumption items	source	Unit	Yearly consumption	Unit price	Total expenditure
Non-durable goods					
Shoe		No.			
Clothing		No.			
Health		No.			
Education		No.			
Gas/fuel		Litre			
Cow dug		Local unit			
Electricity charges		Meter			
Telephone charges		Meter			
Water charges		Meter			
Transportation		Km			
Soap		No.			
Battery and dry cell		No.			
House rent		No.			
Rent for shop		No.			
Salary for H/ servant		No.			
Loan payment		Time			
Tax		Time			
Charities		Time			
Legal disputes		Time			
Recreation		Time			
Ceremonial occasions		Time			
Other, specify					
Total					
Durable goods					
Tables		No.			
Chairs		No.			
Radio		No.			
Tape		No.			
Other, specify					
Total					

Note: for source write 1. if own produced 2. if purchased 3. if gift

11.2. Did you give remittance (cash or crop) to someone else?

Gave _____ Birr _____ quintal of _____

11.3. Livestock Consumption

11.3.1. Livestock owned and consumed by households

List of livestock	Total number owned	Market value in Birr if sold	Consumed	
			Qty.	Value in Birr
Oxen				
Cow				
Heifer				
Calf				
Sheep				
Goat				
Hen				
Horse				
Mule				
Donkey				

11.3.2. Livestock purchased for consumption in the past 12 months?

Livestock	Number bought	Unit cost	Total cost	Source of money	Purpose of buying
Cow					
Ox					
Steers					
Heifer					
Calves					
Sheep					
Goat					
Chicken					

11.3.3. Livestock products purchased for consumption in the last 12 months

Product type	Unit	Amount bought	Total cost	Source of money	Purpose of buying
Fresh milk					
Yogurt					
Cheese					
Butter					
Beef					
Mutton					
Egg					
Others					

11.4. Was there any time you failed to cover your expenses? 0. No 1. Yes

11.5. If “yes” to 11.4, how did you manage the problem? _____

12. Household Income

12.1. Crop income: List of crops grown, annual output in quintals and monetary value in Birr at recent market price for both rain fed and irrigated agriculture

Crops grown	Output in quintals (both rain fed and irrigation)	Unit price per quintal	Monetary value (output*unit price)	The previous Year's yield
<i>Teff</i>				
Wheat				
Barely				
Maize				
Beans				
Peas				
Potato				
Onion				
pepper				
Chick pea				
Lentil				
Cabbage				
Other, specify				

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

12.2. Livestock ownership and income

12.2.1. Livestock wealth, number of livestock sold and income earned by household

List of livestock	Total number owned	Market value in Birr if sold	Sold	
			Qty.	Value in Birr
Oxen				
Cows				
Heifer				
Bull				
Sheep (adult)				
Sheep (young)				
Goat (adult)				
Goat (young)				
Hen				
Horse				
Donkey				
Mule				
Other				

12.2.2. Livestock products sales in the last 12 months

Product type	Unit	Amount sold	Total price	Purpose of selling
Fresh milk				
Yogurt				
Cheese				
Butter				
Beef				
Mutton				
Hides				
Skins				
Horn				
Cow dung				
Egg				
Others				

12.3. Honey Bee ownership

12.3.1. Number of beehives: _____, production in kg (this year) _____ Used
 _____ kg sold _____ kg amount of Birr _____ extra _____ kg.

12.4. Trees and perennial crops owned currently

Species of tree and perennial crops	No. of trees and perennial crops	Total area covered by tree or perennial crops	Purpose of planting the tree or perennial crops	Annual income from the tree or perennial crops
1. Trees				
2. Perennial crops				

12.5. Did you receive remittance (cash or crop) from someone else?

1. Received _____ Birr 2. Received _____ quintal of _____

13. Non-Farm and Off-Farm Income

13.1. Family time allocated to non-farm and off farm wage employment activities and wage received

13.1.1. Did you or a member of your family engaged in any type of non-farm wage work?

0. No 1. Yes

13.1.2. Use the following table to fill the number of hours worked and wage paid

No.	Participants of non-farm			Working days and hours		Wage received (Birr/ hour)		Income received during this period in birr	
	Sex	Age	Education	Days worked	Hours worked				

13.1.3. Did you or a member of your family engaged in any type of off-farm wage work?

0. No 1. Yes

13.1.4. Use the following table to fill the number of hours worked and wage paid

No.	Participants of off-farm			Working days and hours		Wage received Birr/ hour		Income received during this period in birr	
	Sex	Age	Education	Days worked	Hours worked				

13.1.5. Did you or a member of your family engaged in any type of non-farm self employment activities? 0. No 1. Yes

13.1.6. Use the following table to fill the number of days and hours worked and income earned in self employed non-farm activities

No.	Participants of non-farm			Working days and hours in non-farm		Income Earned	
	Sex	Age	Education	Days worked	Hours worked		

14. Household yearly total cash income

Sources of income	In Birr	
Sale of crop products		
Wage and salary		
Remittances		
Rent		
Gift from GOs and NGOs		
Sale of forest products		
Non-farm enterprise		
Livestock and their products		
Sale of eucalyptus tree		
Credit		
Other/specify		
Total		

14.1. If you consider yourself as poor, what do you think were the possible reasons for your being poor?

1. Land size 2. Not working hard 3. Lack of oxen 4. Pests and disease 5. Other please specify _____

15. Social Participation

15.1. Have you ever served as a member of local institutions such as *Edir*, *Equb*, etc.?

0. No 1. Yes

15.2. Had any of your parents or families exercised administrative power in the past?

0. No 1. Yes

II. Appendix Tables

Appendix Table 1. Adult equivalence scale

Age	Male weight	Female weight
0	0.33	0.33
1	0.46	0.46
2	0.54	0.54
3-4	0.62	0.62
5-6	0.74	0.70
7-9	0.84	0.72
10-11	0.88	0.78
12-13	0.96	0.84
14-15	1.06	0.86
16-17	1.14	0.86
18-29	1.04	0.80
30-59	1.00	0.82
60+	0.84	0.74

Source: World development based on a world health organization equivalence scale quoted by Dercon (1998)

Appendix Table 2. Conversion factors used to compute tropical livestock units

Animal category	TLU
Oxen and cow	0.70
Heifer	0.75
Calf	0.25
Sheep	0.10
Goat	0.10
Hen	0.01
Horse	0.80
Mule	0.70
Donkey	0.50

Source: FAO, 1987, 1986.

Appendix Table 3. Multicollinearity test for variables in the tobit model

Variable	VIF
Family size	1.39
Education	1.30
Ln (experience)	1.28
Ln (loan size)	1.24
Extension contact	1.22
Fragmentation	1.18
Ln (off/non-farm income)	1.18
Livestock holding	1.11
Access to irrigation	1.08
Agro-ecology	1.07
Sex	1.07
Social capital	.05
Mean VIF	1.18

Appendix Table 4. Rosenbaum bounds test for sensitivity analysis of impact of irrigation on expenditure (n = 286 matched pairs)

<i>Gamma</i>	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0.000	0.000	3659.59	3659.59	3442.02	3891.67
1.1	0.000	0.000	3577.77	3742.8	3371.38	3973.48
1.2	0.000	0.000	3507.25	3818.15	3309.49	4048.84
1.3	0.000	0.000	3446.55	3886.4	3253.12	4118.03
1.4	0.000	0.000	3394.13	3948.91	3202.84	4175.67
1.5	0.000	0.000	3343.1	4009.45	3157.8	4235.78
1.6	0.000	0.000	3297.22	4060.93	3115.76	4290.31
1.7	0.000	0.000	3257.55	4111.83	3074.29	4345.01
1.8	0.000	0.000	3221.5	4154.92	3036.32	4398.51
1.9	0.000	0.000	3184.53	4197.3	3001.53	4445.93
2	0.000	0.000	3154.7	4239.09	2967.24	4496.9
2.1	0.000	0.000	3124.41	4279.8	2936.84	4543.76
2.2	0.000	0.000	3091.81	4317.88	2909.69	4587.05
2.3	0.000	0.000	3065.33	4359.05	2883.07	4632.21
2.4	0.000	0.000	3038.9	4394.85	2856.41	4670.55
2.5	0.000	0.000	3014.01	4430.46	2833.13	4709.21

* gamma - log odds of differential assignment due to unobserved factors

sig+ - upper bound significance level

sig- - lower bound significance level

t-hat+ - upper bound Hodges-Lehmann point estimate

t-hat- - lower bound Hodges-Lehmann point estimate

CI+ - upper bound confidence interval ($\alpha = 0.95$)

CI- - lower bound confidence interval ($\alpha = 0.95$)

Appendix Table 5. Rosenbaum bounds test for sensitivity analysis of impact of irrigation on economic efficiency (n = 286 matched pairs)

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0.000	0.000	0.50227	0.50227	0.482207	0.522353
1.1	0.000	0.000	0.495015	0.509758	0.474841	0.529711
1.2	0.000	0.000	0.48861	0.51611	0.467911	0.536706
1.3	0.000	0.000	0.482645	0.521951	0.461153	0.542917
1.4	0.000	0.000	0.477102	0.52758	0.455536	0.548454
1.5	0.000	0.000	0.471621	0.532972	0.450163	0.553673
1.6	0.000	0.000	0.466644	0.537746	.445289	0.558886
1.7	0.000	0.000	0.461694	0.542203	0.440456	0.563431
1.8	0.000	0.000	0.457522	0.546623	0.436003	0.567981
1.9	0.000	0.000	0.453487	0.550421	0.431668	0.571985
2	0.000	0.000	0.449738	0.554198	0.427846	0.575935
2.1	0.000	0.000	0.446162	0.557945	0.423895	0.57957
2.2	0.000	0.000	0.442836	0.561157	0.420272	0.582781
2.3	0.000	0.000	0.439514	0.564472	0.416686	0.586231
2.4	0.000	0.000	0.436319	0.567694	0.41324	0.589619
2.5	0.000	0.000	0.43341	0.570535	0.41038	0.592942

* gamma - log odds of differential assignment due to unobserved factors

sig+ - upper bound significance level

sig- - lower bound significance level

t-hat+ - upper bound Hodges-Lehmann point estimate

t-hat- - lower bound Hodges-Lehmann point estimate

CI+ - upper bound confidence interval ($\alpha = 0.95$)

CI- - lower bound confidence interval ($\alpha = 0.95$)

Appendix Table 6. Small and medium scale irrigation schemes in East Gojjam zone

No.	IS	CA	District	No.	IS	CA	District
1	Gedeb	268	Machakel	20	Zembel	30	DE
2	Muga	270	DTG	21	Teshet	45	DE
3	Muga Kulkual	173	DTG	22	Guansa Wonz	19	Anbese
4	Azuary	150	Goncha	23	Goshye	17.25	Anbese
5	Tgidar	60	Goncha	24	Tija Bach	10	Anbese
6	Mar woha	15	Goncha	25	Gudiy	56.6	Anbese
7	Korch	8	Goncha	26	Dedeho	35	Anbese
8	Gedel sir	46	Goncha	27	Waten	148	Anbese
9	Sire Minich	20	Goncha	28	Gilgel	38	Anbese
10	Score	25	Goncha	29	Atmena	3.5	Senan
11	Ambo Minich	25	Goncha	30	Temzig - 1	4.25	Senan
12	Tenguma	94	AE	31	Temzig - 2	5.5	Senan
13	Meteya	64	AE	32	Kuliech	10.75	Senan
14	Angab	11	AE	33	Kuliech	163	Gozamin
15	Ydan	17	AE	34	Sedie	54	Hulet Eju
16	Birk Eshet	15	DE	35	Tijan	212	Hulet Eju
17	Sheburit	45	DE	36	Zebit	150	Hulet Eju
18	Kersa	7	DE	37	Arefnefs Adin	37	Begugn
19	Tied	125	DE				

NB: IS: Irrigation schemes; CA: Command area (ha); AE: Anarij Enawga DE: Debre Elias; DTG: Debay Tilat Gin;
Source: EGZOA (2013)