ANALYSIS OF FACTORS AFFECTING TECHNICAL EFFICIENCY OF SMALLHOLDER MAIZE FARMERS IN ETHIOPIA

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DECLARATION

I, Sorsie Gutema Deme, hereby declare that this dissertation submitted for the degree of Master of Science in Agricultural Economics, at the University of the Free State, is my own independent work and has not previously been submitted by me for a degree at this or any other University, and that all material contained herein has been duly acknowledged. I further cede copyright of the dissertation in favor of the University of the Free State.

Sorsie Gutema Deme

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DEDICATION

I dedicate this work to my family.

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ABSTRACT

Agriculture is the dominant sector of the Ethiopian economy which typically consists of smallholder rain fed farming systems. Low production and productivity characterises Ethiopian agriculture resulting in the country being unable to meet the increasing food demand of its population. As a result, the country continuously faces food insecurity and to some extent relies on food aid and food imports. The key to growth of agricultural production in Ethiopia lies in increasing the productivity and efficiency of smallholder farmers. The Ethiopian government has given substantial policy emphasis to increased productivity of smallholder crop farmers through the Agricultural Development Led Industrialization (ADLI) strategy. The ADLI strategy emphasises on increasing the adoption and intensification of yield enhancing inputs such as fertilisers and improved seeds to boost crop productivity, especially maize which is the principal crop. In response to the efforts of the development strategy, substantial improvements in the adoption and utilisation of the yield enhancing inputs have been observed in maize production; however the maize yield is not showing expected improvements. The low levels of maize productivity might be the result of technical inefficiencies existing in smallholder production. Information about the technical efficiency of smallholder maize farmers at farm level is important for improvements in productivity. However in Ethiopia this information is limited making an empirical study of the technical efficiency necessary. The research investigated the factors affecting the technical efficiency of smallholder maize farmers in Ethiopia with the aim of generating reliable information about the level of technical efficiency and the factors affecting technical inefficiency of smallholder maize production. Stochastic Frontier Analysis technique was employed and the data for the research was secondary data obtained from the Central Statistical Agency of Ethiopia consisting of 438 observations.

From the empirical estimation, it is found that nitrogen is an important input that can increase maize productivity significantly. Seed and labour inputs are found statistically insignificant in explaining maize production. The estimated value of ¥, which is a parameter used to indicate the proportion of total variance that is attributed to technical inefficiency is 0.99 and significant. The value of ¥ revealed that about 99% of the random variation in output of maize production is attributed to the technical inefficiency component which indicates the importance of examining technical inefficiencies in maize production. The estimated mean technical efficiency score of the sample is 77% with the minimum and maximum efficiency scores of 3 to 96%, respectively. The mean technical efficiency implies that on average, the sampled maize farmers are able to obtain 77% of their potential output using the current production inputs. The finding suggested the presence of considerable levels of technical inefficiency that contributed to decreased maize productivity. The farmers have the potential to increase their maize production by about 23% by using their existing resources and technology more efficiently. While examining the determinants of technical efficiency, age, gender, household size, oxen, extension, irrigation, credit, seed type and soil protection were found to be important factors affecting the technical efficiency of the sampled maize farmers.

The study revealed the possibility of improving the current low maize productivity by removing the technical inefficiencies. The current level of low technical efficiency can be addressed through increasing farmers' access to rural credit and extension services, promoting soil and land conservation practices and by promoting small-scale irrigation schemes.

Key Words: productivity, smallholder farmers, maize, technical efficiency, factors affecting technical efficiency, stochastic frontier analysis

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ADLI	**Agricultural Development Led Industrialisation**
AE	**Allocative Efficiency**
AEZs	**Agro-Ecological Zones**
AISE	**Agricultural Input Supply Enterprise**
CSA	**Central Statistical Agency**
DAP	**Di Ammonium Phosphate**
DEA	**Data Envelopment Analysis**
DMU	**Decision Making Unit**
ESE	**Ethiopian Seed Enterprise**
FAO	**Food and Agricultural Organization**
FARA	**Forum for Agricultural Research in Africa**
FDRE	**Federal Democratic Republic of Ethiopia**
GDP	**Gross Domestic Product**
HDI	**Human Development Index**
IFAD	**International Fund for Agricultural Development**
IFPRI	**International Food Policy Research Institute**
MoA	**Ministry of Agriculture**
MoARD	**Ministry of Agriculture and Rural Development**
MoE	**Ministry of Education**
MoFED	**Ministry of Finance and Economic Development**
MOI	**Ministry of Information**
MFIs	**Micro-finance Institutions**
MLE	**Maximum Likelihood Estimation**
NMA	**National Metrological Agency**
N	**Nitrogen**

OECD	**Organization for Economic Cooperation and Development**
OLS	**Ordinary Least Square**
P	**Phosphorus**
PCR	**Principal Component Regression**
PCs	**Principal Components**
RATES	**Regional Agricultural Trade Expansion Support**
RUSACCOs	**Rural Saving and Credit Cooperatives**
SFA	**Stochastic Frontier Analysis**
SNNP	**Southern Nations Nationalities and Peoples**
SPSS	**Statistical Package for Social Science**
TE	**Technical Efficiency**
UNDP	**United Nation Development Organisation**

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Food insecurity and poverty are widespread and persistent in Sub-Saharan Africa with approximately two-thirds of the population depending on agriculture for their livelihood (Mupanda, 2009). Low agricultural productivity and an increased population are the main problems that contribute to increased food insecurity and poverty in Sub-Saharan Africa in general and in Ethiopia in particular (Mupanda, 2009; Geta, Bogale, Kassa & Elias, 2010).

The Ethiopian economy is highly dependent on agriculture which contributes approximately 43% of the Gross Domestic Product (GDP), 85% of employment and 90% of export earnings (MoARD, 2010).Ethiopian agriculture is predominantly rainfed, smallholder farming which is undertaken on areas averaging less than two hectares. About 12 million smallholder farmers are engaged in agriculture, from which about 95% of agricultural GDP is earned (MoARD, 2010), whereas large and medium-scale commercial farms contribute five percent to Ethiopia’s Agricultural GDP (CSA, 2011c).

Maize (*Zea mays*) is one of the most important food crops produced by smallholder farmers in Ethiopia (CSA, 2012a). Maize is used as a staple food for human consumption, animal feed, a source of raw materials for numerous industrial products and an important trade commodity (Nigussie, Tanner & Twumasi-Afriyi, 2002;FARA, 2009). Maize is the most produced crop in the country accounting for 28% of total grain produced during Meher season (September to February) of 2011/12 (CSA, 2012a). Other staple cereal crops grown in Ethiopia are teff (*Eragrostis tef*), sorghum (*Sorghum vulgare*) and wheat (*Triticum aestivum*) which make up about 16%, 18% and 13% respectively of the total grain production in Meher production season of 2011/2012 (CSA, 2012a). More than nine million smallholder farmers were involved in maize cultivation on about two million hectares of land during the 2011/12 Meher season (CSA, 2012a). Total production was about six million tons with an average yield of about 2.95 ton per hectare (ton/ha) during the same season (CSA, 2012a). Due to the relative role of maize in total grain production and due to the participation of a large number of smallholder farmers in maize production, maize is a priority crop contributing to the country’s national food security. Nevertheless, low production and low productivity characterises Ethiopian agriculture, specifically maize production (World Bank, 2006; MoARD, 2009).

The country is naturally endowed with abundant arable land of about 51.3 million hectares and numerous river basins that hold great potential for irrigation, making the country suitable for agricultural development (MoARD, 2010). Despite having abundant resources for agricultural development, there is a growing food shortage in the country attributed to the poor performance of the agricultural sector (Alene & Hassan, 2003) which is evident in lower standards of living of rural farming households. Rural areas of Ethiopia have the largest concentration of absolute poverty, illiteracy and infant mortality (Diao, 2010) with the country facing food insecurity and relying on food aid and to some extent food imports (Adenew, 2003:1; Diao, 2010).

In an agriculture dependent poor economy, it would be expected that growth in agricultural production, especially in crop growth, would contribute more in reducing poverty than strong macro-economic growth (Boccanfuso & Kabore, 2004). Thus, the key to growth in agricultural production in Ethiopia lies in increasing productivity and efficiency of smallholder farmers (Owour, 2000). Substantial policy emphasis is given to the agricultural sector in Ethiopia because of the importance of agriculture in poverty alleviation, improving food security and in promoting overall economic development (Spielman, Kelemwork & Alemu, 2011). The government of Ethiopia adopted the Agricultural Development Led Industrialization (ADLI) strategy in 1994 as its economic development strategy. The main goal of the strategy was to attain fast and broad-based development of the agricultural sector and to promote the overall economy through the linkage effects of agriculture to other sectors of the economy (Diao, 2010). Under ADLI, greater emphasis is given to increasing the productivity of smallholder crop farmers through intensification of yield enhancing technological inputs such as fertilisers and improved seeds along with better extension services and farm management practices (Diao, 2010).

1.2 PROBLEM STATEMENT

Despite having abundant agricultural resource potential and following a consistent agricultural policy to boost agricultural productivity, the expected productivity increment was not achieved. The level of rural poverty is high and about 39% of the Ethiopian population still live below the poverty line measured by the percentage of the population living on less than the equivalent of US$1.25 per day (UNDP, 2013). Nearly 44% of the Ethiopian population are undernourished (CSA, 2011b) and Ethiopia’s inability to feed its population remains a dilemma that triggers broad economic and sociological debates.

The agricultural development strategy of Ethiopia gave due emphasis to increasing agricultural productivity of smallholder farmers through the increased use of technological inputs in cereal crop production (IFPRI, 2010b). In response to the agricultural development strategy, there is an indication of substantial improvements in the adoption and use of chemical fertilisers, improved seeds and other related inputs in Ethiopia, particularly in maize production; however maize yield has not shown substantial improvement (Mulat, 1999; Arega & Zeller, 2005). One of the reasons for low maize productivity could lie in the technical inefficiency existing in smallholder production (Gebreselassie, 2006). From the policy perspective, insufficient attention was given to obtaining information about the production efficiency of the smallholder farmers. This is mainly attributed to farmers’ inability to select appropriate technologies even though farmers are able to use the technologies efficiently when the technologies are chosen for them (Kalirajan, 1991). However, information about farm level technical efficiency of smallholder farmers is equally important in improving the productivity of the smallholder farmers (Alene & Hassan, 2003).

The prevailing empirical studies of the Ethiopian smallholder’s technical efficiency indicate the existence of technical inefficiencies. Among the studies, Fesessu (2008) examined the extent of technical efficiency and factors affecting technical efficiency of coffee production in Southern and South-western Ethiopia. Fesessu (2008) found an average technical efficiency of 71% where age, membership in farming associations, farming experience with other crops, family size and extension services are the determinants that decrease technical inefficiency. Altitude and coffee farming experience are variables that increase technical inefficiency among the coffee producers (Fesessu, 2008). Similarly, Derege (2010) examined the level of technical efficiency and the main determinants of coffee production in Jimma zone of Ethiopia. Derege (2010) obtained an average technical efficiency of 72%. From the study Derege (2010) found that education, distance from the market, family pressure and poor soil fertility tends to increase technical inefficiency while proximity to a source of off-farm income, cereal crop production, gender and good soil fertility decreases technical inefficiency.

Furthermore, Alene and Hassan (2003) examined the determinants of farm level technical efficiency among the adopters of improved maize production technology in Western Ethiopia and obtained an average technical efficiency of 76%. The study indicated that farm size, education, access to credit, timely availability of modern inputs, extension, plot quality, tenure and age are factors that decrease technical inefficiency while distance from the market increases technical inefficiency (Alene & Hassan, 2003). Similarly, Geta *et al*. (2010) analysed the productivity and efficiency of smallholder maize producers in Southern Ethiopia and found an average technical efficiency of 40%. According to Geta *et al*. (2010), agro-ecology, oxen holding, farm size and the use of improved seed are important factors that decrease technical inefficiency among the farmers. Arega and Zeller (2005) estimated technical efficiency of multiple crop production including maize, wheat and barley in Eastern Ethiopia. Arega and Zeller (2005) obtained an average farm level technical efficiency of 79%. The study indicated that extension services, education, credit and input supply systems are the main determinants that decrease technical inefficiency among the farmers (Arega & Zeller, 2005). Bachewe (2009) explored the sources of inefficiency and growth in agricultural output in subsistence agriculture in Ethiopia and obtained an average farm level technical efficiency of 40%. According to Bachewe (2009), availability of sufficient productive labour and increased educational levels of the farmers are factors that decrease technical inefficiency.

From the literature reviewed, it was found that information on farm level technical efficiency on maize production in Ethiopia is limited. No empirical studies were found that investigated maize farmers' technical efficiency incorporating most of the maize producing regions in Ethiopia. The few studies undertaken on maize production efficiency by Alene and Hassan (2003) and Geta *et al*. (2010) are at zone levels which cannot give an indication of efficiency status at national level. Other studies were undertaken on products such as coffee and multiple grain crop production technical efficiency. Bachewe (2009) used a single index real value of output for multiple subsistence crops including maize where a technical efficiency estimate for maize production cannot be separately analysed. Since maize is a priority crop in terms of total production and due to its contribution to national food security, a comprehensive analysis of smallholder maize farmers' technical efficiency is important.

Despite the important role maize has in the livelihood of Ethiopia, its productivity is low compared to the potential level (Alene & Hassan, 2003). According to Schneider and Anderson (2010) and IFPRI (2010b), there is a large maize yield difference between the potential yield and the actual yield estimates in Ethiopia. IFPRI (2010b) noted that maize production has a potential average yield of 4.7 ton/ha where the actual national maize yield estimate is about 2.95 ton/ha during 2011/12 Meher season (CSA, 2012a). Given the persistent food security issues facing Ethiopia, there is a need to improve maize productivity. One way of improving farm productivity is through improving farmers' technical efficiency. Technical efficiency and productivity improvements are possible if farm level technical efficiency and its determinants are identified.

1.3 RESEARCH OBJECTIVES

The main objective of the study is to identify factors affecting technical efficiency of smallholder maize farmers for selected regions in Ethiopia. The main objective will be reached through the completion of the following sub-objectives.

i. Estimating technical efficiency of smallholder maize farmers using Stochastic Frontier Analysis (SFA) which estimates a production frontier against which the farmers' actual production is evaluated to quantify their technical efficiency.

ii. Identifying and analysing the socio-economic and farm management factors that affect technical inefficiency of smallholder maize farmers in order to better understand the constraints that prevent farmers from producing the maximum potential output.

1.4 CHAPTER OUTLINE

The study is organised into the remaining five chapters. Chapter two provides an overview of the relevant literature on productivity and efficiency in production. The concepts of productivity and efficiency in production, measurement of technical efficiency and variables used in Stochastic Frontier Analysis in crop production are reviewed. Chapter three discusses the study area profile and nature of data used in the study. In Chapter four, the methodological framework applied in order to achieve the sub-objectives is discussed. Chapter five provides a presentation and discussion of the results. Finally, Chapter six provides a summary, conclusion and implications.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

When discussing the economic performance of producers, it is usual for them to be described as being more or less “efficient,” or more or less “productive” (Fried, Lovell & Schmidt, 2008:7). Due to performance variation, not all producers are equally successful in utilising their inputs to achieve potential yield, given the technology at their disposal (Kumbhakar & Lovell, 2000:3). Through efficient utilisation of the available resources, farm households can produce maximum possible output under the given technology and favourable operating conditions. Identifying the extent of efficiency is thus important since it can lead to significant resource savings which in turn can have an important effect on policy formulation and farm management (Bravo-Ureta & Rieger, 1991). Efficiency and productivity are interrelated concepts of production. Although these concepts are related, they do not have the same meaning. Therefore, the concepts and relationships of productivity and efficiency should be clearly defined. The next section will discuss the concepts of productivity and efficiency in production, measurement of technical efficiency, review of the production frontier and technical inefficiency models.

2.2 THE CONCEPT OF PRODUCTIVITY

Productivity is a natural measurement of performance that measures the level of the physical output produced from the quantity of input(s) used. Productivity is measured by the ratio of output produced to input(s) used (Latruffe, 2010).Estimating productivity is easy if a producer uses a single input in production. When more than one input is employed, productivity measurement is complex and a method of aggregating the inputs into a single index of inputs is required (Fried *et al*., 2008: 522). Productivity measurement is a relative concept and can be measured by comparing one year’s performance with the previous year’s performance or relative to other producers (Coelli, Prasada, O’Donnell & Battese, 2005:2). Larger ratios of productivity (output/input) measures are associated with better performance (Coelli *et al*., 2005:2). Productivity variation is the difference between output growth and input growth. Variation in productivity across producers or across time is attributed to differences in production technology, scale of operation, differences in operating efficiency and differences in the operating environment (Fried *et al*., 2008:8).

2.2.1 *IMPORTANCE OF PRODUCTIVITY*

Productivity improvement is one means of improving output in production. Agricultural output can be increased either by increasing productivity of inputs or through expansion of farm size in production (FAO & OECD, 2012). Through expansion of farm size, farmers can be more productive by exploiting economies of scale, which arises from the differential access to credit, adoption of more capital intensive technologies, better access to capital, willingness to take risks and personal and political influence (Andrew, 1999). However, there is an argument that smaller farms are more productive than larger farms. For example, Dyer (1996) argued that small sized farms are more productive because they are poorer and are driven to labour intensification through self-exploitation. Given these arguments, increasing output by expanding farm size is not a sustainable way of poverty reduction because an increase in production will take place within an environment characterised by a scarcity of arable land resource (FAO, 2011). As a result, expansion of farmlands could be due to the use of marginal lands that are not suitable for farming (FAO & OECD, 2012).

Increasing agricultural output by increasing productivity through more intensive use of land is very important as it does not require utilisation of additional land for cultivation (FAO & OECD, 2012).Increased agricultural productivity and the resulting increase in output contribute to poverty reduction and to broader economic development (Mellor, 1999). The primary effects of increased agricultural productivity include contributions to ensuring food security and poverty reduction by increasing food availability. The increase in output contributes to the decrease in food prices and increase of farm and off-farm employment which consequently improves the rural economic environment (Adenew, 2003: 2; Clunies-Ross, Forsyth & Huq, 2009:459). Improvement of the rural economic environment in turn decreases urban poverty by slowing down rural-urban migration and urban unemployment (Mellor, 1999; Thirtle *et al*., 2001; Clunies-Ross *et al*., 2009:458).

In addition to the poverty reduction role, agricultural productivity can also contribute to the overall development of an economy (Kuznet, 1965: 239). An increase in agricultural productivity contributes to the growth of other sectors of the economy (Adelman & Morris, 1988). According to Kuznet (1965: 239), agricultural productivity enhances economic development through four contributions namely: product contribution; factor contribution; market contribution and foreign exchange contribution. Product contribution means more output will be available for the economy through increased productivity while factor contribution refers to the release of excess factors such as labour and capital from agriculture to other emerging sectors. Market contribution refers to the increasing demand arising from the agricultural sector for products of the other sectors and the increased supply of food and raw materials by agriculture to the other sectors which develops a market. Foreign exchange contribution refers to the role of agriculture in international trade (Kuznet, 1965: 239). Increased agricultural productivity increases export earnings and determines the competitiveness of countries in global trade, mainly for countries whose export is dominated by agricultural commodities (Cluines-Ross *et al.*, 2009: 457). This is specifically true in Ethiopia where about 90% of the country's export is dependent on agricultural commodities (MoARD, 2010). Given the importance of agricultural productivity in an economy, one of the methods of increasing productivity is through increasing productive efficiency which is discussed in the following section.

2.3 THE CONCEPT OF EFFICIENCY IN PRODUCTION

Production efficiency is the degree of success producers achieve by allocating the inputs at their disposal and the outputs they produce in an effort to meet certain objectives (Kumbhakar & Lovell, 2000:15). Production efficiency is an important factor for productivity growth especially in developing countries where resources are scarce, as production can be increased through improving efficiency in production without the use of additional inputs (Alene & Hassan, 2003). Efficiency in production can be seen in terms of technical efficiency, allocative efficiency or a combination of technical and allocative efficiency which is called economic efficiency (Fried *et al.*, 2008: 20) or overall efficiency (Farrell, 1957). Given the concept of efficiency, the following section is a discussion of technical efficiency.

2.3.1 *TECHNICAL EFFICIENCY*

Technical efficiency (TE) is the ratio of the actual production to an optimal level of production (Greene, 1993). Technical efficiency is defined as the ability to minimise input usage in the production of a given output vector or the ability to obtain maximum output from the given input vector (Kumbhakar & Lovell, 2000:17). A technically efficient producer could produce the same level of output using lessor inputs or could produce more output using the same level of inputs. However, not all producers are technically efficient (Fried *et al*., 2008:20). The concept of technical efficiency can be better explained graphically using a simple example involving a producer using two factors of production (X_1& X_2) to produce a single output (Y). Figure 2.1 provides a graphical representation of productive efficiency under a two input and one output technology set represented by an isoquant SS'. The knowledge of a unit isoquant of fully technically efficient producers represented by SS' in Figure 2.1 permits the measurement of technical efficiency.

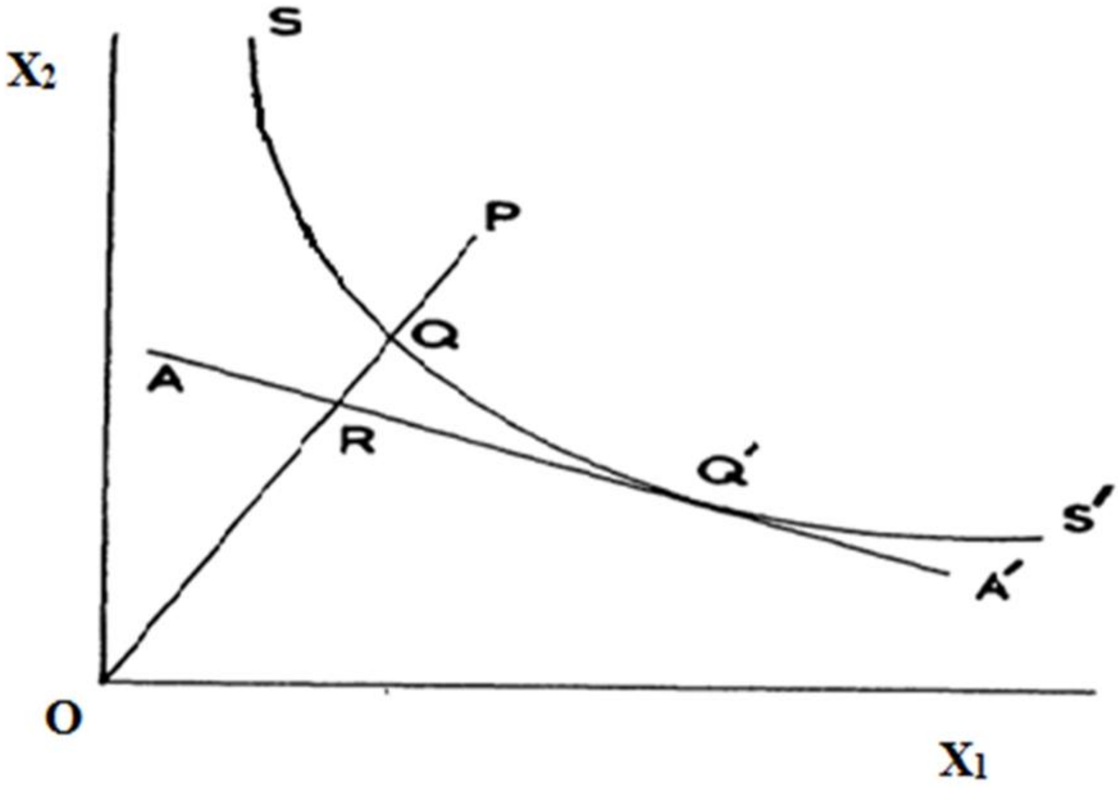

Figure 2.1: Graphical representation of technical and allocative efficiency using two inputs (X_1& X_2) and one output (Y_i)
Source: Farrell (1957)

From Figure 2.1, isoquant SS' represents production of output level Y with different levels of input X_1 and X_2. Suppose a given producer uses an input combination of the two factors defined by point P to produce a unit of output. Under this framework, every input combination along the isoquant SS' is considered technically efficient while any input combination above and to the right of the isoquant SS’ such as point P defines a technically inefficient input combination. This is because, at point P, the input package used is greater than the minimum input necessary to produce a unit of output (Murillo-Zamoralo, 2004). However, point Q represents a technically efficient input combination because it lies on the efficiency isoquant (SS’). Thus the technical efficiency (TE) of the producer at P is defined as:

$$TE = {}^{OQ}/_{OP} \tag{2.1}$$

The value of TE is bounded between zero and one. TE takes a value of one for a perfectly efficient producer and moves towards zero for inefficient producers (Farrell, 1957). Given the theoretical explanation of technical efficiency, estimation and analysis of technical efficiency in crop production assists to determine the scope of raising productivity of inefficient producers. Knowledge of the level of technical efficiency contributes significantly to realisation of national policy goals such as achieving food security, poverty alleviations and growth and development through improving performance of inefficient producers (Uaiene, 2008; Mupanda, 2009). The cost association with the inputs and outputs is also important in production and is considered when calculating Allocative Efficiency.

2.3.2 *ALLOCATIVE EFFICIENCY*

Allocative efficiency (AE) is the ability of a producer to use inputs in optimal proportions given their respective prices (Coelli *et al*., 2005: 5). Allocative efficiency is achieved when a producer operates at the least-cost combination of inputs to produce a specified level of output (Kumbhakar & Lovell, 2000: 15). If information of input prices are known and a particular behavioural objective such as cost minimisation is assumed, allocative efficiency of a producer can be derived. Suppose in Figure 2.1 the producer uses the two inputs (X_1 and X_2) given their respective prices P_1 and P_2 to produce a certain amount of output (Y). It is assumed that a line segment AA’ is an isocost line with a slope equal to the ratio of the prices of the two inputs. With these assumptions, the only points that minimise input costs are allocatively efficient. The optimal input selection for the cost minimising producer is at the point where the isocost line AA’ is tangent to isoquant SS’ which is at point Q’. Thus, Q’ is the point of optimal input combination where the producer is both technically and allocatively efficient. Point Q is where the producer is technically efficient but allocatively inefficient, so it is not the optimal input combination point. Further, if the producer is to change the proportions of input combinations until they are the same as those represented at Q’, the cost can be reduced by a factor of OR/OQ as long as factor prices remain the same. Therefore, allocative efficiency (AE) that characterises the producer at point P is given by the ratio:

$$AE = {}^{OR}/_{OQ} \qquad (2.2)$$

The distance RQ from Figure 2.1 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 a technically efficient, but allocatively inefficient point Q (Coelli *et al*., 2005:53). The measure of AE takes a value of one for an allocative efficient producer and becomes closer to zero as the producer become less allocative efficient.

When producers are both technically and allocatively efficient, they are economically efficient. Given both technical efficiency and allocative efficiency in Figure 2.1, the producer at point Q’ is economically efficient. Economic efficiency can also be computed as the product of technical efficiency and allocative efficiency (Farrell, 1957). Since economic efficiency is a combination of technical and allocative efficiency, economic inefficiencies will arise from technical and/or allocative inefficiencies (Bravo-Ureta & Pinheiro, 1997). Given the distinction of various concepts of productivity and efficiency in production, the following section discusses the measurement techniques of technical efficiency.

2.4 MEASURING TECHNICAL EFFICIENCY

Technical efficiency estimation involves a comparison of actual performance with optimal performance located on the relevant frontier. Since the true frontier is unknown, an empirical approximation is needed (Fried *et al.,* 2008:33). The measurement of a farm specific technical efficiency is based upon deviations of the farm’s actual performance from the efficiency frontier (Kumbhakar & Lovell, 2000:3). If a producer’s actual production point lies on the efficiency frontier (assuming that a production frontier is the same as a production possibility curve), the farm is technically efficient and if it lies below the frontier, it implies the presence of technical inefficiency (Pascoe & Mardle, 2003).

There are two main approaches of estimating technical efficiency among producers, namely a parametric or a non-parametric approach. The difference between the two approaches is that the former approach specifies a particular functional form based on econometric techniques while the latter is based on mathematical programming (Sarafidis, 2002). In empirical work, the two most popular techniques of efficiency measurement are Data Envelopment Analyses (DEA) and Stochastic Frontier Analysis (SFA).The two techniques are different in their treatment of random noise and for flexibility in the structure of production technology (Porcelli, 2009). In the following sub-sections, the distinctions between the two efficiency measurement techniques are discussed.

2.4.1 *DATA ENVELOPMENT ANALYSIS*

Data Envelopment Analysis (DEA) is a non-parametric technique of efficiency measurement that is based on mathematical programming (Sarafidis, 2002). Development of DEA was influenced by the early works of Debreu (1951), Koopmans (1951) and Farrell (1957). DEA was first introduced by Charnes, Cooper and Rhodes(1978) and is widely employed in management sciences mainly in operational researches (Kumbhakar & Lovell, 2000:7). Technical efficiency estimation using DEA involves the use of a linear programming method to construct a non-parametric frontier over the sample data. Efficiency is estimated using the distances of each observation relative to the frontier (Coelli *et al.*, 2005:162). In DEA, relative technical efficiency of each decision-making unit (DMU) is measured by using a ratio of weighted sum of output to a weighted sum of input. The weights for both outputs and inputs are selected in a manner that calculates efficiency measures for each DMU subject to the constraint that no other DMU can have relative efficiency scores greater than unity (Charnes *et al.*, 1994). DEA establishes the basis to identify the level of potential improvement for the inefficient producers relative to the efficient producers (Solwati, 2001). Given the background of DEA efficiency measurement technique, DEA has certain strengths and weaknesses that will influence the decision to utilise the method.

Efficiency estimations using DEA does not require specification of a functional form and there is no imposition of statistical assumptions about the distribution of error terms. These properties free the model from specification bias. In addition, the model can accommodate efficiency estimation involving multiple outputs more easily and provides an indication of the scale of operation for individual DMUs in the sample (Sarafidis, 2002). However, DEA has weaknesses that limit its suitability and appropriateness. The principal limitation of DEA is that the model does not make provision for statistical noise and all deviations from the frontier are considered as inefficiency. As a result, efficiency estimates obtained by using DEA can be biased and unreliable in studies where the data has the influence of statistical noise (Pascoe & Mardle, 2003). In addition, assessment of goodness of fit of a DEA model is difficult as there is no proper definition of goodness of fit that enables model comparisons and the standard criteria cannot be used for assessment of the goodness of fit of DEA model (Sarafidis, 2002). Furthermore, efficiency estimation using DEA is sensitive to outlying observations which can provide misleading information and do not allow hypothesis testing (Sarafidis, 2002; Fried *et al.*, 2008). There is an alternative technique of efficiency measurement called SFA.

2.4.2 *STOCHASTIC FRONTIER ANALYSIS*

Stochastic Frontier Analysis (SFA) is a parametric technique of efficiency measurement that is based on econometric estimation (Sarafidis, 2002). The literature that influenced the development of SFA was the theoretical literature on productive efficiency which began in the 1950s with the work of Koopmans (1951), Debreu (1951), Shephard (1953) and Farrell (1957). Aigner, Lovell, & Schmidt (1977) and Meeusen and van den Broeck (1977) introduced the SFA model simultaneously. The SFA model allows for technical inefficiency and a symmetric random noise error terms (Kumbhakar & Lovell, 2000: 8). The SFA model handles the effects of inefficiency and random noise on output separately through the introduction of a composed error term. The composed error term consists of a symmetric disturbance term (V_i) and a non-negative inefficiency term (U_i) (Kumbhakar & Lovell, 2000: 8). The primary motivation of introducing the symmetric disturbance term into the efficiency estimation is due to the fact that deviations of actual observations from the frontier observations might not entirely be under the control of the producers (Fried *et al.*, 2008: 114). Thus, specification of the SFA model permits output to be specified as a function of controllable factors of production, random noise and technical inefficiency (Kumbhakar & Lovell, 2000).

SFA uses Maximum Likelihood Estimation (MLE) to estimate a frontier function in a given sample, which is the method first used by Greene (1980) and Stevenson (1980). MLE can estimate the production function parameters (β) and the technical inefficiency model parameters (δ), simultaneously (Porcelli, 2009). MLE of an unknown parameter is defined to be the value of the parameter that maximises the probability of randomly drawing a particular sample of observations (Coelli *et al*., 2005:217). By employing specified distributional assumptions, it is possible to derive the likelihood function, which can be maximised with respect to all SFA parameters to be estimated (Fried *et al.*, 2008:36).

In the procedure of efficiency estimation, SFA considers separate assumptions regarding the distributions of the random noise and inefficiency variables that potentially lead to more reliable efficiency estimations (Kumbhakar & Lovell, 2000). The symmetric disturbance term is assumed to be identically, independently and normally distributed with zero mean and constant variance or V_i~ iidN (0, $\sigma^2{}_V$) throughout. The inefficiency variable (U_i), however, has developed into different distributional assumptions. In the original development of SFA, half-normal and exponential distribution were considered (Aigner *et al.,* 1977). These assumptions were developed into more flexible general distributions such as gamma-distribution (Greene, 1980), truncated normal distribution (Stevenson, 1980) and the four-parameter Pearson family distributions (Lee, 1983). The half-normal and exponential distributions assume mode at zero, implying the highest proportion of the producers examined are perfectly efficient. Truncated normal and gamma distributions however, allow wider ranges of distributional shapes including non-zero means. The truncated normal distribution implies that the one sided error term (U_i) is obtained by truncating at zero with the possibility of a non-zero mean that also generalises the half-normal distribution (Fried *et al*., 2008: 130). Some empirical analyses suggest that the use of the truncated normal model has less difficulty in estimation, unlike gamma which has complex procedures to follow (Ritter & Simar, 1997; Fried *et al*., 2008).

Like all other models, SFA has strengths and weaknesses. The main strength of the SFA is that the effects of random noise on output can be separated from the effects of technical inefficiency (Fried *et al*., 2008). This is an important property of SFA, especially when the data undertaken has the influence of random effects (Sarafidis, 2002). The SFA model permits hypothesis testing as to the functional form of the frontier and the significance of individual explanatory variables (Sarafidis, 2002). The main weaknesses of SFA are the requirements of specification of the functional forms and formulation of distributional assumptions about the error terms (Henderson & Kingwel, 2002).

Given the strengths and weaknesses of the two techniques, the SFA is preferred over DEA in certain circumstances. When random influences and statistical noises are perceived to influence the data and when the omitted variables may influence the final results, SFA is preferred. Moreover, when hypothesis testing is important and measurement of goodness of fit of the estimated model is required, SFA model is more appropriate (Sarafidis, 2002).

2.5 THE PRODUCTION FRONTIER AND THE TECHNICAL INEFFICIENCY MODEL

The estimation of technical efficiency and examining the determinants of technical inefficiency using the SFA requires that a production frontier and a technical inefficiency model are estimated. The production frontier is used to estimate the level of technical efficiency whereas the inefficiency model is used to identify the potential determinants of technical inefficiency. The inputs that define a production frontier and factors affecting technical inefficiency in crop production are discussed further to determine the factors that can determine technical efficiency of Ethiopian maize farmers.

2.5.1 *REVIEW OF INPUTS DEFINING PRODUCTION FRONTIER*

Estimation of technical efficiency using SFA involves estimating the unknown production frontier (Coelli *et al*., 2005).Farm inputs such as seed, fertiliser and labour are the primary inputs used in smallholder crop production based on the empirical literature (Alene & Hassan, 2003; Arega& Zeller, 2005; Gebreselassie, 2006; Bachewe, 2009). Application of appropriate seed and fertiliser can increase production considerably (Gebreselassie, 2006). In crop production, farmers use improved or traditional seed as production inputs (Morris *et al*., 1999). Despite the productivity differences between improved and traditional seed, seed is a conventional input in crop production. From the empirical studies, Geta *et al*. (2010) and Idiong (2007) found that seed quantity has a positive influence on cereal production. Another input that is applied in crop production is fertiliser.

Fertiliser is an important input in crop production. Low soil fertility is one of the biophysical constraints affecting smallholder production (Sanchez & Roland., 1997; Ayalew & Dejene, 2011). Through application of fertiliser, soil fertility and land productivity can be improved. Application of either organic or chemical fertiliser or integrated use of both fertilisers is expected to increase production (IFPRI, 2010a; Ayalew & Dejene, 2011). Chemical fertiliser is a yield enhancing input in crop production and its application increases productivity considerably, especially if used with improved seeds and irrigation (Gebreselassie, 2006).Chemical fertilisers enhance the uptake of important nutrients such as nitrogen and phosphorus and their concentration in plant tissues when applied (Abdulahi *et al*., 2006**)**.Smallholder farmers in Ethiopia are constrained from using chemical fertilisers and from applying the recommended amount due to the high cost of the chemical fertilisers in the country (Ayalew & Dejene, 2011). However, the application of fertiliser requires maintaining the levels recommended by agricultural scientists together with the timing and method of application for better productivity (Ayalew & Dejene, 2011). Among the empirical studies, Alene and Hassan (2003) and Geta *et al*. (2010) found an increasing effect of fertiliser on maize production.

Similar to fertiliser, labour is an important input required in crop production. Smallholder farming activities such as land preparation, planting, fertiliser application, weeding and harvesting require adequate labour throughout the production process. Availability of adequate labour enhances production return by enabling the households to undertake the farming activities properly (Geta *et al*., 2010). Sources of agricultural labour include family labour and hired labour. Alene and Hassan (2003), Fesessu (2008) and Bachewe (2009) found that crop production responds to labour use positively. Given the review of variables defining the production function, the following section is a review of the factors affecting technical inefficiency in crop production.

2.5.2 *FACTORS AFFECTING TECHNICAL INEFFICIENCY*

In the technical inefficiency model, the dependent variable is the index of technical inefficiency (U_i) and the independent variables are variables used to explain the technical inefficiency of the producers (Kumbhakar & Lovell, 2000:261). Variables that increase technical inefficiency have positive parameter estimates and *vice versa* (Bachewe, 2009). Identifying and examining the determinants of technical inefficiencies in production can reveal options for technical efficiency improvement (Bachewe, 2009). There are many socio-economic and farm management factors that affect technical inefficiency of smallholder crop farmers. Based on literature, the common factors are age, gender, education, household size, farm size, land tenure, ownership of oxen, access to extension services, irrigation, access to credit, off-farm income, seed type, organic fertiliser and soil protection (Alene & Hassan, 2003; Bachewe, 2009; Derege, 2010; Geta *et al*., 2010). These variables will be discussed by explaining their effects on inefficiencies in farming as cited by previous research and the possible influence on the current research.

2.5.2.1 Age, Gender and Education of Household Heads

Technical efficiency variations across smallholder farmers can be as a result of differences in age, gender or education of the household heads. Age of a household head can have a decreasing effect on technical inefficiency, meaning that when the age of a household head increases, technical inefficiency in production decreases. Among the empirical studies, Ayele *et al*. (2006), Fesessu (2008) and Maseatile (2011) found that age has a decreasing effect on technical inefficiency. Possible reasons for such a relationship can be due to the fact that with increased age, farmers perform better through having better resources at their disposal and can be better aware of mechanisms for risk coping from life experience. In contrast, Makombe *et al*. (2011) found an increasing effect of age on smallholder farmers' technical inefficiency. The increasing effect of age on farmers' technical inefficiency could be due to the fact that older household heads will become more conservative towards acceptance of new ideas, technologies and practices which can result in an increase in technical inefficiency (Gbegeh & Akubuilo, 2013).Other possible reasons could be that when the age of household heads increases, the households may not be able to accomplish the usual farm activity due to old age. In other words, younger farm household heads can have a better education, capacity to work, ability to gather information, new ideas and practices that can decrease the farms' technical inefficiency (Bravo-Uteta & Pinheiro, 1997; Gbegeh & Akubuilo, 2013). From literature, the potential effect of age on technical inefficiency is mixed, meaning that the age of a household head can have either an increasing or a decreasing effect on technical inefficiency. Similar to age, gender of household heads can also influence the level of technical inefficiency.

Gender of household heads provides indications of technical inefficiency variations among the farm households (Bachewe, 2009). According to the empirical findings of Solis *et al*. (2008) and Bachewe (2009), male-headed households are less technically inefficient than female-headed households. A possible reason for gender based technical inefficiency variation could be that male-headed households have better access to land, credit, technological inputs and other supportive services than their female counterparts (AWM, 2009; OXFAM, 2012). Another possible reason could be that female household heads undertake farming activities in addition to their normal homemaker role which can increase their farm technical inefficiency.

Derege (2010) found that female-headed coffee farming households are less technically inefficient than male-headed households. According to Derege (2010), a possible reason could be that the female household heads made an increased effort towards follow up and supervision of the farm work for better production than the male household heads. Literature indicates that the gender of household heads can have either an increasing or a decreasing effect on farm technical inefficiency. Another variable related to farm household heads is education.

Education increases farmers' ability to obtain, process and use information relevant to agricultural practices that can decrease farm technical inefficiency (Bachewe, 2009). Accordingly, education may enhance farm productivity by increasing the ability of the farmers to adjust to risk and adopt new innovations (Weir, 1999). According to Admassie and Asfaw (1997), Ayele *et al*. (2006) and Derege (2010), more years of schooling decreases technical inefficiency in production. The possible reason for this relationship could be that farmers with better educational levels tend to be more efficient since they can respond more readily when using new technologies and can therefore produce closer to a technology frontier (Derege, 2010). In contrast, Mkhabela (2005) and Belloumi and Matoussi (2006) found an increasing effect of education on farm technical inefficiency. The findings indicate the possibility that the increased level of education of a farm household head increases the level of technical inefficiency. A possible explanation for the result is that with increased years of schooling, farmers can have alternative job opportunities to choose from so that their devotion to the farm work will decrease. Based on the above findings, education of a household head can have either an increasing or a decreasing effect on technical inefficiency. Next, the effects of household size, farm size, land tenure and oxen on technical inefficiency of smallholder farmers will be reviewed.

2.5.2.2 Household Size, Farm Size, Land Tenure and Oxen

Household size refers to the number of household members living in each farm household (CSA, 2012a). A farm household can be either a person living alone or a group of people (related or unrelated in either kinship or marriage) who live together in the sense that they have common housing arrangements or they are supported by a common budget (CSA, 2012a). The size of a farm household can affect farm technical inefficiency either positively or negatively. Fesessu (2008) found a decreasing effect of household size on smallholder farmers' technical inefficiency. This confirms the importance of larger household sizes in decreasing technical inefficiency. On the other hand, Derege (2010), Maseatile (2011), Baruwa and Oke (2012) found an increasing effect of household size on farm technical inefficiency. The increasing effect of household size on technical inefficiency has an implication that although a large household size enhances the availability of family labour, it may not guarantee an increased efficiency and it can rather lead to inefficiency. Since smallholder farmers cultivate smaller farmlands, increased household size can result in underutilisation of household labour and increased inefficiency. In other words, when larger households derive their livelihood from farm activities only, much of the household labour could be used on the smaller farms unnecessarily where the task could be accomplished by using less labour (Maseatile, 2011; Baruwa & Oke, 2012).

Farm size is also an important variable commonly included in empirical efficiency analysis of smallholder production (Uaiene, 2008). Smallness or largeness of a farm can affect farm level technical inefficiency. There are different economic arguments about the size of farmlands and associated productivity (Masterson, 2007).Bravo-Uteta and Pinheiro (1997), Huang and Kalirajan (1997), Andrew (1999) and Khaile (2012) found a decreasing effect of farm size on technical inefficiency. This supports the notion that larger farms have an efficiency advantage over smaller farms. These findings indicate that expansion of farm size contributes to better productivity through encouraging adoption of more capital-intensive technologies, better access to capital due to economies in transaction costs, willingness to take risks and personal and political influence (Andrew, 1999). Related to this argument, the average size of farmlands of the Central highlands of Ethiopia has fallen from 0.5 hectare in 1960's to about 0.2 hectare by 2008 (Diao, 2010). The smallness of the farms is usually seen as a constraint to productivity of smallholder producers (Diao, 2010). The decline in farm size in the area is attributed mainly to the fact that farmlands are divided among family descendants and therefore farm size decreases overtime resulting in smaller and fragmented farms (Diao, 2010).Nonetheless, there are researchers who argue that smaller farms are more productive than the larger farms. For example in Egyptian crop farming, Dyer (1996) found an inverse relationship between farm size and productivity. Dyer (1996) argued that small sized peasant farms are more productive than large farms because the farmers are poorer and are driven to labour intensification through self-exploitation. Similarly, Ellis (1993) noted that small farms produce more output per hectare mainly by using family labour which is easy to manage compared to large farms where hired labour needs more supervision and management costs.

Supporting this argument, Parikh *et al*. (1995) and Masterson (2007) found an increasing effect of farm size on technical inefficiency confirming that smaller farms are more technically efficient than larger farms. However, Bardhan (1973) suggested that farm size and productivity relationships cannot be concluded without considering other important factors of production besides land that affect productivity. Given the different views about the effects of farm size on productivity, the empirical findings suggest that farm size has a mixed effect on technical inefficiency, meaning that some studies found a decreasing effect while others found an increasing effect of farm size on technical inefficiency.

Land tenure is another important variable which refers to the type of ownership of farmlands, whether privately owned, rented or share cropping (Uaiene, 2008). One of the key issues related to land tenure is the degree to which the tenure arrangement encourages sustainable farm practices. It is generally believed that privately owned farms provide necessary incentives for farmers to better manage the lands and to make necessary investments that lead to an improvement of productivity of the lands (Nega *et al*., 2003). From the empirical findings, Gavian and Ehui (1999), Alene and Hassan (2003) and Binam e*t al*. (2003) found a decreasing effect of privately owned farms on farm technical inefficiency. This implies that privately owned farms are more technically efficient. In contrast, Corppenstedt and Abbi (1996) and Rahman and Umar (2009) found that privately owned farms are more technically inefficient than rented or share-cropping farms. Although tenure has a mixture of decreasing and increasing effects, most of the literature support the fact that private tenure has a decreasing effect on farm technical inefficiency. Similar to tenure, ownership of an adequate number of oxen can also cause variations in technical inefficiency among farm households.

Ownership of oxen is a variable of interest in technical efficiency analysis of smallholder farmers in Ethiopia. This is because oxen are the main source of draft power used for farming activities in smallholder crop production in the country (Geta *et al*., 2010). Ownership of adequate oxen augments labour input and enhances productivity by reducing the time needed to accomplish farm operations such as land preparation and sowing. Farmers need at least one pair of oxen to be able to prepare their land well and timely. From the empirical studies, Gebreegziabher *et al.* (2004) and Geta *et al*. (2010) found that ownership of oxen is an important variable that has a decreasing effect on smallholder farmers’ technical inefficiency. Therefore, ownership of an adequate number of oxen affects technical inefficiency negatively.

Information availability and funding is also important in the efficiency of farming and these factors are discussed in their importance in determining technical inefficiency.

2.5.2.3 Extension, Irrigation, Credit and Off-farm Income

Extension service refers to the advice and training provided by farm extension workers to the farmers about farming operations (CSA, 2012a). Farmers who receive extension services, advice and assistance can have better information which can decrease their farm's technical inefficiency (Fesessu, 2008). From the empirical studies, Alene and Hassan (2003), Obwona (2006), Fesessu (2008) and Maseatile (2011) found a decreasing effect of extension on farm technical inefficiency. The findings indicate that access to extension services increase productivity. Binam *et al*. (2004) found an increasing effect of extension services on farm technical inefficiency. According to Binam *et al*. (2004), the possible explanation for such a relationship was attributed to the weak performance of information delivery systems inherent in public operated extension services, present in most developing countries. Even though, there is a condition where extension service increases technical inefficiency, most of the studies supported the decreasing effect of extension on farm technical inefficiency. Possible information from extension services would include the use of resources in production, such as water application. Irrigation is an important source of crop water that is seldom used in Ethiopian smallholder production to improve crop yields.

Irrigation of crops also has the ability to increase technical efficiency of farmers through improving crop yields. Irrigation is a means of providing sufficient water for plant growth to prevent water stress that can possibly reduce productivity of the inputs used. Sufficient water is a requirement to attain the potential level of production (Haise & Hagan, 1967). Irrigated agriculture has an important role in reaching the broader development goals of achieving food security, poverty alleviation and improved quality of life (Haise & Hagan, 1967). Irrigation is important in Ethiopian agriculture as the country is vulnerable to weather and climate changes because of high dependence on rainfall (Hordofa *et al*., 2008). Through the use of irrigation, farmers can reduce their production risks associated with inadequate rainfall (Hordofa *et al*., 2008). Supporting the importance of irrigation, Makombe *et al*. (2011) found that farmers that have access to irrigation are more technically efficient than farmers without access to irrigation. Therefore, irrigation has a decreasing effect on farm technical inefficiency. The use of irrigation and other factors in production is limited without funding. Access to funding, such as credit, is therefore important for increased technical efficiency.

Credit can affect the technical inefficiency of farmers by affecting their decisions regarding agricultural financing (Uaiene, 2008). In Ethiopia, the formal financial sectors are not well developed to provide credit services to the poor rural farm households (Yehuala, 2008).Lack of access to formal credit is frequently described as a key problem for smallholder farmers of Ethiopia (Croppenstedt *et al.,* 2003).Constraints of rural credit affect productivity and efficiency of resource lacking farmers by limiting them from financing for both short-term and long-term farm investments (IFPRI, 2010a). Among the empirical studies, Obwona (2000), Binam *et al.* (2004), Gebreegziabher *et al.* (2004) and Maseatile (2011) found a decreasing effect of credit on technical inefficiency. The findings confirm the importance of credit in decreasing technical inefficiency. Another source of smallholder farmers' agricultural financing is off-farm income, which can affect farmers' technical inefficiency.

In rural areas of developing countries, off-farm income participation is an alternative source of income for farm households to support the economic well-being of the household and to finance the farming operations (Beyene, 2008).Off-farm income provides farmers with potential capital for purchasing productivity enhancing inputs such as improved seed and fertiliser in addition to supporting the consumption needs of the farmers (Gebreegziabher *et al.,* 2004). As a result, off-farm income can decrease farm technical inefficiency. In line with this idea, Gebreegziabher *et al.* (2004), Haji (2006) and Maseatile (2011) found a decreasing effect of off-farm income on farm technical inefficiency. The pursuit of off-farm income activities by farmers can also increase farm level technical inefficiency in such a way that the increased participation of the farmers in off-farm income activities reduces the amount of household labour available for the farming activities (McNally, 2002; Goodwin & Mishra, 2004; Geta *et al.,* 2010). The finding supports the idea that increased off-farm income opportunities reduce farm resources and farmers' efforts that could otherwise be used for farming activities. From the empirical literature, it is observed that off-farm income can have either a decreasing or an increasing effect on technical inefficiency. This depends on whether the off-farm income obtained contributes to improving the performance of the farm sector or if off-farm income switches the resources from farm to the off-farm sector. Funding opportunities such as credit and off-farm income is important to finance inputs such as seeds and fertilisers and to participate in soil protection practises.

2.5.2.4 Seed Type, Organic Fertiliser and Soil Protection

Improved seed is expected to provide higher returns than traditional seeds in production. This is due to the fact that the characteristic of improved seed is systematically altered in ways that bring higher productivity (Morris *et al*., 1999). From literature, Geta *et al*. (2010) and Maseatile (2011) found a decreasing effect of improved seeds on technical inefficiency. The findings confirmed the relative importance of improved seeds in decreasing technical inefficiency hence increasing productivity. In addition to the use of improved seed, application of organic fertiliser can influence technical inefficiency of smallholder farmers.

Organic fertiliser application improves the fertility of soils thereby decreasing technical inefficiency in crop production (IFPRI, 2010a; Ayalew & Dejene, 2011). Smallholder farmers commonly apply organic fertilisers such as manure and compost in crop production in order to improve soil fertility (Giller*et al*., 2006). However, organic fertiliser has a lower nutrient concentration compared to chemical fertilisers and release nutrients slowly, therefore larger quantities of organic fertilisers need to be applied (Emiru, 2004). According to Gruhn *et al*. (2000), application of both organic and chemical fertilisers together is the best alternative for a balanced and efficient plant growth and for greater productivity (Gruhn *et al*., 2000). As a result, the application of organic fertiliser has a decreasing effect on technical inefficiency.

The last variable reviewed is soil protection practises of the smallholder farmers. Smallholder farmers protect their farmlands from erosion through practises such as terracing, planting trees and contour ploughing which are expected to contribute to soil conservation and improved farm productivity (IFPRI, 2010a). Geta *et al*. (2010) found that integrated soil fertility management practises decrease technical inefficiency significantly. Although the organic fertiliser application and soil protection practises are important variables in productivity improvement, they were not investigated in previous technical efficiency studies.

2.6 CONCLUSION AND IMPLICATIONS FOR THE RESEARCH

Technical efficiency indicates how efficient producers are in the way they use their limited resources in production. Therefore, information about the level of technical efficiency is important to improve crop production. Technical efficiency analysis in Ethiopian smallholder maize production is important to improve the food insecurity problems of the country.

Productivity of maize can be improved by having adequate information about farm technical efficiency and the associated constraints. From the literature, the distinction of DEA and SFA in measuring technical efficiency is identified. The principal difference between SFA and DEA efficiency estimation is that SFA, unlike DEA, can distinguish between the effects of random shocks and inefficiency separately. Estimation of technical efficiency and investigation of the determinants of technical inefficiency by using SFA requires estimation of a production frontier and technical inefficiency models. The former is used to estimate the level of technical inefficiency while the latter is used to examine the determinants of technical inefficiency. The inputs defining the production frontier and factors affecting technical inefficiency models were reviewed thoroughly.

Based on literature, the inputs defining the production function are seed, fertiliser and labour. The common factors affecting technical inefficiency in crop production are age, gender, education, household size, farm size, tenure, oxen, extension, irrigation, credit, off-farm income, seed type, organic fertiliser and soil protection. Previous studies indicate that private tenure, ownership of adequate oxen, access to extension, irrigation, credit, off-farm income, improved seed, organic fertiliser and soil protection would decrease technical inefficiency. The variables age, gender, education, household size, farm size and off-farm income would either decrease or increase technical inefficiency. The review of the variables provides a framework in determining the variables to be incorporated in the study and provides information about the possible effects of these variables on technical inefficiency.

CHAPTER THREE: THE STUDY AREA PROFILE AND NATURE OF THE DATA EMPLOYED

The objective of this Chapter is to provide an overview of the study area in terms of location, topography and agriculture. The chapter discusses the data used and characteristics of the farm households studied.

3.1 LOCATION AND TOPOGRAPHY

Ethiopia, officially known as the Federal Democratic Republic of Ethiopia, is located in the North-Eastern part of the horn of Africa with a total surface area of 1.12 million square kilometres (Mengistu, 2006). Ethiopia is bordered by Eritrea to the North, Djibouti and Somalia to the East, Kenya to the South and the Republic of Sudan and the Republic of Southern Sudan to the West (Mengistu, 2006). At present, Ethiopia is structured into a federation of nine ethnic based administrative regions and two centrally chartered city administrations (Sori, 2009). Figure 3.1 is a graphical representation of the administrative regions and city administrations of Ethiopia.

As indicated in Figure 3.1, the administrative regions are: Tigray, Afar, Amhara, Oromia, Somali, Benishangul Gumuz, Southern Nations Nationalities and Peoples (SNNP), Gambela and Harari. The two chartered city administrations are Addis Ababa and Dire Dawa. Among the regions, the study area includes Tigray, Amhara, Oromia, Somali, Benishangul Gumuz, SNNP, Harari and Dire Dawa regions. Dire Dawa city administration is included because there are rural agricultural areas that were surveyed. Although the study was planned to cover all the regions in the country, Afar and Gambela regions were not included because the secondary data used for the study did not provide adequate information relevant to the study for the two regions. Therefore, the selection of the study area is based on the data obtained for each region from the secondary data source.

Figure 3.1: Graphical representation of the nine administrative regions and the two city administrations of Ethiopia
Source: (Oromia Region Map, 2013**)**

Ethiopia has an extremely varied topography which consists of high mountains, deep gorges with rivers, rolling plains and dissected plateaus divided by the great East African Rift Valley (FAO, 1984). The altitude ranges from 110m below sea level at the Danakil Depression to the highest peak at mount Ras Degen which is 4 600m above sea level (FAO, 2005). The diversity of the country's topography determines the wide variations in agro-ecology, climates, soils, vegetation, and settlement patterns (Camberlin & Philippon, 2001; FAO, 2005; CSA, 2009b). In the following section, the agro-ecological classifications, the related climatic conditions and soil types of the study area are discussed.

3.2 AGRO-ECOLOGY

Agro-ecological zones (AEZs) are areas where predominant physical conditions guide relatively homogenous agricultural land use options (CSA, 2006b). Elevation is the basis for the traditional agro-ecological division of Ethiopia. The six traditional agro-ecological zones of Ethiopia are: Bereha, Kolla, Weina-Dega, Dega, Wurch and Kur. Figure 3.2 indicates the traditional AEZs of Ethiopia.

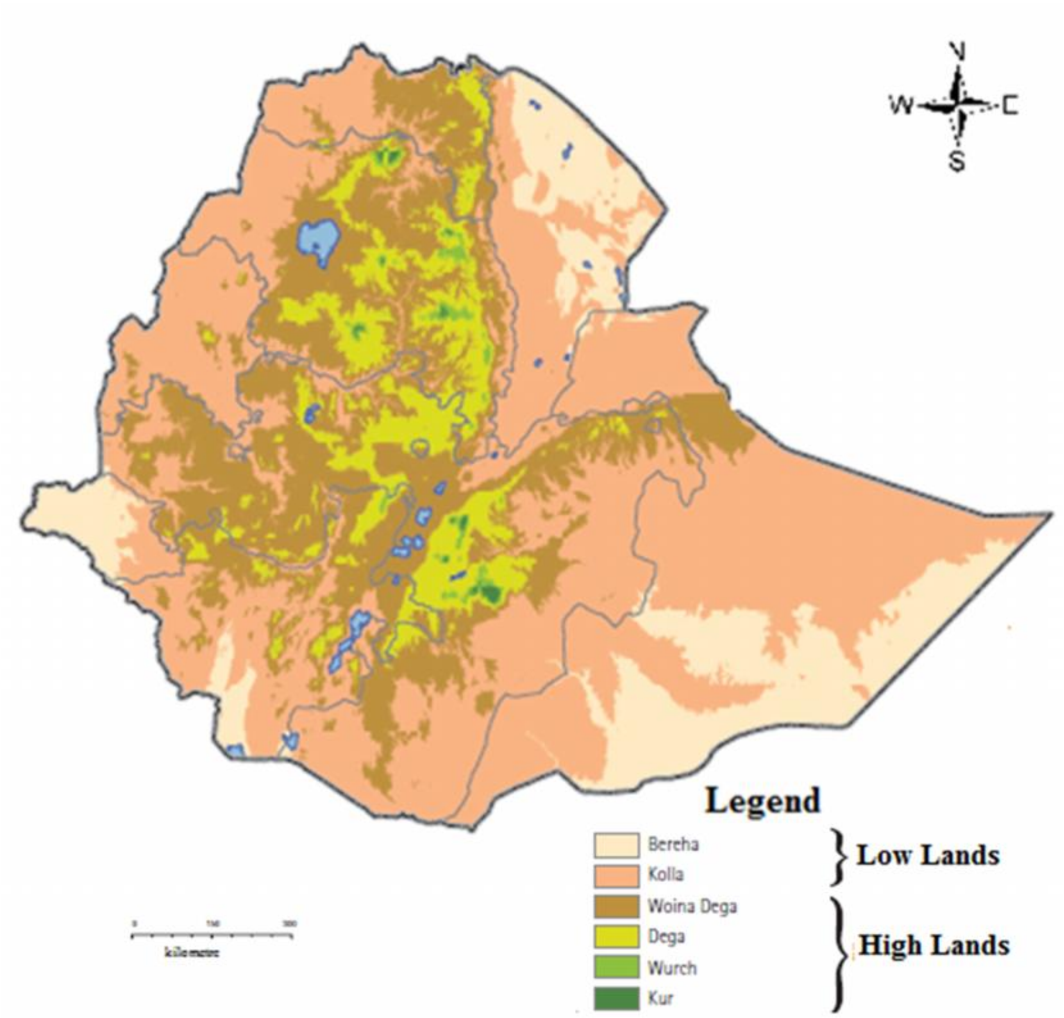

Figure 3.2: Traditional Agro-ecological Zones of Ethiopia
Source: (CSA, 2006b)

Bereha refers to hot lowlands of less than 500m above sea level and crop production in this region is limited due to a shortage of rainfall. Kolla refers to lowlands between 500 to 1 500m above sea level. Sorghum, finger millet, sesame, cowpeas and groundnuts are crops predominantly grown in Kolla AEZ. Generally, Bereha and Kolla are AEZs of the low land areas of Ethiopia and are not suitable for maize production (CSA, 2006b). Woina Dega refers to highlands between 1 500 and 2 300m above sea level and it is the most suitable AEZ for crop production, particularly for maize and teff. Dega refers to cold highlands between 2 300m and 3 200m above sea level. Barley, wheat, oilseeds and pulses are commonly cultivated crops in Dega AEZ (CSA, 2006b). Woina Dega and Dega are AEZs where most of the population of the country live and where agricultural activities are predominantly practised (Chamberlin & Schmidt, 2011). Wurch refers to highlands between 3 200m and 3 700m above sea level and it is conducive for barley production. Kur refers to highland areas of altitude above 3 700m above sea level and is primarily used for grazing animals and is not suitable for crop production (CSA, 2006b).

The general climatic elements such as rainfall, temperature, humidity, sunshine and wind are affected by geographic locations and altitudes (Mengistu, 2006). The average temperature and distribution of rainfall vary across regions in the country. The average annual temperature varies from below 10ºC in the cool highlands to above 35ºC in the hot lowlands (FAO, 2005). Areas having elevations above 1 500m receive substantially more rainfall than the lowlands. The average annual rainfall for the country is about 848mm, varying from about 2 000mm over some areas in South-West Ethiopia to less than 100 mm over lowlands in Afar region (Tadesse, 2000). The general feature of Ethiopian rainfall is that the rainfalls are often followed by storms, with very high rainfall intensity and extreme spatial and temporal variability. There is also very high annual and intra-seasonal drought prevalence in the country (Tadesse, 2000).

There are diverse soil types in Ethiopia. The MoA (2000) identified 19 soil types in the country based on the chemical and physical properties derived from parent geological materials that are modified by weathering and other transformative processes. The six dominant soil types with their respective distribution in the country are: Leptosols (29.8%), Nitosols (12.5%), Vertisols (10%), Cambisols (9.4%), Calcisols (9.3%) and Luvisols (7.8%) (CSA, 2006b). Leptosols have limited agricultural potentials due to the shallowness of the soils. Vertisols also have limited agricultural potential due to water logging nature (drainage problem) of the soil, despite having good chemical properties. Cambisols, Calcisols, Nitosols and Luvisols have relatively good physical and chemical properties for crop production (CSA, 2006b). Given the national summary of agro-ecology, climate and soil types of the country, in the following section the general overview of agro-ecology, climate, and soil distribution in the regions of the study are discussed with respect to the relative location of the regions from the north to west, south, central and East Ethiopia.

3.2.1 *TIGRAY*

Tigray region is situated in Northern Ethiopia and has a diverse topography including peak highlands, mid-lands and lowlands, which together create diversified agro-ecological zones (Gebrehiwot, 2008). The dominant agro-ecological zones of Tigray region are Kolla, Weina-Dega and Dega in decreasing order (CSA, 2006b). The wide range of variation in altitude influences temperature and climatic conditions of the region. Tigray region has a semi-arid climate characterised by a long dry season (NMA, 2007). The main rainy season is between June and September. Rainfall distribution in the region is characterised by high temporal and spatial variability with annual precipitation ranging from 500 to 1 000mm (NMA, 2007). The region is mostly prone to drought which causes catastrophic food shortage and periodic famine (Gebrehiwot, 2008). The main soil types available in Tigray region are Cambisols, Vertisols, Nitosols and Fluvisols (Hadgu*et al.*, 2013). Like other parts of the country, Tigray has high soil degradation problems in that the soils are deficient in Nitrogen (N) and Phosphorus (P) (Nedasa, 1999). Although application of N and P is necessary for production, most of the farmers of the region are not using chemical fertiliser (Hadgu *et al.*, 2013).

3.2.2 *AMHARA*

Amhara region is found in Northern Ethiopia with diverse altitude ranging from 500 to 4 620m above sea level (Alemu *et al.*, 2009). The region is predominantly characterised by Kolla, Weina Dega and Dega agro-ecological zones. The average annual rainfall of Amhara region varies from 300 to over 2 000mm. The region receives rainfall during the months of June to September (BoFED, 2011). Drought and land degradation are main challenges to crop production in Amhara region. The region is inherently prone to food shortage and famine related to rainfall variability (Bewket, 2009). The dominant soil types of Amhara region are Vertisols, Leptosols, Luvisols, Alisols and Nitosols (CSA, 2006b). According to Bewket (2009), most of the soils of Amhara region are deficient of N, P and organic nutrients. The factors that aggravated soil degradation in the region are ruggedness of the topography, expansion of cultivation into steep lands owing to increasing population pressure, intense grazing pressure, and torrential rains that cause soil erosion (Bewket, 2009).

3.2.3 *BENISHANGUL GUMUZ*

Benishangul Gumuz region is located in the North-western part of Ethiopia. The region has a diverse altitude that ranges from 580 to 2 731m above sea level. The dominant AEZs in the region are Kolla, Weina Dega and Dega in a decreasing order (CSA, 2006b). According to the Benishangul Gumuz Food Security Strategy (BGRFSS) (2004) report, average annual rainfall of the region ranges from 800 to 2 000mm. Predominant soil types of the region are Nitosols and Vertisols (CSA, 2006b). Generally, the region is characterised by erratic rainfall, soil degradation, weak infrastructure development of roads and markets and heavy prevalence of crop pests and diseases that constrain agricultural productivity of the region (BGRFSS, 2004).

3.2.4 *SOUTHERN NATIONS NATIONALITIES AND PEOPLES*

The Southern Nations Nationalities and Peoples (SNNP) region is located in the Southern and South-western part of Ethiopia. The predominant agro-ecological zones of the SNNP region are Kolla, Weina Dega, Dega and Bereha (CSA, 2006b). The region has diverse climatic conditions ranging from a hot arid and semi-arid climate to tropical humid climate. Average annual rainfall of SNNP ranges from 400mm to 2 200mm while temperature ranges from 10^oC to 27^oC. There is a wide variety of soil distribution in the SNNP region and predominant soils include Nitosols, Cambisols, Vertisols, Phaeozems, Luvisols and Andisols (CSA, 2006b). Agriculture is the dominant economic activity of the SNNP where, maize, sorghum, teff, wheat, coffee and root crops are the main crops produced (BoARD, 2006).

3.2.5 *OROMIA*

Oromia region extends from Central to Eastern, Southern and Western parts of the country sharing borders with all other regions except Tigray (CSA, 2006b). Western and Central Oromia have predominantly Weina Dega and Dega AEZs while the Eastern and Southern Oromia consist of Kolla AEZ (CSA, 2006b). Annual rainfall of Oromia region ranges from 400 to 2 400mm in which Western Oromia gets the highest rainfall while the lowlands of Eastern and South-Eastern Oromia has the lowest rainfall in the region (PCDP, 2010).Average annual temperature of the region varies from less than 10^oC in the highlands to over 30^oC in the lowlands (PCDP, 2010). Oromia has relatively fertile soils of volcanic origin, although there are acidic, basic, ferrogenous, sodic or saline soil types of low agricultural potential (PCDP, 2010). Dominant soil types of the region are Nitosols, Vertisols, Cambisols, Leptosols and Luvisols (CSA, 2006b). Because of the relatively suitable soil types and higher rainfall, Oromia is the leading crop producing region in Ethiopia (Oromia Investment Commission, 2012). Accordingly, Oromia region accounts for 49% of major food crops produced in the country (CSA, 2007). Nevertheless, the soils in the highlands of Oromia have been subjected to degradation due to erosion, over grazing, deforestation and inappropriate farm management (PCDP, 2010).

3.2.6 *HARARI*

Harari is the smallest region which is located in the South-eastern highlands of Ethiopia within altitudinal range of 1 300 to 2 300m above sea level, surrounded by Oromia region in all directions (CSA, 2006b). The major agro-ecological zones of Harari region are Weina Dega and Kolla. Average annual rainfall of Harari varies between 850mm and 870mm and the main soil types of the region are Luvisols, Vertisols, Cambisols and Acrisols (HPRS, 2011). Maize, teff and sorghum are the main crops produced in the Harari region (Abesha, 2009).

3.2.7 *SOMALI*

Somali region is found in the Eastern and South-eastern part of Ethiopia with altitudes ranging from 200m to 1 800m (DPPB, 2004). Agro-ecology of Somali region is mostly Kolla and Bereha (CSA, 2006b). Average annual rainfall of Somali ranges from 150mm to 1 000mm while average temperature ranges from $19^{o}C$ to $40^{o}C$ (DPPB, 2004). Although mixed farming is practised, including maize production, pastoralism is the most prevalent livelihood of the Somali region (DPPB, 2004). The main soil types of the Somali region are Calcisols, Leptosols and Gypsisols (CSA, 2006b). Most parts of the region have sandy soils, rocky and hilly landscapes which are not suitable for crop production (DPPB, 2004). Nevertheless, sorghum and maize are grown in some parts of the Somali region. There are many problems confronting the socio-economic conditions of the Somali region. These are drought, flood, conflict, environmental degradation, crop and livestock diseases, lack of water and poor infrastructure (SRSS, 2004).

3.2.8 *DIRE DAWA*

Dire Dawa city administration is found in South-eastern Ethiopia, neighboured by Somali region in the North, East and West as well as by Oromia region in the South (CSA, 2006b).

Dire Dawa administration includes Dire Dawa city and the surrounding rural areas of the region with altitudes between 960m to 2 450m above sea level. Kolla and Weina Dega are the main AEZs of the region (CSA, 2006b). Mean annual rainfall varies from 550mm to 850mm. Dire Dawa has large distributions of Leptosols soil type (CSA, 2006b). Mixed farming systems are the common farming practise in which sorghum and maize are the main cereal produced along with livestock rearing (DDAEPA, 2011). Given the regional discussion of the agro-ecology, climate, soil and cropping potential of respective areas in the study, the following section provides an overview of agriculture in Ethiopia.

3.3 AGRICULTURE

Ethiopia is an agrarian country where about 43% of GDP and 85% of total employment is agriculture based (MoARD, 2010). Within agriculture, about 60% of agricultural GDP is derived from crop production whereas livestock and other agriculture accounts for 27% and 13% of agricultural GDP, respectively (Gebre-Selassie & Bekele, 2013). Because of the greater contribution of agriculture to the national economy, the government of Ethiopia has adopted the Agricultural Development Led Industrialisation (ADLI) strategy as a national development strategy (Diao, 2010).The main goal of ADLI was to attain fast and broad-based development within the agricultural sector and to stimulate the overall development of the economy through the linkage effects of agriculture to other sectors (Diao, 2010). Implementation of ADLI focuses on increasing agricultural productivity of smallholder farmers through increasing the use of modern farm inputs (example: fertiliser, improved seeds, pesticides, herbicides) along with better farm management practises (Dercon & Hills, 2009).

However, the agricultural productivity of Ethiopia remains low and the country is unable to match the food demand of the ever increasing population (IFAD, 2008). Low agricultural productivity of the country is commonly attributed to limited access of the smallholder farmers to agricultural inputs, financial services, improved production technologies, irrigation, agricultural markets, the prevailing poor soil and land management practices (IFAD, 2008). Given the general overview of Ethiopian agriculture, the farming systems and the rural land use of the country is summarised as follows.

3.3.1 FARMING SYSTEM AND RURAL LAND USE IN ETHIOPIA

Farming in Ethiopia is generally rainfed farming. According to Awulachew *et al*. (2007), only about five percent of the total annual agricultural production uses irrigation while the remaining 95% is based on rainfall. The country is naturally endowed with many irrigable river-basins and lakes that can be used to irrigate about 3.7 million ha (Awulachew *et al*., 2007). The main river basins are Mereb, Tekeze, Awash, Denakil, Abbay, Ayisha, Baro-Akobo, Omo-Gibe, Wabi-Shebele, Genale-Dawa and Ogaden while most of the lakes are found in the Rift Valley basin of Ethiopia (Awulachew *et al*., 2007). Despite having good potential for irrigation development, the operational irrigation schemes of Ethiopia covers nearly two percent of the total agricultural land which contributes to the nearly five percent of agricultural production (Awulachew, 2007). The existing irrigation scheme of Ethiopia is classified as small-scale if the area covered by irrigation is less than 200ha; medium-scale if the area is between 200 to 3 000ha and large-scale if the irrigation covers an area larger than 3000ha (Awulachew *et al*., 2007). Only small-scale irrigation schemes are used for grain crop production, while medium and large-scale irrigations are used for production of crops such as cotton, sugarcane, vegetables and fruit in the country (Hordofa *et al*., 2008). Of the prevailing small-scale irrigation scheme, 17 to 22% is found in Oromia, Amhara, SNNP and Tigray regions (Hordofa *et al*., 2008).

The small-scale irrigation schemes include the modern schemes and traditional schemes. Modern schemes usually have fixed or improved water control or diversion structures, and water-users' associations that have laws while the traditional scheme is developed and managed by community tradition (Awulachew *et al*., 2007). The medium and large scale schemes however, are mostly public schemes owned and managed by the government and in certain cases by large communities (Awulachew *et al*., 2007). Some of the reasons for low levels of irrigation development of the country are a lack of capital to invest in irrigation development and lack of appropriate water resources' development strategies for long periods (Adenew, 2003). Because of the extreme dependence of the country on rainfall, climatic changes and variability of rainfall influences the livelihood of the country (Awulachew *et al*., 2007).

Rural land use in the country is categorised into: crop areas (82%), fallow land (4%), grazing land (9%), wood land (1%) and other land use (4%) (CSA, 2012b). Crop areas are the parts of rural land that is under annual or perennial crop production, while fallow land refers to rural land that is kept idle for at least one agricultural season and with a maximum period of five years. Fallowing of rural land is used to protect farmlands from exhaustion of the important mineral nutrients caused by continuous cultivation (CSA, 2012b). Grazing land refers to part of rural land that is used for growing herbaceous forage, while woodland is rural land that is under tracts of timber which has a value as wood, timber and other wood products (CSA, 2012b).Other rural land use includes areas occupied by the farmers' houses, gardens, barns, wells and ponds (CSA, 2012b). The classification indicates that most of the rural land of Ethiopia is already occupied by crop production. In the following section, crop production and soil protection practises of the country are assessed.

3.3.2 *CROP PRODUCTION*

Crop production in Ethiopia consists of cereals, pulses, oilseeds, vegetables, root crops, fruits, coffee, enset, khat, hops, sugarcane, cotton and tobacco production (CSA, 2012a). Crop farming is generally categorised into smallholder farming and large-scale commercial farming based on the acreage cultivated. If crop farming is operated on areas less than 25.2ha, it is considered as smallholder farming whereas if farming is operated on areas greater than 25.2ha, it is considered as commercial farming (CSA, 2009a). Commercial farms are not widely spread in Ethiopia and the contribution of these farms to total agricultural output is less than four percent of the total agricultural production (CSA, 2009a; Alemayehu *et al*., 2011). Smallholder farming is mostly mixed subsistence farming in which crop production is undertaken side by side with livestock farming. Smallholder farming accounts for 96% of the total area under agriculture and nearly 95% of the total agricultural GDP (Alemayehu *et al*., 2011; Gebre-Selassie & Bekele, 2013).

Given the dominance of the smallholder farming in Ethiopian crop production sector, there are two distinct cropping seasons for temporary crops in Ethiopia, Meher and Belg (CSA, 2012a). The classification is based on harvesting time of temporary crops. Belg includes crops harvested during March to August while Meher includes crops harvested between September and February. Meher is the main cropping season that accounts for 92% of total crop cultivated area and 97% of total crop production while Belg season accounts for only eight percent of total crop cultivated area and three percent of total crop production (Alemayehu *et al*., 2011). In this study, Meher season's crop production performance of smallholder farmers is evaluated because Meher is the main grain crop production season which is also true for maize production. Given the distinctions of Meher and Belg seasons, a summary of total area cultivated and total production for cereals, pulses and oilseeds for the year 2011/12 Meher season is given in Table 3.1.

Table 3.1: Total area cultivated (hectares) and total production (tons) of cereals, pulses and oilseeds for smallholder farming in 2011/12 Meher season, Ethiopia

Crop	**Area**		**Production**	
	Hectares	**%**	**Tons**	**%**
Cereals	9 588 923.71	79.34	18 809 961.70	86.06
Pulses	1 616 809.37	13.38	2 316 201.24	10.60
Oilseeds	880 870.81	7.28	730 880.03	3.34
Total	12 086 603.89	100	21 857 042.97	100

Source: CSA (2012a)

As is indicated in Table 3.1, during the year of 2011/12 Meher season, the total estimate of grain crops (cereals, pulses and oilseeds) cultivated areas were about 12.08 million hectares whereas total production was about 21.86 million tons. Cereal was cultivated over an area of about 9.59 million hectare which accounts for 79.34% of total grain crops area cultivated. The total cereal production was about 18.8 million tons which accounts for about 86.06% of total grain production. The five main cereal crops grown in Ethiopia are maize, teff, wheat sorghum and barley which accounts for the three-quarters of total area cultivated and 29% of agricultural GDP (Alemayehu *et al.*, 2011). Cereals are the most produced crops in the country.

Pulses and oil seeds are the second and third highest produced crops, after cereals based on acreage. Pulses are cultivated on areas of more than 1.6 million hectares which accounts for about 13.8% of the total grain crop area. Total pulse production is about 2.3 million tons which accounts for 10.6% of total grain production. The three dominant pulse crops produced are faba-beans, haricot beans and chickpeas. Likewise, oilseeds are cultivated from an area of about 880 000 hectares which is equal to 7.29% of total grain area cultivated. The total quantity of oilseeds produced is about 730 000 tons which accounts for 3.34% of the total grain production. The main oil seeds produced in the country are niger-seed, sesame and linseed (CSA, 2012a). Of all grain crops, maize is widely produced in Ethiopia and accounts for 17% of total grain area cultivated and 28% of total grain production. Therefore, maize production is discussed in the next section.

3.3.2.1 Maize Production

Maize is produced in almost all regions of the country, but the three largest maize producers are Oromia (61%), Amhara (20%) and SNNP (12%) (Schneider & Anderson, 2010). Smallholder farmers are the predominant producers of maize during both the Meher and Belg seasons (RATES, 2003). Meher season accounts for about 78% of total maize area cultivated and 90.5% of total maize production annually while Belg accounts for 22% of total maize area cultivated and 9.5% of total maize production (Alemayehu *et al*., 2011). This study will assess smallholder farmers' maize production performance in Meher season only.

The CSA (2012a) report indicated that in 2011/12 Meher season, maize is cultivated from an area of more than two million hectares, which accounted for 17% of total grain crop cultivated area, by more than six million smallholder farmers. The total quantity of maize produced on this area was about six million tons (28% of total grain production) with an average maize yield of about 2.95 ton/ha (CSA, 2012a). According to the annual reports of CSA during 2003/04 to 2011/12 Meher season, the total area cultivated, total maize production and yield were following increasing trends (Alemayehu *et al*., 2011). Figure 3.3 provides the general increasing trend of the maize area cultivated, total production and yield over the period of 2003/04 to 2011/12 Meher season.

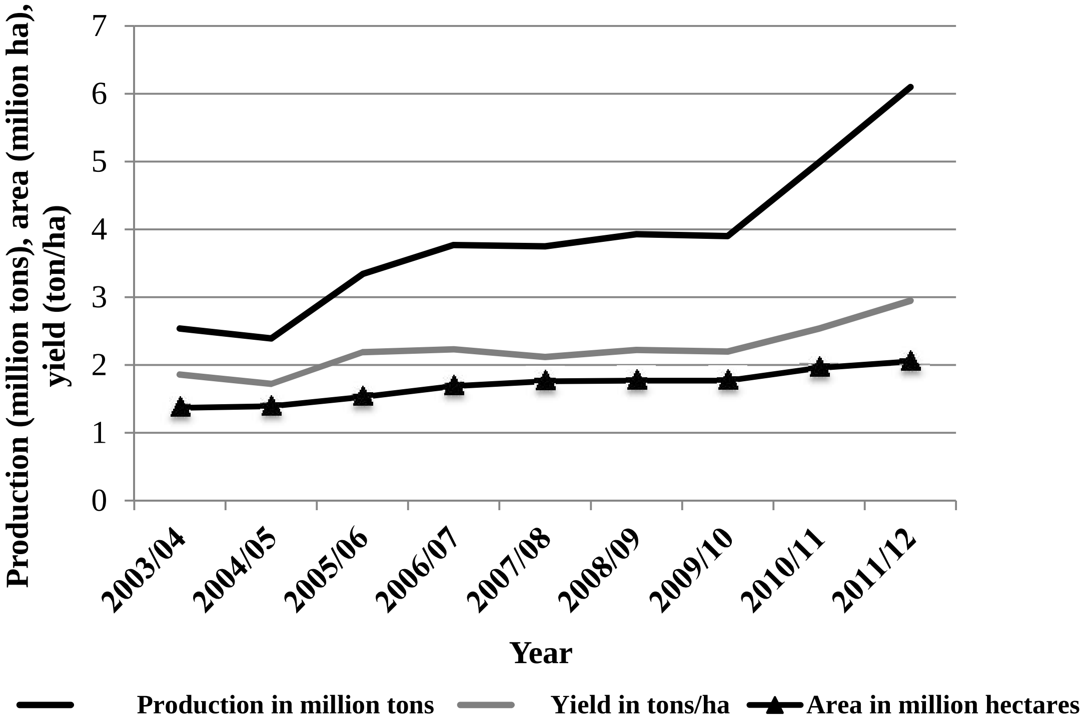

Figure 3.3: **Graphical representation of smallholder farmers' maize area cultivated, total production and yield during 2003/04 to 2011/12 Meher season, Ethiopia**

Source: CSA (2003/04 to 2011/12)

From Figure 3.3, total maize area cultivated, yield and total production showed an increasing trend for the given period. The level of maize area cultivated increased from about 1.34 million hectares to more than two million hectares between 2003/04 and 2011/12 (49% increase). Total maize production also increased from about 2.5 million tons to about 6.1 million tons (144% increase). The increase in production is partly due to the increased cultivation of additional lands and due to increased yield overtime. The increase in yield is the bigger contributor to the increase in production relative to the area. The average maize yield increased from about 1.86 ton/ha in 2003/04 to about 2.95 ton/ha in 2011/12 (58% increase). The increase in yield is mainly attributed to the increased use of modern farm inputs such as fertiliser and improved seeds as well as better utilisation of farm management practises (Alemayehu *et al.*, 2011). Even though, maize yield was increasing, the observed yield level is still lower than the potential yield level of the country (Alemayehu *et al.*, 2011). According to Alemayehu *et al.* (2011), there are various constraints in Ethiopian maize production such as underutilisation of modern farm of inputs (*i.e*, fertiliser, improved seeds and pesticide), insufficient use of irrigation, high soil degradation due to erosion, inadequate agricultural research and extension services and constraints in market development (i.e, input supply, storage problem and price volatility).

The increase in production that is attributed to an increase in area cultivated can be as a result of increased cultivation of marginal and less productive lands that are potentially not suitable for crop production (Alemayehu *et al*., 2011). This is because the more productive highland areas of Ethiopia are already under cultivation and any expansion of areas cultivated can be at the expense of reduction in forests and grazing lands (Alemayehu *et al*., 2011). Increasing production by further increasing the area cultivated is not a sustainable means of production growth due to the facts that land is a limited resource and due to the negative environmental implications(Alemayehu *et al*., 2011). Sustainable growth of crop production requires increasing the productivity of the farms already under operation rather than expanding areas cultivated to marginal and unproductive areas (Alemayehu *et al*., 2011). Soil conservation and land management practises can contribute to enhanced productivity of the operational farmlands and can also ensure sustainability of the land use. Given the overview of smallholder maize production, in the following section, soil conservation and land management practise of the country is discussed.

3.3.3 *SOIL CONSERVATION AND LAND MANAGEMENT*

Soil conservation and land management practise enhances land productivity. For example, Benin (2006) and Pender and Gebremedhin (2006) found that soil protection through terracing increased crop yield. Similarly, Zikhali (2008) found that contour ridges have a positive impact on land productivity while Kassie *et al*. (2011) found that minimum tillage has a strong positive influence on crop productivity. Soil conservation practises such as crop rotation, fallowing and inter-cropping are very limited in the highlands and potentially agricultural areas of the country due to small and fragmented farm sizes which are not suitable for such practises (IFPRI, 2010a).

As a result, Ethiopia became one of the countries that have the highest rate of soil nutrient depletion in sub-Saharan Africa (IFPRI, 2010a). There is severe topsoil degradation, organic matter depletion and depletion of soil physical, macro and micro-nutrients as well as salinity and acidity problems (IFPRI, 2010a).According to Hurni (1993), soil erosion causes on average, a loss of about 4.2 tons of soil per hectare per year in Ethiopia which contributes to the decrease in productivity. As a result, most of the soils are depleted and became deficient in important soil nutrients including N and P (Mengistu, 2006).

Land degradation in the country is exacerbated by factors such as deforestation, erosion, population pressure, overgrazing and inadequate planning of land use (MoARD, 2010). Furthermore, Pender and Gebremedhin (2006) noted that factors such as cultivation of marginal lands, soil erosion, continuous mono-cropping, climatic changes and high population growth are factors that contributed to the increased land degradation in Ethiopia. The cumulative impact has resulted in the continued dependence of the country on food aid (Pender & Gebremedhin, 2006).

3.3.4 *SUMMARY*

Ethiopia has a diverse topography which determines the agro-ecology, climate and farming systems in the country. Agriculture is the dominant sector of the Ethiopian economy and is characterised by smallholder rainfed farming systems. Crop production is the largest contributor of the agricultural GDP and there are two cropping seasons, Meher and Belg. Among the crops produced in the Ethiopia, maize is an important food crop where Oromiya, Amhara and SNNP are the largest maize producing regions. Maize is produced during both seasons but, Meher is the main maize production season in terms of total area, total production and yield.

Historical data of maize production in Ethiopia during 2003/04 to 2011/12 Meher season, indicated that maize production increased over time, along with the maize area cultivated and yield. Therefore, the increase in maize production is the result of the increase in area cultivated and yield. The increase in output through increasing the area cultivated is not a sustainable way of increasing productivity because an increase in production will take place within an environment characterised by a scarcity of arable lands. Rather, increasing productivity from the operational farms is important for sustainable crop production. The prevailing low level of soil conservation practise in the country also resulted in the depletion of important soil nutrients including phosphorous and nitrogen which in turn decreases the level of productivity. By having adequate information about the state of technical efficiency of the smallholder maize farmers and by examining the determinants, productivity can be improved.

3.4 TYPE AND SOURCE OF DATA

The data used in this study is secondary data obtained from the Central Statistical Agency of Ethiopia. The data formed part of the Ethiopian Rural Socio-economic Survey (ERSS). The Central Statistical Agency of Ethiopia, in collaboration with the World Bank, conducted a living standard and agricultural survey in 2011/12. The purpose of the survey was to obtain comprehensive agricultural, welfare and socio-economic information on rural and small town households in the country. Under the ERSS, the CSA used a two-stage stratified cluster sampling procedure to select the agricultural households, first by selecting enumeration areas (EAs) and then the households surveyed. The CSA employed a questionnaire based on personal interviews to collect the data. For the current study, only farm households that are involved in maize productions were considered consisting of 438 observations. The sampled farm households considered from the corresponding regions and the associated percentage are provided in Table 3.2.

Table 3.2: Number of sampled households considered from the selected regions and respective percentages in the secondary data set used

Regions	Number of households chosen from each region	Percentage of households in the sample from respective regions
Tigray	64	15
Amhara	107	24
Benishangul Gumuz	27	6
SNNP	96	22
Oromia	103	24
Harari	21	5
Somali	9	2
Dire Dawa	11	2
Total	438	100

Table 3.2 indicates the number of sampled households considered from the selected regions and respective percentages in the sample. In order to ensure a sufficient sample size in the most populous regions, the CSA has set larger quotas for Amhara, Oromia, SNNP, and Tigray regions. Therefore, the percentage of the sample for the respective regions include: Oromia (24%), Amhara (24%), SNNP (22%), Tigray (15%), Benishangul Gumuz (six percent) and Harari (five percent), Somali (two percent) and Dire Dawa (two percent). Based on the data

used in the study, the respondents can be characterised on their production, socio-economic and farm management information.

3.5 CHARACTERISATION OF RESPONDENTS

The purpose of this section is to discuss the characteristics of the respondents. The first section discusses maize yield and the production inputs used by the respondents. The second section is used to discuss the socio-economic and farm management practices of the respondents.

3.5.1 *MAIZE YIELD*

Maize yield is the quantity of maize produced in tons per hectare. Maize yield estimation is calculated based on the maize crop cutting from an area of 4m^2 for respective farmers in the sample (CSA, 2013). The summary statistics of maize yield of the respondents in the sample is provided in Table 3.3.

Table 3.3: Summary Statistics of maize yield of the sampled respondents during 2011/12 Meher season

Variable	Unit	Average	Std. Deviation	Minimum	Maximum
Maize Yield	ton/ha	2.61	1.50	0.00	8.30

From Table 3.3, the average maize yield estimate is 2.61 ton/ha. The yield level was highly variable among the respondents with minimum and maximum yields of zero and 8.3 ton/ha, respectively and a standard deviation of 1.5 ton/ha. The minimum crop yields of zero ton/ha was not expected. However, upon investigation of the maize yield reported, it was found that farmers were not able to harvest a crop due to damage to the crop. Crop damage could be due to frost, drought, flood, insects or other natural calamities (CSA, 2013). The inputs used in maize production include several different variables including seed, fertiliser and labour. The input variables used to estimate the production function is discussed in the following section.

3.5.2 *SEED AND FERTILISER*

Seeds and fertilisers are the primary inputs in crop production (Ayele & Bosire, 2011). Summary statistics of total seed and chemical fertilisers used are provided in Table 3.4. Farmers had the choice to use either improved seeds or traditional seeds. Similarly, the respondents used different combinations of fertiliser, including chemical, organic, combinations of chemical and organic or neither. Information regarding the quantity of the organic fertiliser applied was not available therefore the quantity of organic fertiliser used will not be discussed.

Table 3.4: Summary statistics of seed and fertiliser use of respondents

Variables	Unit	Average	Std. Deviation	Minimum	Maximum
Seed (total)	Kg/ha	72	207	1	3 473
Improved seed	Kg/ha	45	59	1	447
Traditional seed	Kg/ha	77	226	1	3473
Phosphorus	Kg/ha	15	58	0	999
Nitrogen	Kg/ha	20	63	0	988

From Table 3.4, the average quantity of total seed used in maize production for the sample is nearly 72 kg/ha with a standard deviation of 207 kg/ha. The standard deviation indicates a very wide variation in seed use among respondents. It is observed that some of the farmers used improved seed while others used traditional seed in maize production. The average quantity of improved seed used is 45 kg/ha while that of traditional seed use is 77 kg/ha. This indicates that the farmers applied on average greater quantities of traditional seeds than improved seeds per hectare. The standard deviation is 59 kg/ha for improved seed and 226 kg/ha for traditional seed which also indicates wider dispersion in the quantity of traditional seed used over that of improved seed. The percentage of respondents using improved seeds compared to those using traditional seeds is provided in Figure 3.4.

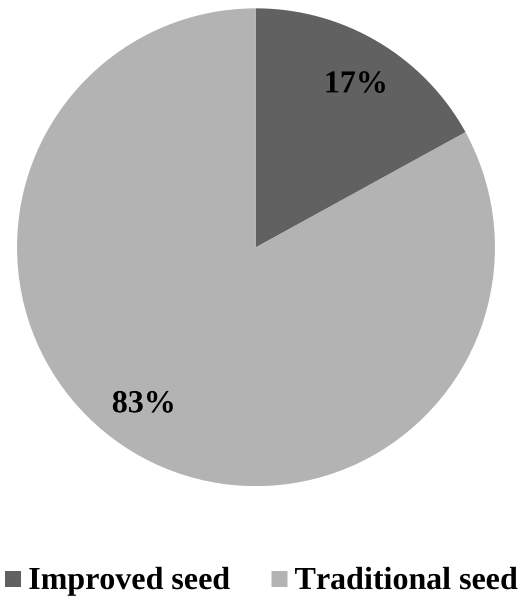

Figure 3.4: **Distribution of respondents by type of seed used**

Figure 3.4 indicates that only 17% of the respondents used improved seed while 83% used traditional seed. This indicates that the use of improved seed is very low compared to traditional seed. Based on the type of seed used, there is a yield difference among the households in the sample. The average maize yield of the households that applied improved seed is 3.38ton/ha while the average of the farmers that used traditional seed is 2.47ton/ha. The maize yield obtained from improved seed is greater than that of traditional seed, which is expected. According to the literature, less improved seed is used in Ethiopia as there is insufficient supply of improved seed relative to demand, limited choice in the varieties available in the market, lack of rural credit, low level of extension services, high costs of improved seeds and limited competition among seed suppliers (Alemu *et al*., 2009).

According to Spielman *et al*. (2011), 60% of maize seed supply is controlled by the public sector, primarily the Ethiopian Seed Enterprise (ESE).Due to the low seed production, the supply of improved seed in Ethiopia usually falls short of the demand (Spielman *et al*., 2011). In addition, seed is distributed after the appropriate planting time (Sahlu & Kahsay, 2002 & DSA, 2006).Other problems experienced in the seed supply chain include poor quality seeds such as poorly cleaned seeds, broken seeds and low germination rates (DSA, 2006).To improve the nutrient levels of soils in the ground in order to increase productivity, farmers may apply chemical and organic fertilisers in maize production.

The quantities of Phosphorus and Nitrogen nutrients used that are presented in Table 3.4 are calculated based on DAP and Urea fertilisers used by each household. On average, farmers in the sample applied 15kg/ha of Phosphorus with a standard deviation of 58 kg/ha while the average application of Nitrogen is 20kg/ha with a standard deviation of 63 kg/ha. Integrated application of organic fertiliser (farm yard manure, compost, green manure and transferred biomass of leguminous trees) and chemical fertiliser improves soil fertility and enhances crop yield (Ayalew & Dejene, 2011). Therefore, distribution of the respondents with regard to application of chemical and organic fertiliser is important. Figure 3.5 provides graphical representation of the distribution of respondents based on fertiliser use.

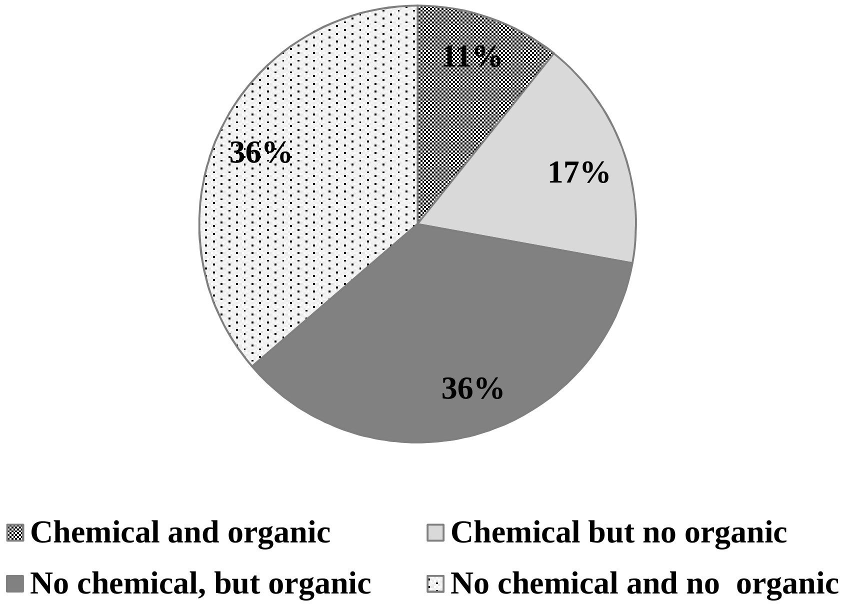

Figure 3.5: Distribution of respondents based on fertiliser use

Figure 3.5 indicates four categories of respondents observed which include farmers that used only chemical fertiliser, farmers that used both chemical and organic fertilisers, farmers that used only organic fertiliser and farmers that used neither of the two fertilisers. The percentage of respondents that used a combination of chemical and organic fertiliser is 11%, while the percentage of respondents that used only chemical fertiliser is 17%. Another 36% of the respondents used only organic fertiliser while the remaining 36% used neither chemical nor organic fertiliser.

Despite the fact that the use of chemical fertiliser increases maize productivity considerably, most of the respondents did not use chemical fertiliser. There are various reasons for the low adoption and utilisation of chemical fertiliser in Ethiopia. According to Fufa and Hassan (2006) and Tesfaye *et al*. (2011), the primary reasons for low utilisation of chemical fertilisers are farmers' expectations of rainfall, high price of fertiliser, limited risk management services, lack of rural credit, small farm sizes, lack of transportation infrastructure and unavailability of fertiliser in the markets at the right time.

According to Fufa and Hassan (2006), farmers' expectations about rainfall conditions influence the use of chemical fertiliser. Whenever the expected rainfall is less than normal, farmers are unwilling to use chemical fertiliser (Fufa & Hassan, 2006). The high price of fertiliser is associated with high transaction costs incurred by the suppliers (related to transportation, storage and handling costs), as well as taxes and profit earned by the sellers (Jayne *et al*., 2003). Unavailability of fertiliser at the right time for the farmers is related to the international procurement and shipping to import fertiliser (Tesfaye *et al*., 2011).Currently, the Agricultural Input Supply Enterprises (AISE) and the cooperative unions are the sole importers and distributors of chemical fertilisers in the wholesale and retail market in Ethiopia (Spielman *et al*., 2011). Absence of competitive private traders as an alternative supply source is also a problem causing lower adoption and utilisation of fertiliser (Spielman *et al*., 2011). In addition, low levels of education amongst the farmers and insufficient information provided by extension services contributes to the limited adoption and utilisation of chemical fertilisers (Zerfu & Larson, 2011; Spielman *et al*., 2011). The cost and utilisation of seed and fertiliser is affected by the farm size and availability of labour. These attributes are also important and discussed in the following section.

3.5.3 *FARM SIZE AND LABOUR*

Farm size refers to the size of the maize farm lands measured in hectares (ha). Similarly, labour refers to the quantity of labour used in man-days per/ha during the entire Meher season for maize production. Labour is an aggregation of household and hired labour with the assumption that each person works on average eight hours per day on maize farms. Table 3.5 provides a summary of farm size and labour use of the respondents.

Table 3.5: Summary statistics of farm size and labour use of respondents

Variables	Unit	Average	Std. Deviation	Minimum	Maximum
Farm size	ha	0.13	0.18	0.001	2.36
Labour	man days/ha	392.33	1 185.07	1.19	14 549.28

From Table 3.5, the average farm size is 0.13 ha with a standard deviation 0.18 ha. The minimum and maximum farm sizes are 0.001 ha and 2.36 ha, respectively. Although the average farm size of the sample is very small, there is strong variability of the sizes cultivated. The average farm size of the sample (0.13 ha) is smaller than the national average farm size of smallholder farmers in Ethiopia which is 0.96 ha (CSA, 2012b). The average amount of labour used is 392 man days/ha with a standard deviation of 1 185 man days/ha. There is also wide variation of labour used among the respondents. This can be due to the fact that the farmers are cultivating very small farm sizes and when the amount of labour used is converted on a per hectare basis, the value of labour is magnified. Apart from physical inputs used in the production process, several other factors can also influence the efficiency of production such as age, gender of the household heads and several other socio-economic variables.

3.5.4 *SOCIO-ECONOMIC VARIABLES*

The socio-economic variables in the study include age, gender, education, household size, tenure, ownership of adequate oxen, credit and off-farm income. The descriptive statistics of the variables are discussed subsequently starting with age and household size.

3.5.4.1 Age and Household Size

Age of a household head is measured in years while household size refers to the number of household members living in each farm household which can be either a person living alone or a group of people who live together sharing a common house or supported by a common budget (CSA, 2012a).Table 3.6 provides information on the summary of age and household size of the respondents.

Table 3.6: Summary statistics of age of farm household heads and family size

Variables	Unit	Average	Std. Deviation	Minimum	Maximum
Age of household head	years	44	15	18	93
Family size	count	5	2	1	13

The average age of the head of the farm household is 44 years. The minimum and maximum ages are 18 and 93, respectively. Similarly, average household size of the respondents is five. The minimum household size is one while the maximum is 13. The household size of the sample is also nearly equal to the average rural household size in Ethiopia which is 4.9 (CSA, 2011b). Household size commonly influences agricultural performance through the contribution to family labour (Fesessu, 2008; Baruwa & Oke, 2012).

3.5.4.2 Gender and Education

The distribution of the respondents based on gender of the household heads is represented graphically in Figure 3.6.

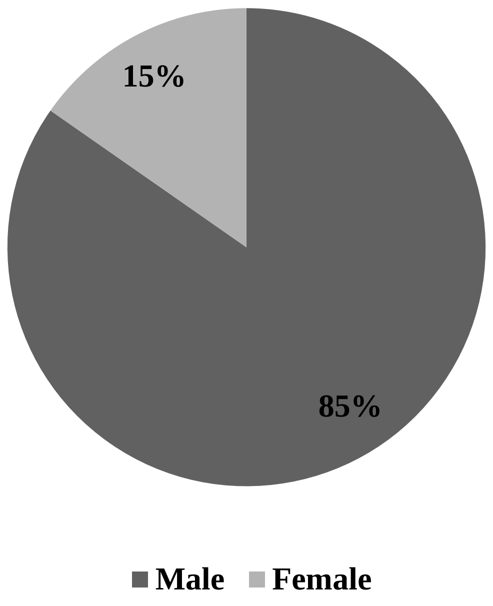

Figure 3.6: Gender distribution of the household heads

From Figure 3.6, the gender distribution revealed that 85% of the respondents are male-headed households while 15% are female-headed households. In other words, the sample contains 371 male-headed and 67 female-headed households. The gender of farm households can be a cause for technical efficiency variation among the respondents (Bachewe, 2009). Gender is an important issue in Ethiopia because of the prevalence of gender inequality in the country. Female-headed households can be inefficient relative to male-headed households as female-headed households have less opportunities to access land, credit and technological inputs (OXFAM, 2012; AWM, 2009).As education can influence decision making and other managerial capabilities on a farm, the following section is a discussion of the education level of the respondents.

Education of household heads may enhance farm productivity by affecting households' decisions to adopt and use technological innovations better (Weir, 1999). Based on education, the sampled households are classified into two categories: those having household heads with formal education of grade three or less and those with grade four or above. The classification is in accordance to the current education policy of Ethiopia, where completion of formal education of grade four is considered as a basic education threshold that can influence agricultural decision making of the farmers (MoE, 2008).Education distribution of the sample is indicated in Figure 3.7.

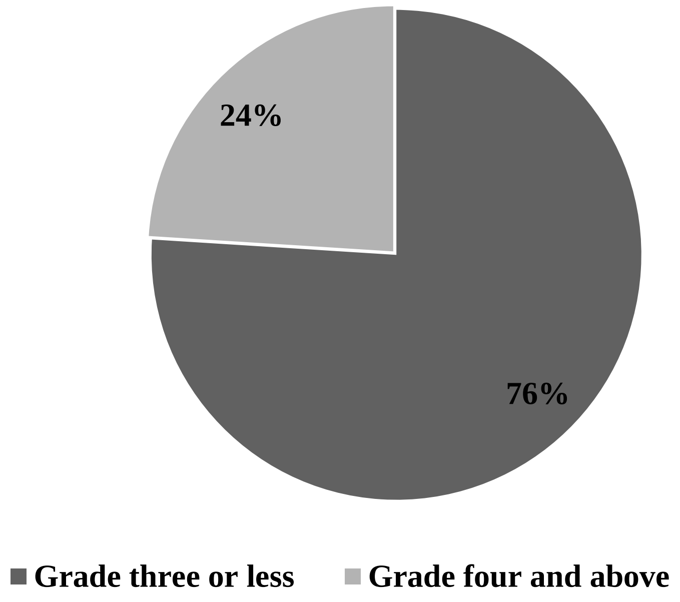

Figure 3.7: Distribution of respondents based on education of the household heads

From Figure 3.7, about 76% of the respondents have household heads with an educational level of grade three or less while 24% of the respondents have an education of grade four or above. The category is based on the idea that farmers that have completed grade four could develop basic knowledge that is required to handle the agricultural decision makings better than the farmers not having the educational level. Due to variations in the education of the household heads, the extent of technical efficiency of the farmers can vary.

3.5.4.3 Ownership of Resources (Tenure and Oxen)

Tenure refers to the form of farm land ownership of the respondents which is categorised into private ownership and other forms of land ownership that can be renting or share cropping. Figure 3.8 provides the distribution of respondents based on tenure type.

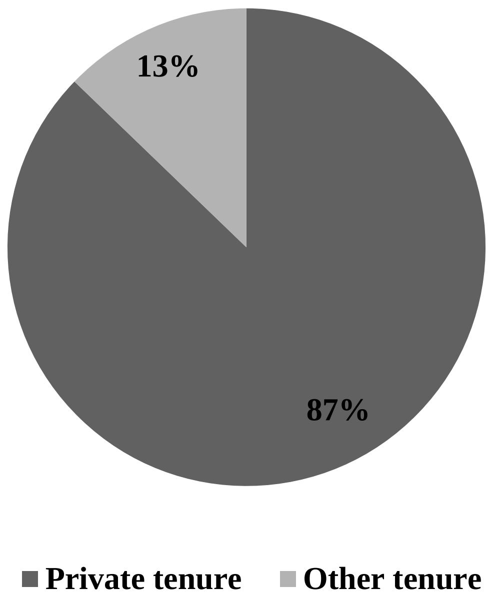

Figure 3.8: Tenure distribution of the respondents

As indicated in Figure 3.8, about 87% of the respondents own the land they farm on while 13% of the respondents are operating on rented or share cropping land. Private ownership of farm lands gives the farmers greater incentives for practising conservation and investing in the farm (Alene & Hassan, 2003; Uaine, 2008).

Similar to tenure, ownership of oxen of the respondents during the production season can cause performance variation. Ownership of adequate oxen enables the farmers' timely operation of farming activities. Distribution of the respondents based on ownership of sufficient oxen (having at least two oxen) is provided graphically in Figure 3.9.

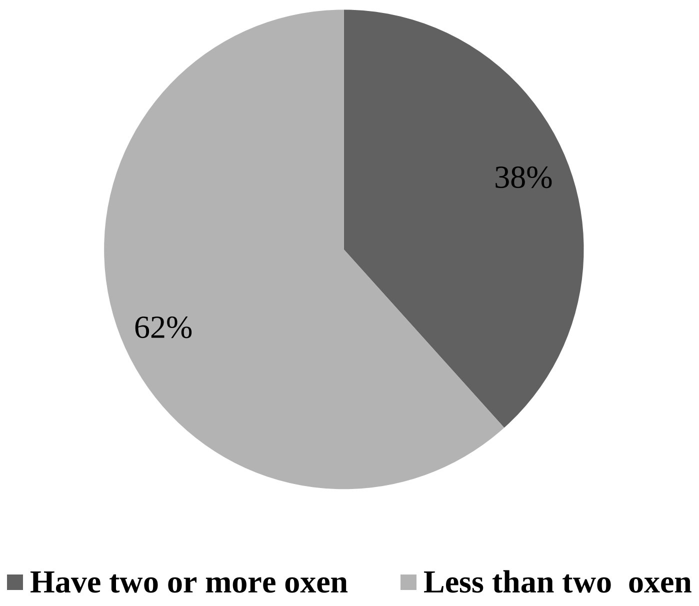

Figure 3.9: Oxen ownership distribution of the respondents

As indicated in Figure 3.9, about 62% of the respondents did not have an adequate number of oxen, while 38% of the respondents had an adequate number of oxen. Farmers that had adequate oxen may have had an advantage over the farmers that did not have adequate oxen for timely preparation of their farmlands (Gebreegziabher *et al*., 2004; Geta *et al*., 2010).

3.5.4.4 Credit and Off-farm Income

Access to rural credit and off-farm income activities are important socio-economic variables that can influence smallholder farmers' ability to purchase inputs and can also improve the livelihood of the households. Figure 3.10 provides the distribution of the respondents with regard to credit access.

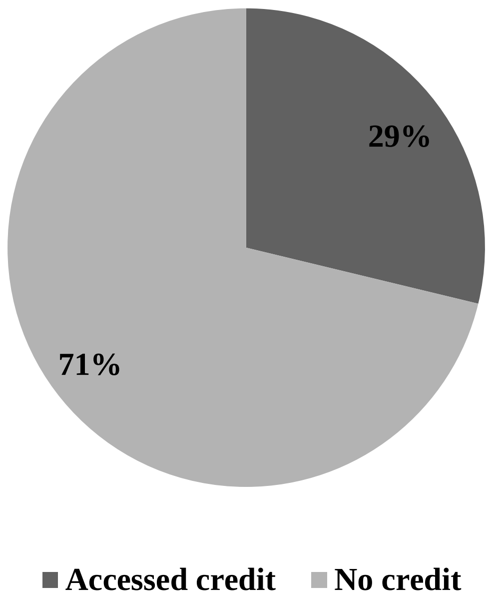

Figure 3.10: Credit access based distribution of the respondents

As indicated in Figure 3.10, only about 29% of the respondents received credit while the remaining 71% did not receive credit. The sources of finance in Ethiopia are state and private owned banks, Micro Finance Institutions (MFIs), rural saving and credit cooperatives (RUSACCOs), and informal money lenders that include traders, neighbours, friends and family (Ameha, 2011).The existing banks and their branches are concentrated in urban areas and provide credit to traders, wealthy individuals and government projects. In addition, the banks set high interest rates and request collateral which limits credit to mainly large land owners (Getahun, 2001). Therefore, most of the needy smallholder farmers are excluded from credit services provided by banks in Ethiopia (Ameha, 2011). The predominant suppliers of credit for smallholder farmers are the MFIs and RUSACCOs. Ameha (2011) noted that MFIs have achieved remarkable growth in terms of credit outreach and service delivery to rural farm households.

Many factors constrain rural credit in Ethiopia. The literature indicates that some of the constraints are: limited capacity of credit outreach to rural areas; absence of financial institutions and the associated high travel costs; shortage of loanable funds and low saving habit of the clients (Yehuala, 2008; IFAD, 2011). Yehuala (2008) noted that the presence of complicated credit application procedures, requirement of security, minimum loan amounts, terms of repayment, restriction of credit for specific purposes are some of the constraints farmers face. Furthermore, Ali and Deininger (2012) found that political and social networks are key determinants of credit access in the rural credit service system of the country. Given the credit system and the constraints in Ethiopia, farmers' access to credit service can potentially cause performance variation among the respondents (Binam *et al.*, 2004).

Similar to credit, some of the farmers have participated in off-farm income activities as a supplementary source of income. The distribution of respondents with regard to off-farm income participation is presented graphically using Figure 3.11.

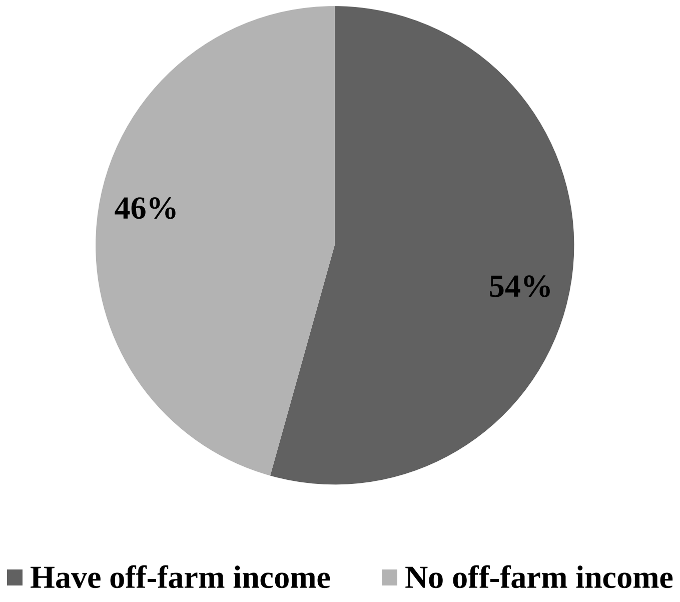

Figure 3.11: Off-farm income participation based distribution of the respondents

Figure 3.11 indicates that 54% of the respondents have received off-farm income whereas 46% of the respondents received none. Since production and productivity of the smallholder farmers is low, the households' farm income may not be sufficient for the household's consumption, to purchase inputs and make necessary investments on their farms (Beyene, 2008). As a result Ethiopian households commonly participate in off-farm income activities to get additional income during slack periods (Tesfaye *et al.*, 2011). The off-farm income participation of the households consider if any of the household members have participated in off-farm income activities. Farm households that received off-farm income could be able to purchase inputs and necessary investments in the farming sector which could potentially improve their farm productivity (Beyene, 2008). The pursuit of off-farm income could also lead to a decrease in farm productivity if the farmers failed to manage the farms properly due to their involvement in other activities. Although farm households commonly participate in the off-farm income activities during the slack periods, the secondary data used do not provide information whether the households participated in any off-farm income activities during slack periods. The shortfall of information on the off-farm activities of the household can hold a shortcoming for the research. It is expected that household who participate in off-farm activity can show increased technical efficiency in production (Haji, 2006).

3.5.5 *FARM MANAGEMENT PRACTISES*

This section discusses farm management practises of the respondents, including the distribution of respondents with regard to access to extension services, irrigation use and soil protection activities.

3.5.5.1 Extension Services

Extension service refers to the advice and training provided by agricultural extension experts regarding better farm management. Figure 3.12 provides the distribution of respondents with respect to extension.

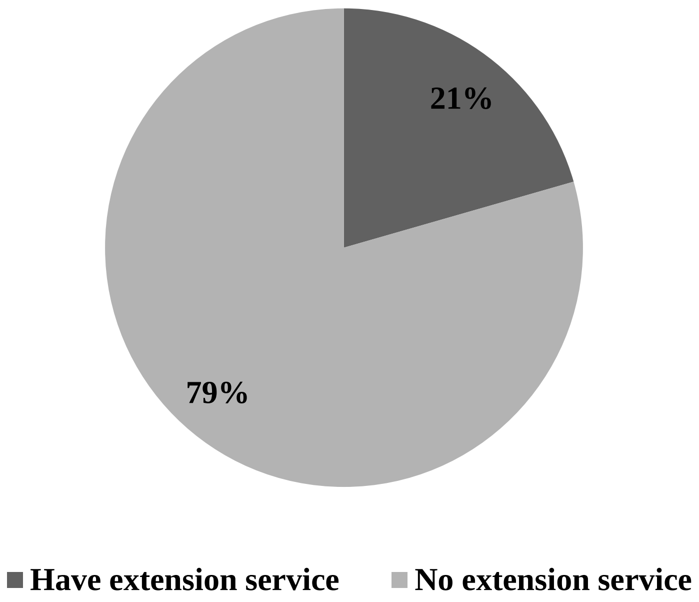

Figure 3.12: Extension service based distribution of the respondents

Figure 3.12 indicates that 79% of the households have no access to extension services whereas 21% of the respondents have access to extension services during the production season. The low level of extension service use by the respondents can be due to the low outreach of extension services in the country (Spielman *et al*., 2011). Nonetheless, there are some improvements in the extension service system of the country in recent years which include expansion of training and deployment of extension agents, shifting the responsibility of input distribution from extension agents to co-operatives and the provision of agro-ecological zone specific extension services (Spielman *et al*., 2011).However, rigorous monitoring and impact evaluation of the extension service delivery system is lacking in the country (Spielman *et al*., 2011).

3.5.5.2 Irrigation

Irrigation is a means of supplying sufficient water for better crop production which is specific to the smallholder farmers studied. Through the use of irrigation, farmers can improve crop production and intensification, thereby sustaining and improving their livelihood and food security (Hordofa *et al*., 2008).Distribution of the sampled households based on the use of irrigation is presented in Figure 3.13.

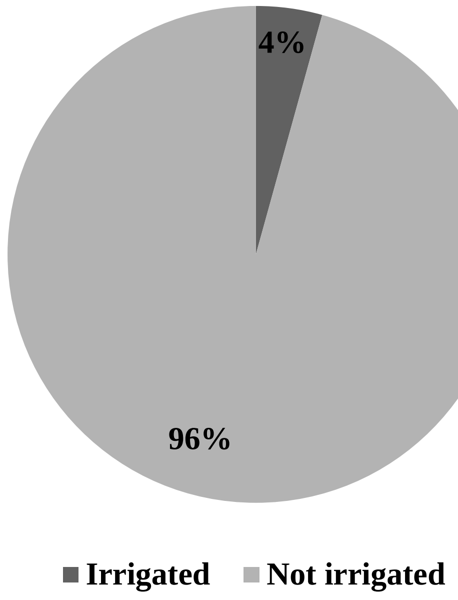

Figure 3.13: Distribution of respondents based on irrigation use

From Figure 3.13, it is observed that about four percent of the respondents used irrigation whereas the remaining 96% used none. This suggests that the use of irrigation in the smallholder farmers studied is very limited. The overall existing irrigation schemes in the country(including the commercial farms) cover about two percent of the total agricultural land (Hordofa *et al*., 2008).Only small scale irrigation and water harvesting schemes are used for smallholder grain crop production (Hordofa *et al*., 2008). Ground water irrigation and agricultural water management schemes are not integrated into the agricultural development policy and strategy of the country (Awulachew *et al*., 2007).

3.5.5.3 Soil Protection

Soil protection refers to soil conservation practises by the respondents to protect maize farmlands from erosion by using different methods such as contour ploughing, terracing, planting trees, inter-cropping. Soil conservation practises are very important for sustainable productivity improvement (IFPRI, 2010a).Figure 3.14 provides the distribution of respondents based on their practising of soil protection.

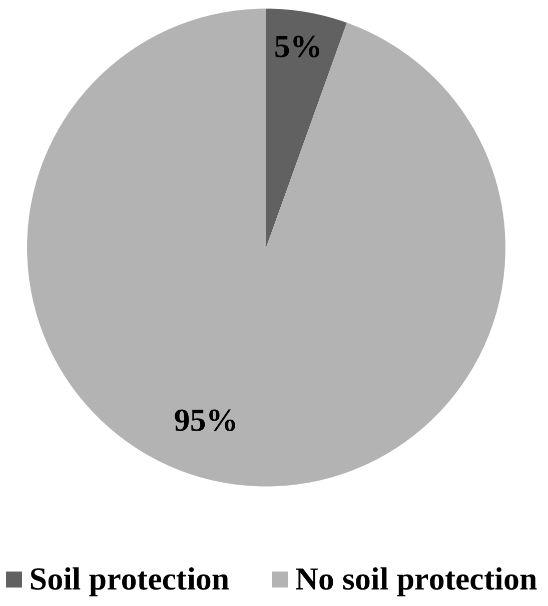

Figure 3.14: Distribution of respondents based on soil protection

Figure 3.14 indicates that only five percent of the respondents practised soil conservation to avoid erosion, while 95% of the respondents did not. This distribution shows that most of the maize farms are not protected from erosion and the soils and soil nutrients are likely to be easily eroded.

3.6 SUMMARY

Characterisation of the respondents shows that there are low levels of maize yield and utilisation of improved seeds and chemical fertilisers. Farm specific socio-economic variables of the data indicated that the average farm size is very small. Most of the households in the sample are male-headed and most of the household heads have an educational level of grade three or less. Tenure distribution of the sample implied that most of the households are operating on their private farmlands while the oxen distribution shows that most of the households do not have an adequate number of oxen. The respondents' credit and off-farm income distribution indicated that the majority of the households in the sample were not receiving rural credit whereas nearly half of the households received additional off-farm income. Farm management practises of the sample indicated that there is little use was made of extension services (due to low supply), irrigation or soil conservation.

Given the low levels of output and input use, weak socio-economic status, and poor farm management practises, measurement of technical efficiency and examining the determinants based on the current state of input and technology is important to have sufficient information about the scope of performance improvement of the smallholder maize farmers.

CHAPTER FOUR: METHODOLOGY

Chapter four discusses the methodology used to achieve the objective of the study. The chapter is divided into five sections. The first section is a justification of the SFA model. The second section discusses the procedures followed to estimate technical efficiency and to analyse the factors affecting technical inefficiency. The third section discusses the empirical application of the SFA model, while the fourth section discusses the Principal Component Regression technique used in the SFA estimation. The final section discusses the hypothesis tests used to evaluate the estimation procedure.

4.1 JUSTIFICATION OF THE STOCHASTIC FRONTIER ANALYSIS MODEL

SFA was developed nearly simultaneously by Aigner *et al*. (1977) and Meeusen and van den Broeck (1977) who were motivated by the idea that deviation from the production frontier might not entirely be under the control of the producer. The SFA model has the ability to separately identify the effects of statistical noise from that of technical inefficiency through a composed error term(ε_i). The composed error term consists of a random noise component (V_i) that captures the effects of statistical noise and an inefficiency component (U_i) that captures the effects of technical inefficiency (Kumbhakar & Lovell, 2000).The use of SFA has found wide acceptance in literature because of its consistency with theory, versatility and relative ease of estimation (Battese & Coelli, 1992; 1996). The SFA is commonly applied in agricultural efficiency measurements, especially in developing countries where data are heavily influenced by statistical noise (Sarafidis, 2002).

Efficiency analysis using SFA requires separate assumptions about the distributions of the two error components that leads to a more accurate efficiency estimation. The independently distributed noise component follows a normal distribution with zero mean and constant variance. The inefficiency component however, has developed from the original half-normal and exponential distributions of Aigner *et al*. (1977) to truncated normal and gamma distributions by Stevenson (1980) and Green (1990), respectively. The truncated normal distribution generalises the half-normal distribution through assuming U_i to be truncated at zero and to have a non-zero mean (Fried *et al*., 2008: 130). As a result, either mean or mode of the technical inefficiency error term is used to estimate technical efficiency of each producer (Kumbhakar & Lovell, 2000: 85). Distributional assumptions to estimate some frontier models are automated in software packages (Coelli *et al*., 2005:252).For example, FRONTIER estimates half-normal and truncated normal models whereas LIMDEP estimates exponential and gamma models (Coelli *et al*., 2005: 252).For this study, a truncated normal distribution is assumed as the truncated normal distribution provides a more flexible representation of the pattern of efficiency in the data (Kumbhakar & Lovell, 2000).

SFA estimates a production efficiency frontier by using the actual data. The efficiency scores are obtained from the deviations of the observed production from the relative production frontier (Sarafidis, 2002).After the introduction of SFA, the model was used to estimate technical efficiency (Battesse & Coelli, 1993). However, the studies were unable to explain technical inefficiency because the model could not analyse the sources of efficiency variations among the producers (Battesse & Coelli, 1993). In the pursuit of finding explanations of the technical inefficiency model, two approaches have been developed to explain technical inefficiency (Pitt & Lee, 1981; Kumbhakar *et al*., 1991; Battesse & Coelli, 1995).Early studies adopted a two-stage approach where, efficiencies are estimated first and then the estimated efficiencies are regressed against a vector of explanatory variables in the second stage (Kumbhakar & Lovell, 2000). The two-stage approach suffers from inconsistency of assumptions regarding the independence of distribution of the inefficiency error terms (Kumbhakar *et al*., 1991; Binam *et al*., 2004; Fried *et al.*, 2008). The inconsistency of assumptions implies that in the first step, SFA model estimates technical efficiency by assuming that the inefficiency error term is independent of the influence of the vector of farm specific explanatory variables. In the second step, the relationships between the inefficiency error term and the farm specific explanatory variables is assumed as if there is a linear relationship (Schmidt, 2011).

More recent studies including Kumbhakar *et al*. (1991), Reifschneider and Stevenson (1991) and Battesse and Coelli (1995) adopted a single-stage approach. In a single-stage approach, technical efficiency estimation and the relationships of technical inefficiency error term and the vectors of explanatory variables are estimated in a single step. Unlike the two-stage approach, the single-stage approach allows simultaneous estimation of the production frontier and the technical inefficiency model parameters (Coelli & Battese, 1995). In this study, a single-stage SFA model is used. The choice of the single-stage approach over the two-stage is due to the short-comings of the two-stage approach arising from inconsistency of assumptions about the distribution of the inefficiency error terms. The estimation of technical efficiency and its determinants required the use of FRONTIER 4.1 (Coelli, 1996).

4.2 ESTIMATING TECHNICAL EFFICIENCY USING STOCHASTIC FRONTIER ANALYSIS

Assuming that producers are producing a single output using multiple inputs, SFA provides the relative frontier against which production performance is evaluated (Kumbhakar & Lovell, 2000: 63). The specification of SFA incorporates the effects of random noise and technical inefficiency $U_{i,}$ on output(Kumbhakar & Lovell, 2000).The stochastic production frontier specification incorporates the difference of the technical inefficiency variable from that of the symmetric random variable that affect output (Bachewe, 2009). A stochastic production frontier given by Battesse and Coelli (1995) for a cross-sectional data takes the form:

$$\boldsymbol{Y_i = exp(X_i\beta + V_i - U_i)} \qquad (\mathbf{4.1})$$

where, Y_i is the scalar of output for producer *i; X_i* is a vector of input variables used by producer *i*; β is a vector of unknown parameters to be estimated; V_i is a symmetrically distributed error term which is assumed to be identically and independently distributed with mean zero and unknown variance, that is $V_i \sim$ iidN($0,\ \sigma^2_V$); U_i is a non-negative random variable associated with technical inefficiency in production. U_i is assumed to be independently distributed and is obtained by truncation (at zero) of the normal distribution with a mean,($Z_i\delta$) and variance, (σ^2_U) (Battesse & Coelli, 1995).The truncation(at zero)distribution of U_i implies that the deviation of actual production from a frontier production is assumed to take a zero or positive value. Producers with zero deviations are efficient producers that lie on the efficiency frontier while those with positive deviations lie below the efficiency frontier and are inefficient (indicating shortfalls from the frontier output, for the given level of inputs and technology) (Bachewe, 2009).Z_i is a vector of variables that influence technical inefficiency of the producers and δ is a vector of technical inefficiency parameters to be estimated (Battesse &Coelli, 1995).Given the stochastic production frontier of producer *i* by Equation 4.1, the associated technical efficiency (TE) can be estimated.

TE measures the output of producer *i* relative to the output that could be produced by a fully efficient producer using the same input vector (Coelli *et al.*, 2005). TE of producer *i* is estimated by the ratio of actual output to the relative frontier output as specified by Coelli *et al*. (2005):

$$\boldsymbol{TE_i = \frac{Y_i}{exp(X_i\beta + V_i)}}$$
$$\boldsymbol{= exp(-U_i)} \qquad (4.2)$$

where, $Y_i = exp(X_i\beta + V_i - U_i)$ is the actual output which is obtained in the presence of the technical in efficiency effects whereas $exp(X_i\beta + V_i)$ is the corresponding frontier output under condition of random shocks (Coelli *et al.*, 2005).When dividing the actual output by the frontier output, after cancelling the similar terms, the remaining value is exp$(-U_i)$, which represents technical efficiency. The value of TE ranges between zero and one (0≤TE≤1). *TE* takes a value of one when the producers are technically efficient, becomes closer to zero when the producers are less technically efficient and becomes zero when producers are fully inefficient (Bachewe, 2009).

Given the stochastic production frontier specification by Equation 4.1, the potential determinants of technical efficiency can be identified. The technical inefficiency term U_i is assumed to be a linear function of some explanatory variables, Z_i and a parameter of the technical inefficiency model to be estimated, δ. According to Battesse and Coelli (1995), the technical inefficiency effect, U_i in the stochastic frontier model displayed in Equation 4.1 takes the form:

$$\boldsymbol{U_i = Z_i\delta + \omega_i} \qquad (4.3)$$

where,$\omega_i$is a random variable defined by normal distribution with a mean of zero and unknown variance ($\sigma^2{}_{\omega}$). This assumption is consistent with U_i being a non-negative truncation of normal distribution with a mean, ($Z_i\delta$)and variance, ($\sigma^2{}_U$) such that the point of truncation is at ($-Z_i\delta$) that means $\omega_i \geq Z_i\delta$ (Battesse &Coelli, 1995).

The empirical estimation of the technical efficiency required the use of principal component analysis to eliminate the structure in the variables used to explain technical inefficiency. During the estimation of the production frontier and the technical inefficiency model a significant level of mulitcollinearity was present. The data structure was therefore reduced with the use of principal component analysis before the production frontier and technical inefficiency model was solved using Frontier. The regression results along with the eigenvector information were used to estimate the significance of the individual variables that was retained in the principal components. The next section will discuss the estimation of technical efficiency

The rest of the Chapter is used to discuss the procedures used to estimate the production function and the factors of technical inefficiency. The first section will discuss the choice of the functional form the estimation and the variables used to determine the production frontier and the inefficiency model. The last section of the Chapter is dedicated to explaining the Principal Component regression procedure used to overcome multicollinearity followed by the some hypothesis tests.

4.3 EMPIRICAL ESTIMATION OF TECHNICAL EFFICIENCY

4.3.1 *CHOICE OF FUNCTIONAL FORMS*

The production frontier given by Equation 4.1 can be specified using different functional forms such as linear, quadratic, Cobb-Douglas, translog and Leontief (Coelli *et al*., 2005: 211). Functional forms are commonly determined by requirements such as flexibility of the functional forms, the general conformity and adequacy of the models in explaining a given data and on theoretical bases hypothesised to adopt a specific functional form (Griffin *et al*., 1987). The uses of Cobb-Douglas and translog functional forms dominate applications of production frontier literature (Fried *et al*., 2008: 98). Given the alternatives, different functional forms were compared using the data and various model evaluation criteria such as R-squared, Log likelihood, Aikaike info criterion and Schwarz criterion. The results of alternative production functions fitted are provided in Appendix A. Based on the criteria, the Cobb-Douglas production function was found to fit the data best and was chosen for the final SFA specification.

4.3.1.1 Production Frontier Model Specification

Assuming a Cobb-Douglas production function, Equation 4.1 can be re-written as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{3} \beta_j \ln X_{ij} + V_i - U_i \qquad (4.4)$$

where, $\ln Y_i$ represents logarithm of output (maize yield) measured in ton/ha for i observations ($i = 1, 2, 3, \ldots ,438$). $\ln X$ refers to logarithm of inputs involved in the production function including seed (kg), nitrogen (kg) and labour (man days) used in maize production. β_j refers to parameters of the production function to be estimated corresponding to the inputs used, whereas V_i and U_i are the error terms representing random effects and technical inefficiency effects, respectively.

4.3.1.2 Variables Defining Production Frontier

In the estimation of the production frontier, the explanatory variables considered are seed, nitrogen and labour. All the variables are measured on a per hectare basis. The variables included in the production function, the measurement units and expected signs are given in Table 4.1. The choice of the input variables is made on the basis that these inputs are conventional inputs used in maize production by smallholder farmers in the country (Gebreselassie, 2006; Spielman *et al*, 2011). Other conventional inputs such as pesticides and herbicides were not included because the secondary data set used for the study does not contain these variables.

Table 4.1: Definitions of variables included in the production function, measurement units and expected signs

Variables	**Measurement unit**	**Expected signs**
X_1= Seed	Quantity of total seed used (kg/ha)	+
X_2= Nitrogen	Quantity of Nitrogen used (kg/ha)	+
X_3= labour	Quantity of labour used (man days/ha)	+

Seed refers to the quantity of seed used in maize production measured in kg/ha. According to Geta *et al*. (2010) and Idiong (2007), increased application of seed quantity results in increased crop production. Based on these findings, the quantity of maize seed applied is expected to increase maize production and the expected sign is positive. Nitrogen is another important input applied in maize production which is also measured in kg/ha. Increased application of Nitrogen increases maize productivity through enhancing the uptake and concentration of Nitrogen and Phosphorus nutrients in maize tissues which are important for plant growth (Abdulahi *et al*., 2006; IFPRI, 2010a).Among the empirical studies, Maseatile (2011), Alene and Hassan (2003) and Geta *et al*. (2010) found that the increased application of Nitrogen results in an increase in maize production. Based on these findings, the expected sign of Nitrogen is positive. Another input considered is labour which refers to the total labour used in maize production measured in man days/ha, during Meher season of 2011/12. Labour is an aggregation of household labour and hired labour used in maize production by assuming that each person works on average, eight hours per day on a maize farm. Among the empirical studies, Fufa and Hassan (2003) and Bachewe (2009) found that with the use of additional labour, crop production increases. This is due to farming activities such as land preparation, planting, weeding and harvesting requiring availability of adequate labour for timely operation of the activities (Geta *et al*., 2010). Based on the results, labour is expected to have an increasing effect on production and the expected sign is positive.

It is important to note that phosphorus was also another input considered in maize production, but it was excluded from the analysis because the variable was highly correlated with Nitrogen. Producers use DAP as a source of fertiliser which contains both Nitrogen and Phosphorus in fixed proportions. Correlation between Nitrogen and Phosphorus was therefore expected. However, when the two variables are included together for estimation of the production function, they resulted in biased parameter estimates. Although applications of both nutrients are required to increase maize productivity, the application rate indicates that more quantity of Nitrogen is required than Phosphorus in maize production due to the nature of maize in nutrient utilisation (Plessis, 2003; Onasanya *et al*., 2009). Nitrogen is a vital nutrient for plant and yield growth in maize production because it is a major component of substances such as amino-acids and nucleic-acids which form the living plant tissue for growth (Haynes, 1986: 24).It is also an integral component for many other compounds essential for plant growth processes including chlorophyll and many enzymes (Onasanya *et al*., 2009). In addition, application of Nitrogen enhances the uptake and concentrations of Nitrogen and

Phosphorus nutrients in the maize tissues more than Phosphorus (Abdulahi *et al*., 2006). By considering the above reasons, Nitrogen was retained for analysis.

4.3.2 *TECHNICAL INEFFICIENCY MODEL SPECIFICATION*

In order to identify and analyse the determinants of technical efficiency, a technical inefficiency model was employed. In the technical inefficiency model, the dependent variable is the technical inefficiency variable (U_i) and the explanatory variables are the factors that are hypothesised to affect technical inefficiency (Z_i). A positive sign of a coefficient of a technical inefficiency model parameter implies that the variable considered has an increasing effect on technical inefficiency and *vice versa*. The implication of the relationship is that variables that increase technical inefficiency will decrease technical efficiency. Given the distinction of technical inefficiency and efficiency, the next section provides an empirical specification of the technical inefficiency model.

The empirical specification of the technical inefficiency model of Battesse and Coelli(1995) in Equation 4.3 takes the form:

$$\boldsymbol{U_i = \delta_0 + \sum_{l=1}^{14} \delta_l Z_i + \omega_i} \qquad (4.5)$$

where, U_i is the technical inefficiency variable derived from Equation 4.1 and is assumed to be a function of farm specific socio-economic and farm management explanatory variables. The farm specific explanatory variables that are proposed as determinants of technical inefficiency are age, gender, education, household size, farm size, tenure, oxen, extension, irrigation, credit, off-farm income, seed type, organic fertiliser and soil protection. The variable ω_i refers to a random variable which is assumed to be obtained by normal distribution with zero mean and unknown variance confirming that U_i is non-negative and truncated at zero with the point of truncation given by ($-Z_i\delta$) *i.e.*, ω_i ǐ$Z_{i.}\delta$. The empirically specified production frontier and technical inefficiency models are then estimated using a single-stage SFA approach. The Maximum Likelihood estimates of all the parameters of the production frontier and the technical inefficiency models, defined by Equations 4.4 and 4.5 are estimated simultaneously using the FRONTIER 4.1 program. The Likelihood function is expressed in terms of the variance parameterisation given by sigma square (σ^2) and gamma (γ)upon which test for the presence of technical inefficiency in an estimated model is based (Battesse & Coelli, 1993). σ^2 refers to the total model variance consisting of a variance due to random effects ($\sigma^2{}_v$) and a variance due to technical inefficiency effects ($\sigma^2{}_u$) which is parameterised as (Battesse & Coelli, 1995):

$$\boldsymbol{\sigma^2 = \sigma^2{}_v + \sigma^2{}_u} \tag{4.6}$$

where, $\sigma^2{}_v$ and $\sigma^2{}_u$represent variances accounted by random effects (V_i) and technical inefficiency effects (U_i) in the model, respectively. The estimates ofvariance parameter are mainly used to identify the γ parameter which represents the proportion of total model variance that accounts for technical inefficiency. The parameterisation of γ given by Battesse and Coelli (1995) takes the form:

$$\boldsymbol{\gamma = {\sigma^2{}_u}/{\sigma^2}} \tag{4.7}$$

The value of γ ranges between zero and one (Baruwa & Oke, 2012).When γ is zero, it indicates that technical inefficiency effects are absent in the estimated SFA model and all variation from the frontier is due to random noise which suggests the appropriateness of the use of OLS than SFA technique for analysis. When γ is closer to one, the model indicates that most of the variation of output from the frontier is accounted by technical inefficiency, which suggests the presence of technical inefficiency in the model and confirms appropriateness of SFA technique (Baruwa & Oke, 2012).

4.3.2.1 Variables Defining Technical Inefficiency Model

Fourteen farm specific explanatory variables are included in the technical inefficiency model. Table 4.2 provides the variables with their respective measurement units and expected signs. Age, gender and education of the household heads are variables to be discussed first. The reason for considering age, gender and education of the household heads is due to the assumption that household heads are responsible for farm households' production decisions which result in differences in the technical efficiency levels (Pattanyak *et. al.*, 2003).Age of a household head is measured in years and is included in the technical inefficiency model to identify whether differences in age among the household heads contribute to differences in technical inefficiency. Based on past empirical studies, age has a mixed effect on technical inefficiency. In some studies, age has a decreasing effect (Fesessu, 2008; Derege, 2010) while in others, it has an increasing effect on technical inefficiency (Makombe *et al*., 2011; Gbegeh & Akubuilo, 2013). Thus, the expected sign of age of a household head can be either positive or negative.

Similarly, gender of a household head is included in the model to determine if gender has a significant impact on farm level technical inefficiency. Gender is a dummy variable that is assigned a value of “1” for male-headed households and “0” for female-headed households. Literature indicates that gender of household heads can have a negative or a positive effect on farm technical inefficiency. For example, Bachewe (2009) found a negative effect of gender on technical inefficiency which implies that male-headed households are less technically inefficient. This is attributed to the fact that male-household heads have better access to resources such as land, credit and technological inputs than female-headed households. In addition, female household heads undertake normal household homemaker activities as well as the usual farm work (AWM, 2009; OXFAM, 2012). Derege (2010) found a positive effect of gender on farm technical inefficiency indicating that the female-headed households are more technically efficient than the male-headed ones. Derege (2010) explained that the female-headed household farms were more efficient due to the increased follow-ups and closer supervision the female household heads made to the farms. Based on the findings, the expected sign of gender can be either positive or negative.

Table 4.2: Description of variables included in the technical inefficiency model, measurement units and expected signs

Variables	Measurement unit	Expected signs
Z_1=Age	Age of household heads in years	-/+
Z_2=Gender	Dummy variable = 1 if the household head is male, 0 otherwise	-/+
Z_3=Education	Dummy variable = 1 if the household head has educational of grade four or above, 0 otherwise	-/+
Z_4=Household size	Number of people living in a farm household (count)	-/+
Z_5=Farm size	Farm size in hectare	-/+
Z_6 =Tenure	Dummy variable = 1 if the farm land is privately owned, 0 otherwise	-
Z_7=Oxen	Dummy variable = 1 if the respondent has two or more oxen, 0 otherwise.	-
Z_8=Extension	Dummy variable = 1 if the farm is under extension service, 0 otherwise	-
Z_9=Irrigation	Dummy variable = 1 if the farm is irrigated, 0 otherwise	-
Z_{10}=Credit	Dummy variable = 1 if the respondents has received credit, 0 otherwise	-
Z_{11}=Off-farm income	Dummy variable = 1 if the respondent received off-farm income, 0 otherwise	-/+
Z_{12}=Seed type	Dummy variable = 1 if improved seed is used, 0 otherwise	-
Z_{13}=Organic fertiliser	Dummy variable = 1 if organic fertiliser is used, 0 otherwise	-
Z_{14}=Soil protection	Dummy variable =1 if the respondent used soil protection from erosion, 0 otherwise	-

Education of a household head is included as a dummy variable where a value of “1” was assigned to household heads that have completed education of grade four or above and “0” for household heads with an education level of grade three or less. The classification is in accordance to empirical literature by Appleton and Arsene (1996) that education of at least grade four is needed to affect crop production. Most of the sampled farmers did not acquire any formal education that this classification can provide the required information whether education is a determinant of technical inefficiency in the sample. Empirical literature indicates that education has a mixed effect on technical inefficiency. Education can increase farmers’ ability to obtain, process and use information relevant to agricultural practices that can decrease farm technical inefficiency (Jamison & Lau, 1982; Phillips, 1994; Weir, 1999).In contrast, increased education can make farmers more inefficient in farming by shifting educated labour into off-farm employment (Alemu *et al*., 2009). Based on the findings, the expected sign of education is either positive or negative.

Another important variable used in technical inefficiency analysis is household size, which is included as a continuous variable. The variable is used to determine if household size is an important factor affecting technical inefficiency among the respondents. From literature, household size can have either a decreasing or an increasing effect on technical inefficiency. For example, Fesessu (2008) found a decreasing effect of family size on technical inefficiency indicating that large households are important sources of family labour. While Derege (2010) found an increasing effect of household size on farm technical inefficiency where large household sizes increase farm technical inefficiency. Therefore, the expected sign of household size can be either positive or negative. Farm size is another continuous variable of the model which is measured in hectare. There are different economic arguments about farm size and the associated technical inefficiency(Masterson, 2007).Some studies found an increasing effect of farm size on technical inefficiency(Parikh *et al*., 1995; Masterson, 2007)while others found a decreasing effect of farm size on technical inefficiency (Bravo-Uteta & Pinheiro, 1997, Huang & Kalirajan, 1997; Khaile, 2012). As a result, the expected sign of farm size is either positive or negative. A closely related variable to farm size is farm tenure.

Tenure is a dummy variable that refers to the type of farmland ownership and has a value of “1” for private ownership and “0” for other form of ownership. The variable is included to determine if type of tenure affects farm technical inefficiency among the respondents. Past studies indicate that private ownership of land encourages sustainable farm practises by creating an incentive to manage and invest in the lands (Alene & Hassan, 2003; Nega *et al*., 2003). This indicates that private ownership of land decreases technical inefficiency. Based on literature, private ownership of land is hypothesised to decrease farm technical inefficiency and the expected sign is negative. Similar to tenure, the ownership of oxen is a dummy variable that is assigned a value of “1” for farmers that own adequate numbers of oxen (minimum of one pair of oxen) and “0” for farmers that did not own oxen during the production season.

Interest in the oxen variable is due to the fact that oxen are the main source of draft power used in smallholder farming in Ethiopia (Geta *et al*., 2010). Ownership of oxen enhances productivity by augmenting labour input to accomplish farm operations such as land preparation, sowing and fertiliser application timely. Gebreegziabher *et al*. (2004) and Geta *et al*. (2010)found that ownership of oxen decreases technical inefficiency. Based on the findings, ownership of adequate oxen is hypothesised to decrease farm technical inefficiency and the expected sign is negative.

Access to extension, irrigation, credit and off-farm income is included as dummy variables in the technical inefficiency model. Farmers that have access to extension services are assigned a value of “1” and those without the service are assigned a value of “0”. Extension is expected to have a negative effect on farm technical inefficiency because farmers that received extension services would obtain advice and training about better farming operations (Alene & Hassan, 2003; Fesessu, 2008). Irrigation can also be a source of variation for farm level technical inefficiency. Irrigation is included as a dummy variable taking a value of “1” for farmers that used irrigation and “0” for farmers that did not. Irrigation is a means of providing sufficient water for plant growth to prevent water stress that can possibly reduce productivity of the inputs used (Haise & Hagan, 1967). Therefore, irrigation is expected to have a decreasing effect on farm technical inefficiency and the expected sign is negative. Similarly, farmers that received credit are assigned a value of “1” and farmers that did not receive credit are assigned a value of “0” to determine whether access to credit affects technical inefficiency of the respondents. Obwona (2000) and Binam *et al.* (2004)indicated that access to credit enabled farmers to finance the farming operations and is expected to have a decreasing effect on technical inefficiency. Based on the findings, access to credit is expected to decrease farm technical inefficiency and the expected sign is negative. In the same manner, off-farm income is included as a dummy variable assigned by a value of “1” for maize farmers that received off-farm income and “0” for maize farmers that did not receive off-farm income. Literature indicates that off-farm income has a mixed effect on technical inefficiency. For example, Gebreegriabher *et al*. (2004) and Haji (2008) found a decreasing effect of off-farm income on technical inefficiency whereas McNally (2002), Goodwin and Mishra (2004) and Geta *et al*. (2010) found an increasing effect of off-farm income on technical inefficiency. Therefore, the expected sign of off-farm income is either positive or negative.

The final variables to be discussed in the technical inefficiency model are seed type, organic fertiliser and soil protection. The type of seed used in maize production is included as a dummy variable having a value of “1” for farmers that used improved seed and “0” for farmers that used traditional seed. Farmers that used improved seed are expected to be more productive than those using traditional seeds. Therefore, improved seed is expected to have a negative effect on farm technical inefficiency and the expected sign is negative. Similarly, application of organic fertiliser is included as a dummy variable with a value of “1” representing respondents that applied organic fertiliser and “0” for respondents that did not use organic fertiliser. Utilisation of organic fertiliser is expected to improve nutrient content of the soils which in turn increases productivity hence decreasing technical inefficiency. From the empirical findings, Tadesse and Abdissa (1996), Gruhn *et al*. (2000) and Ayalew and Dejene (2011) found that application of organic fertiliser increased maize yields. Based on the findings, the use of organic fertiliser decreases technical inefficiency and the expected sign is negative.

The final variable of the model is soil protection from erosion which is a dummy variable assigned a value of “1” for respondents that used soil protection and “0” for respondents that did not. The variable is included to determine the effect of soil protection from erosion on farm technical inefficiency. Soil erosion is a serious problem that causes loss of soil and important soil nutrients and thereby increases technical inefficiency (Hurni, 1993). Utilisation of soil protection from erosion is expected to increase productivity sustainably (IFPRI, 2010a). From empirical studies, Geta *et al*. (2010) found that integrated soil management practices decreased technical inefficiency. Based on the finding, soil protection is expected to decrease technical inefficiency and the expected sign is negative.

4.3.2.2 Multicollinearity Problem

Given the description of the variables included in the SFA model, the final data prepared for the SFA analysis consists of 438 observations. The first attempt to estimate the SFA was unsuccessful due to the presence of high multicollinearity among the technical inefficiency model explanatory variables. Multicollinearity refers to linear correlations among the explanatory variables in the inefficiency model that can lead to biased parameter estimates (Gujarati, 2003). Principal Component Regression (PCR) is one of the multivariate statistical techniques that can solve problems of multicollinearity (Jouan-Rimbaud *et al*., 1995). The

PCR technique is used to solve the problem of multicollinearity detected among the explanatory variables of the technical inefficiency model. The idea of PCR is to transform the originally correlated explanatory variables into a new set of uncorrelated variable called Principal Components (PCs) (Kline, 1994). The following section is a discussion of the Principal Component Regression.

4.4 *PRINCIPAL COMPONENT REGRESSION*

In this section, the procedures and application of the Principal Component Regression (PCR) are discussed. First, the theoretical basis of PCR is discussed followed by the empirical application. When applying a PCR the first step is to standardise the original explanatory variables that is used to fit the technical inefficiency model. The eigenvalues and eigenvectors of the correlation coefficient matrix will also be obtained. This is followed by the estimation of the PCs which is accomplished by multiplying the standardised variables with eigenvector matrix of the correlation coefficient. The estimated PCs are then incorporated in a SFA regression as the explanatory variables for the technical inefficiency model. The the significance of the PCs are determined based on the SFA regression results. The significant PCs are used to determine the significances of the standardised variables. Finally by using the coefficients and significances of the standardised variables, the coefficients of the original variables are determined. In the empirical application of the PCR, the same procedures are pursued to determine significances of the originally correlated variables so that the problem of multicollinearity is solved.

4.4.1 *THEORETICAL BASIS OF PCR*

Through the process of PCR, the dimensionality of the original data is reduced without loss of information (Motsoari, 2012). The process starts by standardising the original explanatory variables. Following Fekedulegn *et al*. (2002), the variables are standardised as:

$$\boldsymbol{Z_i^s = (Z_i - \overline{Z})/S_{Zi}} \qquad \textbf{(4.8)}$$

where, Z_i^s refers to the i^{th} standardised variable, Z_i refers to the original explanatory variables. $\bar{Z}$ and S_{zi} represent the mean and standard deviation of the original explanatory variables, respectively. After standardising the variables, the next procedure is estimation of PCs.

4.4.1.1 Estimation of Principal Components

Formulation of eigenvalues and eigenvector of the correlation coefficient matrix of the correlated variables is also required to estimate PCs. Eigenvalues indicate the amount of variances explained by each PC while eigenvectors are the weights used in a linear transformation when computing PC scores (Kline, 1994). While estimating the PCs, components of all the variables involved in the PCR are ranked in order of their importance based on the eigenvalues of each PC in a decreasing order (Khaile, 2012). The procedure then involves retaining PCs that have eigenvalues of greater than one whereas the PCs with eigenvalues of less than one are excluded from further analysis (Khaile, 2012).

Given a correlation coefficient matrix (C) of the correlated variables that has a k x k dimension, assuming $a_{1}, a_{2}, \ldots, a_{j}$ be the eigenvalues and $V=[V_1, V_2, \ldots, V_j]$ be a matrix of eigenvectors of the correlation coefficient matrix. Estimation PCs involve calculating the eigenvalues by solving a determinant equation given by Draper and Smith (1981) as:

$$\left|\boldsymbol{C} - a_{j}\boldsymbol{I}\right| = \boldsymbol{0} \qquad (4.9)$$

and calculating the associated eigenvectors (V_j) of the correlation matrix by solving a determinant equation given by Fekedulegn *et al.* (2002) as:

$$\left|\boldsymbol{C} - a_{j}\boldsymbol{I}\right|\boldsymbol{V_j} = \boldsymbol{0} \qquad (4.10)$$

The computed eigenvectors (V) are orthogonal to one another and provides a solution which satisfies the condition that the product of an orthogonal vector with its transpose equals 1 ($V_i^T V_i = 1$) and given two vectors V_i and V_j, they are orthogonal if and only if the inner products of the two vectors is zero ($V_i' V_j = 0$) for $i \neq j$ (Fekedulegn *et al.*, 2002).The computed eigenvectors are arranged to form a matrix of eigenvectors as:

$$V=\begin{vmatrix} V_{11} & V_{12} & \cdots & V_{1k} \\ V_{21} & V_{22} & \cdots & V_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ V_{k1} & V_{k2} & \cdots & V_{kk} \end{vmatrix} \qquad (4.11)$$

Once the eigenvalues and eigenvectors of the correlation matrix are formulated, the PCs are estimated by multiplying the standardised explanatory variables given by Equation 4.8 with the matrix of eigenvectors given in Equation 4.11 (Fekedulegn *et al*., 2002). Therefore, the estimation of the PCs represented as P is given by multiplying the matrix of the standardised variables with the matrix of eigenvector based on Fekedulegn *et al*. (2002) as:

$$\boldsymbol{P} = \boldsymbol{Z^s V} \qquad (\mathbf{4.12})$$

where, Z^s refers to a matrix of standardisedexplanatory variables and V is a matrix of eigenvectors (Fekedulegn *et al*., 2002). Equation 4.12 can be re-written in matrix form as:

$$\begin{vmatrix} P_{11} & P_{12} & \cdots & P_{1k} \\ P_{21} & P_{22} & \cdots & P_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ P_{k1} & P_{k2} & \cdots & P_{kk} \end{vmatrix} = \begin{vmatrix} Z^s{}_{11} & Z^s{}_{12} & \cdots & Z^s{}_{1k} \\ Z^s{}_{21} & Z^s{}_{22} & \cdots & Z^s{}_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ Z^s{}_{k1} & Z^s{}_{k2} & \cdots & Z^s{}_{kk} \end{vmatrix} \mathrm{x} \begin{vmatrix} V_{11} & V_{12} & \cdots & V_{1k} \\ V_{21} & V_{22} & \cdots & V_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ V_{k1} & V_{k2} & \cdots & V_{kk} \end{vmatrix} \qquad \mathbf{(4.13)}$$

The estimated PCs contain the same number of information as the original variables except that the PCs are uncorrelated and can be ranked by the magnitude of their eigenvalues (Draper & Smith, 1981). Starting with *n* number of correlated original explanatory variables, the same *n* number of PCs can be obtained through estimation. However, only PCs that can account for the majority of variances among the variables are retained (Kline, 1994). Therefore, only the PCs that are associated with eigenvalues of greater than one will be retained (Loehlin, 1992).

4.4.1.2 Regression with Principal Components

The significance of the retained PCs will be estimated by SFA regression by involving the PCs instead of the originally correlated explanatory variables in the technical inefficiency model of the SFA (Magingxa *et al*., 2006).The technical inefficiency model of SFA that involves the retained PCs can be specified as:

$$\boldsymbol{U_j} = \boldsymbol{\delta_0} + \sum_{\boldsymbol{l}} \boldsymbol{\alpha_l P} + \boldsymbol{\varepsilon} \qquad (\mathbf{4.14})$$

where, *P* represents a matrix of the PCs obtained by Equation 4.12; α_l represents amatrix of coefficients associated with *l* number of retained PCs (Magingxa *et al*., 2006). Standard errors of the coefficients of the PCs are computed from the corresponding variances of the coefficients of the estimated PCs (Magingxa *et al*., 2006). Variances of the estimated coefficients of the PCs $(\alpha_l)$is formulatedbased on Fekedulegn *et al*. (2002) as:

$$\boldsymbol{Var(\hat{\alpha}) = \hat{\delta}^2(P'P)^{-1} = \hat{\delta}diag(\lambda_1{}^{-1}, \lambda_2{}^{-1} \ldots, \lambda_l{}^{-1})} \qquad \mathbf{(4.15)}$$

where, $\hat{\delta}^2$is variance of residuals obtained from the regression given in Equation 4.14. Standard errors of coefficients of the retained PCs are given by:

$$\boldsymbol{std^s(\hat{\alpha}) = (std.\hat{\alpha}_1, std.\hat{\alpha}_2, \ldots std.\hat{\alpha}_l)} \qquad \mathbf{(4.16)}$$

where, $\text{std}.(\hat{\alpha})$ represent estimates of standard errors for respective α_l coefficients. With the use of the estimated coefficients and standard errors and the associated t-ratios, the significances of the PCs are determined (Fekedulegn *et al*., 2002). The significant PCs are used to determine significances of the standardised variables while the insignificant PCs are eliminated (Magingxa *et al*., 2006). After the elimination of the insignificant PCs, Equation 4.14 is adjusted to the number of significant PCs (Khaile, 2012). Following Khaile (2012), given *l* number of retained PCs, assuming elimination of *r* number of insignificant PCs, Equation 4.14 is re-written as:

$$\boldsymbol{U_j = \delta_0{}^o + \sum_{l-r} \alpha_{l-r} P + \varepsilon^o} \qquad \mathbf{(4.17)}$$

where, $\delta_0{}^o$ and ε^o are used in Equation 4.17 to differentiate the intercept and residual terms pertaining to regression with the significant PCs from the ones used in retained PCs (Equation 4.14) of the SFA technical inefficiency model (Khaile, 2012). The next procedure is transformation of the PCs to the standardised explanatory variables and determining their significances (Fekedulegn *et al*., 2002).

4.4.1.3 Determining the Significances of the standardised Variables Using Significant PCs

By using the significant PCs, the coefficients and standard errors of the standardised variables will be determined. The estimated coefficients of the significant PCs will be used to determine the coefficients of the standardised variables (Maseatile, 2011). Similarly, standard errors of the PCs are used to estimate the associated variances of the PCs to be used in computing the variances of the standardised variables (Maseatile, 2011). The coefficients of the PCs are transformed back to the standardised explanatory variables as: $b^{s}{}_{k,PC}=V_{l-r}\hat{\alpha}_{l-r}$ which is written in matrix form as (Magingxa *et al.*, 2006):

$$\begin{vmatrix} b^{s}{}_{1,PC} \\ b^{s}{}_{2,PC} \\ \vdots \\ b^{s}{}_{k,PC} \end{vmatrix} = \begin{vmatrix} V_{11} & V_{12} & \cdots & V_{1l} \\ V_{21} & V_{22} & \cdots & V_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ V_{k1} & V_{k2} & \cdots & V_{kl} \end{vmatrix} \mathrm{x} \begin{vmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_l \end{vmatrix} \qquad \mathbf{(4.18)}$$

where, V_{l-r} is an eigenvector matrix of the correlation coefficient; $\hat{\alpha}_{\mathrm{l-r}}$ is a vector of coefficients of the significant PCs estimated using Equation 4.17 (Khaile, 2012). Once the coefficients of the standardised variables are determined, the associated variances of the coefficients will be determined by using the PC variance estimators. Based on the procedure of Magingxa *et al.* (2006), PC estimator of variances of the standardised variables is given as:

$$\boldsymbol{Var\left(b^{s}{}_{pc}\right) = u^{s}{}_{l}K^{s}} \qquad \mathbf{(4.19)}$$

where $u^{s}{}_{l}$ represents the square of eigenvector elements obtained by squaring the eigenvector elements given by Equation 4.11. K^{s}refers to a matrix of squared standard error elements of the coefficients of the significant PCs given in Equation 4.17 (Khaile, 2011). Furthermore, the standard errors of the PC estimators of the standardised variables are obtained by the square root of the variance estimators of the standardised variables which is given as:

$$\boldsymbol{std\left(b^{s}{}_{pc}\right) = \left[Var\left(b^{s}{}_{pc}\right)\right]^{1/2}} \qquad \mathbf{(4.20)}$$

The estimated coefficients and the standard errors of the standardised variables are used to estimate the coefficients and standard errors associated with the original variables (Maseatile, 2011). Following the procedures of Fekedulegn *et al.* (2002), the estimated coefficients of the standardised variables, $b^s{}_{k,PC}$ are transformed back to the original unstandardised coefficients as:

$$\boldsymbol{b_{i,pc}} = \frac{\boldsymbol{b^s{}_{i,pc}}}{\boldsymbol{1/S_{ai}}}\ , \qquad\qquad \boldsymbol{i = 1, 2, 3 \dots k} \qquad\qquad (4.21)$$

and

$$\boldsymbol{b_{o,pc}} = \boldsymbol{b^s{}_{o,pc}} - \frac{\boldsymbol{b^s{}_1\bar{a}_1}}{\boldsymbol{S_{a1}}} - \frac{\boldsymbol{b^s{}_{2,pc}\bar{a}_2}}{\boldsymbol{S_{a2}}} \dots - \frac{\boldsymbol{b^s{}_{2,pc}\bar{a}_k}}{\boldsymbol{S_{ak}}} \qquad\qquad (4.22)$$

Where S_{ai} refers to standard deviations of the unstandardised variables and $b^s{}_{o,pc}$, $b^s{}_{1,pc}$, $b^s{}_{2,pc}$,… $b^s{}_{k,pc}$ represent coefficients of the standardised variables. The coefficients of unstandardised variables can be computed when standard deviations (S_{ai}) of the unstandardised variables are calculated by $1/S_{ai}$ (Khaile, 2012).

4.4.2 *APPLICATION OF PCR*

Given the theory of PCR discussed above, this section discusses the application of the PCR in SFA to solve the problem of multicollinearity observed among the correlated technical inefficiency model variables. During the first estimation of the SFA it was noted that correlation between variables in the technical inefficiency model result in biased results. The 14 variables for the technical inefficiency model were therefore standardised and before a Principal Component Analysis were used to identify uncorrelated components that can be included in the SFA. The PC's were included in the SFA regression as the explanatory variables in the second stage model. The use of Frontier 4.1 allows the researcher the opportunity to estimate the production function and the technical inefficiency model as simultaneous equations to overcome a two-stage estimation procedure. The significant PC's were identified based on the SFA regression results. From the regression output, it is found that all the retained PCs are statistically significant and the PCs are then used to estimate the significances of the standardised variable. The coefficients of the standardised variables are finally transformed back to the original unstandardised variables. The procedures pursued are discussed in the next sub-sections.

4.4.2.1 Estimation of Principal Components

Estimation of PCs is based on the formulation of eigenvector matrix of the correlation coefficient of the variables and the standardised variables. Therefore, the 14 technical inefficiency model variables are standardised based on the formula given by Equation 4.8. The eigenvalues and eigenvectors of the correlation coefficient matrices are obtained by using Statistical Package for Social Science (SPSS). The PCs are then estimated by multiplying the standardised variables with the eigenvector matrix of the correlation coefficient. Only five PCs with eigenvalues of greater than one were retained as they account for the majority of the variances among the correlated variables. Table 4.3 provides the five retained PCs with their respective eigenvalues and percentage of variances explained.

Table 4.3: Principal Components estimated, eigenvalues and cumulative percentage of variances explained

Principal Components	Eigenvalues	Percentage of variances explained
PC_1	1.78	13.93
PC_2	1.51	13.23
PC_3	1.29	12.78
PC_4	1.18	11.89
PC_5	1.06	10.07
Total	**6.82**	**61.90**

As indicated in Table 4.3, each PCs has an eigenvalue of greater than one. The result indicates that the five PCs explained about 61.9% of the variation within the originally correlated variables. The result fulfilled the goal of determining a reduced number of PCs that can explain most of the total variance. Once the important PCs are estimated, the next step is regression with the five retained PCs to determine the significances of the PCs.

4.4.2.2 Determining Significance of the Principal Components

Significances of the retained PCs were determined by the SFA regression in which the PCs were incorporated in the technical inefficiency model. The results of the parameters of the PCs and respective statistics are given in Table 4.4.

Table 4.4: Maximum Likelihood Estimates of the retained PCs

Variables	Parameter	Coefficients of the PCs	Std-errors	t- ratios	Probability
Constant	α_o	-9.2944	3.3246	-2.7956	0.005^{***}
PC1	α_1	-0.9789	0.3491	-2.8040	0.005^{***}
PC2	α_2	-0.9667	0.3388	-2.8532	0.005^{***}
PC3	α_3	-0.5474	0.1916	-2.8571	0.005^{***}
PC4	α_4	-0.2221	0.1246	-1.7836	0.075^{*}
PC5	α_5	0.8766	0.3023	2.8993	0.004^{***}

*** refers to significant at 1%, * refers to significant at 10%.

The SFA estimation result given in Table 4.4 indicates that all the five PCs are statistically significant. Four of the five retained PCs are significant at a one percent level while PC_4 is significant at a 10% level. Since all PCs are significant, the estimated parameters of the PCs are used to determine the significances of the correlated explanatory variables. The coefficients of the PCs are used to estimate the coefficients of the standardised explanatory variables. This is accomplished by multiplying the coefficients of the PCs with the eigenvectors of the correlation coefficient matrix.

The standard errors of the PCs are used to estimate variances of the standardised variables. The procedures of variance estimation include first estimating the variance matrix of the PCs by squaring the standard errors of the PCs. Then, variances of the standardised variables are estimated by multiplying the variance matrix of the PCs with the squared eigenvector matrix. The standard errors of the standardised variables are then obtained from the square root of the variance matrix of the standardised variables. After the coefficients and the standard errors of the standardised variables are determined, the corresponding t-ratios are obtained by dividing the estimated coefficients to their respective standard errors. The significances of the variables are then determined by using the t-distribution of the variables. The coefficients of the estimated standardised variables are transformed back to the original unstandardised coefficients by dividing the standardised variables by standard deviations of the unstandardised variables. Finally, the MLE result of all the variables of the technical inefficiency model after transformation in to the original variables are presented and discussed in Chapter five.

4.5 HYPOTHESIS TESTING

SFA allows various hypotheses tests including tests for the presence of technical inefficiency and tests to determine whether the technical inefficiency effects are stochastic (Belloumi & Matoussi, 2006). For hypothesis testing, the generalised Likelihood Ratio is used which is defined by:

$$\boldsymbol{\lambda = -2\{Ln[L(H_0)] - Ln[L(H_1)]\}(4.23)}$$

Where *Ln [L* (H_0)*]* and *Ln [L* (H_1)*]* are the values of Log Likelihood function for the frontier model under the null hypothesis and alternative hypothesis, respectively (Battesse & Coelli, 1995). The generalised Likelihood Ratio (λ)hasapproximately chi-square or a mixture of chi-square distribution with degrees of freedom determined by the number of parameters assumed to be equal to zero in the null hypothesis, H_0 (Battesse & Coelli, 1995). The decision to accept or reject the null hypothesis is based on the comparison of λ against the chi-square critical value. If λ is greater than the critical value, the null hypothesis is rejected, but if λ is less than the critical value, the null hypothesis is accepted (Battesse & Coelli, 1995).

Two hypotheses were tested, one is to test for the presence of technical inefficiency effects in the SFA model and the other is to determine if the technical inefficiency effects are stochastic. The hypotheses tested and the final decisions are presented in Table 4.5.

The first hypothesis is used to determine the presence of technical inefficiency effects in the SFA model. Information about the presence of technical inefficiency effects in an estimated model is important to determine whether the use of the SFA with the technical inefficiency model is appropriate.

Table 4.5: Generalised Log likelihood tests of hypotheses

Null Hypothesis (H_0)	Log likelihood function	LR test statistic (ª)	Critical Value with (¡$^{2}_{0.05}$)	Decision
$\text{¥} = \delta_0 = \delta_1 = \delta_2 = \dots \delta_8$	-74.59	297.97	17.67*	Reject H_0
$\text{¥} = 0$	-114.69	217.76	5.14*	Reject H_0

*The critical values for both hypotheses involving $\gamma = 0$ are obtained from Kodde and Palm (1986), with degrees of freedom equal to 10 for the first hypothesis and degrees of freedom equal to 2 for the second hypothesis based on Belloumi and Matoussi (2006)

In doing so, a null hypothesis was imposed with a restriction implying that technical inefficiency effects are absent from the SFA model. The restrictions involve both the gamma (¥)parameter and technical inefficiency model parameters are jointly zero (Alene & Hassan, 2003). The null hypothesis can be written out as given by Alene and Hassan (2003):

$$H_0\text{: ¥} = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \cdots = \delta_8 = 0 \qquad (4.24)$$

The decision rule to accept or reject the null hypothesis is determined by comparing the calculated ª against the chi-square critical value. The calculated value of ª is 297.97 whereas the critical value is 17.67. Since the value of ªis greater than the critical value, the null hypothesis is rejected and the alternative hypothesis is accepted. The rejection of the null hypothesis confirms the presence of technical inefficiency effects and the appropriateness of using the SFA with the technical inefficiency model (Alene & Hassan, 2003).

The second hypothesis test was used to determine whether the technical inefficiency effects are stochastic. Information about the stochastic nature of the technical inefficiency effects is important to determine whether the SFA is an appropriate model of efficiency analysis. To test the second hypothesis, a null hypothesis that states the technical inefficiency effects are not stochastic is imposed with restriction that ¥ is equal to zero (Hassan & Ahmad, 2005). The null hypothesis is written out following Hassan and Ahmad (2005) as:

$$H_0\text{: ¥} = 0 \qquad (4.25)$$

If the gamma parameter is equal to zero, then the variance of the technical inefficiency effects is zero so that the SFA model is reduced to the traditional mean response function (Hassan &

Ahmad, 2005). The decision rule to accept or reject the null hypothesis is by comparing the calculated value of ªagainst the chi-square critical value following the same procedure as the first hypothesis testing. The calculated value of ªis 217.76 while the critical value is 5.14. Since the value of ª is greater than the critical value, the null hypothesis stating that technical inefficiency effects are not stochastic is rejected. The rejection of the null hypothesis implies that technical inefficiency effects are stochastic which supports the appropriateness of the use of the SFA model. In conclusion, the hypothesis tests indicated the presence of technical inefficiency effects among the maize farmers and the appropriateness of fitting the SFA model which includes the technical inefficiency model.

4.6 SUMMARY

The chapter discusses the procedures used to achieve the objective of the study. The study employs a SFA model which requires the use of FRONTIER to estimate technical efficiency and to analyse the determinants of technical inefficiency (Coelli, 1996). Assuming that producers are producing a single output using multiple inputs, SFA provides the relative frontier against which production performance is evaluated (Kumbhakar & Lovell, 2000: 63). Different functional forms such as linear, Cobb-Douglas and translog can be used to specify the production frontier (Coelli *et al*., 2005: 211). The functional forms are compared using the data and model evaluation criteria such as R-squared, Log likelihood, Aikaike info criterion and Schwarz criterion. Based on the evaluation, Cobb-Douglas production function is found to fit the data well and is chosen for the final SFA specification.

In the production function estimated, the dependent variable is maize yield (ton/ha), and the explanatory variables are seed (kg), nitrogen (kg) and labour (man days) used in maize production. In the technical inefficiency model, the farm specific explanatory variables are age, gender, education, household size, farm size, tenure, oxen, extension, irrigation, credit, off-farm income, seed type, organic fertiliser and soil protection. The first attempt to estimate the SFA was unsuccessful due to the presence of severe multicollinearity among the technical inefficiency model explanatory variables. Principal Component Regression (PCR) is a multivariate statistical techniques used to solve the problem of multicollinearity. The PCR transforms the correlated technical inefficiency model explanatory variables into a new set of uncorrelated Principal Components (PCs) (Kline, 1994). The PCs are then used in SFA regression and their significances are determined. Five PCs are extracted that explained about

61.9% of the variation within the originally correlated variables. All the five PCs are statistically significant and are used to determine the significances of the correlated explanatory variables.

SFA allows various hypotheses tests by using the generalised Likelihood Ratio against the Chi-square distribution (Battesse & Coelli, 1995). Two hypotheses were tested where the first one is the test for the presence of technical inefficiency effects in the estimated model and the other is the test to determine if the technical inefficiency effects are stochastic. The hypotheses tests confirmed the presence of technical inefficiency effects and the technical inefficiency effects are stochastic supporting the appropriateness of using of the SFA model.

CHAPTER FIVE: RESULTS AND DISCUSSION

Chapter five presents and discusses the empirical results of the SFA. The empirical results are obtained from the FRONTIER software used to fit a production frontier (Coelli, 1996). The chapter is organised into three main sections. In the first section, the estimated parameters of production function are presented and discussed. The second section presents and discusses the technical efficiency estimation results. In the third section, the results of the technical inefficiency model are presented and discussed. Although a single stage SFA approach is used to generate the results of the production function and the technical inefficiency models, for ease of discussion, the two sets of variables are discussed in separate sections.

5.1 ANALYSIS OF PARAMETERS OF THE STOCHASTIC PRODUCTION FRONTIER

This section is used to present and discuss the estimated parameters of the Cobb-Douglas stochastic production frontier. The discussion includes the estimated statistics of input parameters used in maize production including seed, nitrogen and labour as well as the diagnostic statistics indicating model variance and gamma. Table 5.1 presents the Maximum Likelihood estimates of the parameters of the Cobb-Douglas production frontier.

Table 5.1: Maximum Likelihood estimates of stochastic production frontier parameters

Variable	Parameter	Coefficient	Std. error	t-ratio	Probability
Constant	βo	0.6912	0.0472	14.6544	0.0000***
Ln (Seed)	β_1	0.0166	0.0324	0.5122	0.6088
Ln (Nitrogen)	β_2	0.0234	0.0054	4.3122	0.0000***
Ln (Labour)	β_3	-0.0278	0.0197	-1.4170	0.1572
Diagnostic Statistics					
Sigma-Square	$\sigma^2=\sigma^2_u+\sigma^2_v$	2.7664	0.8573	3.2267	0.0013***
Gamma	$\gamma=\sigma^2_u/\sigma^2$	0.9931	0.0024	409.1748	0.0000***
LR function	-74.59				
LR test	297.97				
Mean Technical Efficiency	0.77				

*** represents significant at 1%.

The estimated coefficients of the production frontier parameters are positive for seed and nitrogen, but negative for labour. The positive coefficients of seed and nitrogen indicate that increasing the use of seed and nitrogen increases maize production. The increasing effect of seed and nitrogen on maize production is as expected because production of maize is dependent on the quantities of these inputs used. However, only the coefficient of nitrogen is found statistically significant at a one percent level in explaining maize production while seed is found insignificant at all levels. The increasing effect of nitrogen on maize production is in line with the findings of Alene and Hassan (2003), Rahman and Umar (2009) and Geta *et al*. (2010) in which application of fertiliser increases production significantly. Unexpectedly, the negative sign of the labour coefficient indicates that the use of additional labour will decrease maize production, but the relationship is statistically insignificant.

Along with the stochastic production frontier parameters, variance parameters of the model are also estimated and given in Table 5.1. Sigma square ($\pm^2$) represents the variance of the composed error term which consists of the variance due to random effects ($\pm^2_v$) and the variance due to technical inefficiency effects ($\pm^2_u$) (Battese & Corra, 1977). The estimated value of $\pm^2$ is 2.06 and is significant at a one percent level, which confirms the correctness of the specified distributional assumptions of the error terms. The other variance parameter estimated is gamma (¥).The ¥ parameter is used to show the proportion of total variance that is attributed to technical inefficiency in the estimated model. The value of ¥ is 0.99 and is significant at a one percent level. The magnitude of ¥ implies that 99% of the random variation in output of maize production is attributed to the technical inefficiency component which indicates the importance of capturing technical inefficiency in production. The significance of ¥ indicates that technical inefficiency effects are significant in determining the level and variability of maize production. From the estimated value of¥ , it is observed that only about one percent of random variation in maize production is attributed to random shocks that are out of the control of the farmers.

The estimated production frontier leaves much to be desired with very few explanatory variables and low level of significance for the explanatory variables. The data used for the estimation of the SFA is from secondary data obtained from the Central Statistical Agency of Ethiopia. The data formed part of the Ethiopian Rural Socio-economic Survey (ERSS). The data available to the study was therefore limited and hence limited the researcher in explanatory variable that could be included in the production function.

5.2 TECHNICAL EFFICIENCY ESTIMATIONS

This section presents and discusses the SFA estimation of technical efficiency scores. As is indicated in Table 5.1, the estimated mean technical efficiency score for the sample is 77%. The mean technical efficiency of 77% indicates that on average, the sampled maize farmers are able to obtain only 77% of potential output from the given mix of production inputs. The finding suggests the presence of considerable level of technical inefficiency among the studied households. The mean technical efficiency estimated provides an indication that the sampled maize farmers have a potential of increasing their output by about 23% by using the existing resources and technology more efficiently. The cumulative probability distribution of the estimated technical efficiency scores of the sample is summarised in Figure 5.1.

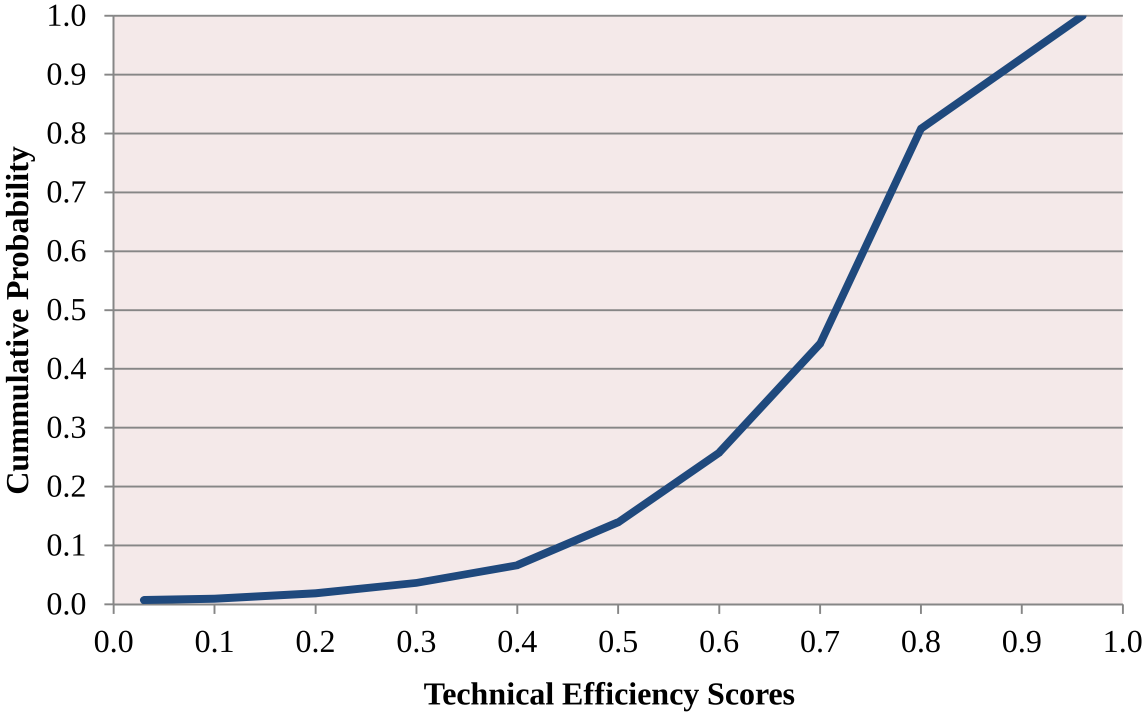

Figure 5.1: Cumulative probability distribution of technical efficiency scores for sample of smallholder maize farmers in Ethiopia

Figure 5.1 indicates that the estimated technical efficiency scores range from 3 to 96%. The cumulative probability distribution of the efficiency scores indicates that the lower 10% of the sample is associated with technical efficiency of less than 45%. About 50% of the sample has technical efficiency scores of less than 70%. It is also observed that nearly 81% of the sample has mean technical efficiency scores of less than 80%. However, the final 19% of the sample has technical efficiency scores ranging from 80 to 96% which is the highest efficiency category. More than half of the sampled farmers are operating with a technical efficiency score of less than the sample mean.

The estimated mean technical efficiency is closely comparable to the technical efficiency estimates of Alene and Hassan (2003) where the reported mean technical efficiency of sampled maize farmers was 76% in Western Ethiopia. The other closely comparable finding was that of Arega and Zeller (2005) where the mean technical efficiency score reported was 79% for a sample of maize, wheat and barley farmers in Eastern Ethiopia.

5.3 ANALYSIS OF TECHNICAL INEFFICIENCY MODEL PARAMETERS

The hypothesis testing confirmed that technical inefficiency effects are present in the SFA model. Given the presence of technical inefficiency, there is a need to improve technical efficiency of the farmers by examining the determinants of technical inefficiency. The aim of this section is therefore to present and discuss the technical inefficiency model parameters of the smallholder maize farmers.

The estimated coefficients of the technical inefficiency model parameters are of particular interest in examining technical inefficiency model parameters. In the technical inefficiency model, the dependent variable is a technical inefficiency variable (U_i) and the explanatory variables are farm specific socio-economic and farm management explanatory variables (Z_i).A variable that has a positive parameter estimate will have an increasing effect on farm technical inefficiency and *vice versa*. The implication is that the variable that has an increasing effect on technical inefficiency will have a decreasing effect on technical efficiency and *vice versa*.

Table 5.2 presents a summary of the SFA results of parameters of the technical inefficiency model and respective statistics. Of the total technical inefficiency model explanatory variables, the estimated coefficients of age, gender, household size, oxen, extension, irrigation, credit, seed type and soil protection are negative and statistically significant. These variables were found as having decreasing effects on technical inefficiency hence increasing effects on technical efficiency of the maize farmers. The estimated coefficient of off-farm income is positive and statistically significant indicating that off-farm income increases technical inefficiency of the maize farmers. The remaining variables: education, tenure, farm size and organic fertiliser are not statistically significant determinants of technical inefficiency. The variables that are found significant in determining technical inefficiency are discussed as socio-economic and farm management variables.

Table 5.2: Maximum Likelihood estimation results of technical inefficiency model variables[1]

Variable	Parameter	Coefficient	Std-errors	t-ratios	Probability
Constant	α_o	-9.2944	3.3246	-2.7956	0.0054***
Age	δ_1	-0.5988	0.15407	-3.88689	0.0001***
Gender	δ2	-0.7318	0.22999	-3.18200	0.0016***
Education	δ3	0.1266	0.14430	0.87770	0.3806
Household size	δ4	-0.75049	0.26590	-2.82241	0.0049***
Farm size	δ5	-0.11697	0.88783	-0.13175	0.8952
Tenure	δ6	-0.69203	0.14291	-4.84257	1.7872
Oxen	δ7	-0.62774	0.25054	-2.50554	0.0126**
Extension	δ8	-0.90109	0.29507	-3.05382	0.0024***
Irrigation	δ9	-0.43334	0.26620	-1.62789	0.0030***
Credit	δ10	-0.47581	0.14696	-3.23771	0.0013***
Off-farm income	δ11	0.79963	0.31460	2.54177	0.0114**
Seed type	δ12	-0.72495	0.28263	-2.56504	0.0111**
Organic fertiliser	δ13	-0.20670	0.12732	-1.62352	0.1052
Soil protection	δ14	-1.62213	0.79844	-2.03164	0.0428**

*** refers to significant at 1%, ** refers to significant at 5%

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[1] The results presented in Table 5.2 are the individual significance of the explanatory variables included in the inefficiency model estimated within the SFA/PCR framework.

5.3.1 *SOCIO-ECONOMIC VARIABLES*

5.3.1.1 Age and Gender

From Table 5.2, the estimated coefficient of age is negative and highly significant. The relationship implies that whenever age of household heads increases, farm technical inefficiency will decrease. A possible reason for such a relationship can be due to the fact that with increased age, farmers can have better resources at their disposal and can be better aware of mechanisms for risk coping that is developed from life experience, which can potentially decrease their technical inefficiency (Fesessu, 2008).The finding is consistent with the results obtained by Fesessu (2008), Maseatile (2011) and Khaile (2012).

Similarly, the estimated coefficient of gender is negative and highly significant on affecting technical inefficiency, suggesting that male headed households are more technically efficient than female-headed households. A possible explanation for the finding is that male headed households have better access to farm resources such as land, credit, technological inputs and other supportive services than their female counterparts in Ethiopia, which makes the male headed households more efficient (FARA, 2009; AWM, 2009). Another possible explanation is that female household heads are responsible for other household activities (such as child bearing and care, cooking and cleaning) that compete with the time and effort allocated to the farm work, making them less efficient (Solis *et al*., 2008). The result is consistent with the findings reported by Solis *et al*. (2008), Bachewe (2009) and Maseatile (2011). Analysis of age and gender of household heads revealed that farm technical inefficiency will decrease whenever the age of household heads increase and male headed households are less technically inefficient than female headed households.

5.3.1.2 Household Size and Oxen

The estimated coefficient for household size is negative and highly significant. The finding suggests that whenever household sizes increase, technical inefficiency will decrease. A possible reason for a decreasing effect of household size on technical inefficiency is mainly attributed to the fact that large households contribute to family labour to assist in the farming activities such as sowing, weeding and harvesting. This is particularly true whenever most of the household members contribute to the farming activities. The result is consistent with the findings of Bachewe (2009), Geta *et al*. (2010) and Rahman and Umar (2009).

Another important variable is ownership of an adequate number of oxen which was included to determine whether ownership of oxen is a source of technical inefficiency variation. The estimated coefficient of oxen is negative and significant at a five percent level. The finding suggests that ownership of oxen decreases technical inefficiency. The result is as expected and confirmed the importance of ownership of an adequate number of oxen to augment labour input and enhance productivity by reducing the time needed to accomplish farm operations such as land preparation and sowing. The finding is consistent with the finding of Geta *et al*. (2010) where ownership of oxen is found to be an important determinant of technical inefficiency in production. The empirical analysis of household size and oxen suggested that both variables have decreasing effects on technical inefficiency.

5.3.1.3 Credit and Off-farm Income

The estimated coefficient of credit is negative and highly significant which indicates the importance of credit in decreasing farm technical inefficiency. Access to credit can decrease technical inefficiency of the farmers through enabling them to make necessary short and long-term farm investments (IFPRI, 2010b). The finding is as expected and is in line with the findings of Alene and Hassan (2003), Obwona (2006) and Maseatile (2011). Despite the important role credit has in smallholder maize production, it was observed that about 71% of the farm households did not receive credit. The low level of credit participation of the farm households could be mainly due to low level of credit coverage, which can also be attached to the lack of loanable funds by the suppliers of rural credit. Other problems associated with credit are complicated credit application procedures that the farmers undergo to obtain credit and the requirements of high collateral in the country (Ameha, 2011).Off-farm income is a dummy variable that is proposed as a determinant of technical inefficiency. The estimated coefficient of off-farm income is positive and statistically significant at a five percent level. The result suggests that with an increase in pursuit of off-farm income, technical inefficiency will increase. The possible explanations for an increasing effect of off-farm income on maize farm technical inefficiency could be that the off-farm income received might not be used for financing the farming activities and the farmers might spent much of their time working off the farm and failing to manage the maize farms properly. The finding supports the fact that increased off-farm income opportunities will reduce farm resources and farmers' effort that could otherwise be used for farming (McNally, 2002; Goodwin & Mishra, 2004).The result is consistent with the findings reported by Alene and Hassan (2003), Obwona (2006) and

Baruwa and Oke (2012). The analysis of credit and off-farm income revealed that credit decreases farm technical inefficiency whereas off-farm income increases farm technical inefficiency in the sample.

5.3.2 *FARM MANAGEMENT PRACTISES*

The estimated coefficients of the farm management variables of the technical inefficiency model are discussed in this section. The variables discussed include extension, irrigation, seed types, organic fertiliser and soil protection.

5.3.2.1 Extension and Irrigation

Extension is a dummy variable that was hypothesised to influence technical inefficiency of maize production negatively. The empirical result indicates that extension has a negative and highly significant coefficient. Extension therefore decreases technical inefficiency as expected. The possible reason for the result is that farmers who obtained extension services can have better information about farm management practises and better agricultural technologies. The finding is supported by Obwona (2006) and Bachewe (2009) who acknowledged the importance of extension services as a key policy instrument to improve agricultural productivity. Despite the fact that most of the farmers studied (79%) do not receive extension services, the study revealed that extension services are an important determinant of technical inefficiency.

Irrigation is another important dummy variable proposed to affect technical inefficiency negatively. The estimated coefficient of irrigation is negative and significant at a five percent level. The negative coefficient of irrigation suggests that the use of irrigation decreases technical inefficiency and the relationship is expected. Although most of the farmers (96%) in the sample did not use irrigation, the empirical findings confirmed that the use of irrigation contributes to a reduction of technical inefficiency significantly. From the distribution of the estimated technical efficiency, it was observed that the irrigated farms were much more efficient than the non-irrigated farms. The average technical efficiency score specific to the irrigated farms is 85% which is much greater than the average technical efficiency for the non-irrigated farms, which is 77%. The findings for irrigation is in line with the results reported by Makombe *et al*. (2011) and Khai and Yabe (2011) that supported the importance of irrigation in increasing crop productivity of smallholder farmers. The low usage of irrigation in Ethiopia is mainly due to a lack of development of irrigation infrastructure. The empirical analysis of extension and irrigation services indicated that both variables have decreasing effects on farm technical inefficiency.

5.3.2.2 Seed Type and Soil Protection

Given the fact that smallholder maize farmers use either improved seed or traditional seed, the variable of seed type is included as a dummy variable to determine if the use of improved seed decreases technical inefficiency. The empirical results indicate that improved seed has a negative and significant coefficient at a five percent level. The finding is in line with the initial hypothesis and the use of improved seed indeed has a decreasing effect on technical inefficiency. The finding is consistent with the empirical studies of Geta *et al*. (2010) and Maseatile (2011) where the use of improved seed increases technical efficiency of maize production.

Soil protection is the final dummy variable which was hypothesised to decrease technical inefficiency. The estimated coefficient of soil protection is negative and statistically significant at a five percent level. The finding is in line with the initial hypothesis and confirms that soil protection can significantly increase technical efficiency in maize production in the country. The average technical efficiency for the farmers that used soil protection is nearly 83% which is greater than the average technical efficiency of the total sample (77%). The result of soil protection is consistent with the finding reported by Geta *et al*. (2010) where soil and land management practises decrease technical inefficiency significantly. The findings of seed type and soil protection confirmed that the two variables are important factors that have decreasing effects on technical inefficiency.

5.4 SUMMARY

Chapter five presented the empirical findings of the study. The chapter contained three main sections which include presentation and discussion of the estimated parameters of production function, the estimated results of the technical efficiency and the technical inefficiency model parameters in Ethiopian maize production. The inputs defining the production frontier in the study are seed, nitrogen and labour. The estimated coefficients are positive for seed and nitrogen, and negative for labour, though only nitrogen is found statistically significant. The positive coefficients of seed and nitrogen indicate that increasing the use of seed and nitrogen increases maize production. The negative sign of the labour coefficient indicates that the use of additional labour decreases maize production, but the relationship is statistically insignificant and the finding is unexpected. Along with the stochastic production frontier parameters, variance parameters of the model are also estimated. Sigma square (±^{2}) represents the variance of the composed error term (Battese & Corra, 1977). The estimated value of ±^{2} is 2.06 and is highly significant, confirming the correctness of the specified distributional assumptions of the error terms. The other variance parameter estimated is gamma (¥), which shows the proportion of the total variance that is attributed to technical inefficiency in the model. The value of ¥ is 0.99 and is highly significant implying that 99% of the random variation in output of maize production is attributed to the technical inefficiency. The significance of ¥ indicates that technical inefficiency effects are significant in determining the level and variability of maize production.

The estimated results of the technical efficiency indicate that the mean technical efficiency score is 77% for the sample. The mean technical efficiency of 77% implies that the sampled maize farmers are able to obtain only 77% of potential output from the given mix of production inputs, on average. The finding suggests the presence of considerable level of technical inefficiency that the sampled maize farmers have a potential of increasing their output by increasing their technical efficiency by about 23%. The estimated mean technical efficiency is closely comparable to the technical efficiency estimates of Alene and Hassan (2003) and Arega and Zeller (2005).Given the presence of technical inefficiency in the study, maize production, and the study analysed the determinants of technical inefficiency.

Among the technical inefficiency model explanatory variables involved in the study, the estimated coefficients of age, gender, household size, oxen, extension, irrigation, credit, seed type and soil protection are negative and statistically significant. The variables were found having decreasing effects on technical inefficiency hence increasing effects on technical efficiency of the maize farmers. The estimated coefficient of off-farm income is positive and statistically significant indicating that off-farm income increases technical inefficiency of the maize farmers. The remaining variables: education, tenure, farm size and organic fertiliser are not statistically significant determinants of technical inefficiency.

CHAPTER SIX: SUMMARY, CONCLUSION AND IMPLICATIONS

Chapter six provides a summary, conclusion and the implications of the research. In the first part of the chapter a summary is presented of the introduction, literature review, study area and data, methodology and results. This is followed by the conclusion with regard to achievement of the objectives, possible policy implications and implications for further research.

6.1 SUMMARY

6.1.1 *BACKGROUND AND MOTIVATION*

Low agricultural productivity and an increasing population are the main problems in the Sub-Saharan Africa and in Ethiopia in particular that increased food insecurity and poverty (Geta *et al.*, 2010). Ethiopian economy is highly dependent on the agricultural sector where agriculture accounts for 43% of GDP, 85% of employment and 90% of export earnings (MoARD, 2010). Agriculture in Ethiopia is predominantly rainfed smallholder farming from which about 95% of the agricultural GDP is derived (MoARD, 2010).

Maize is one of the most important food crops produced by smallholder farmers in the country and accounts for 28% of total grain crops produced during the 2011/12 Meher season (CSA, 2012a). Due to the relative role of maize in total grain production and the participation of a large number of smallholder farmers in its production, maize is a priority crop that can contribute significantly to national food security of the country. Nevertheless, low production and productivity characterises Ethiopian agriculture, specifically in maize production (MoARD, 2009).

The country is endowed with abundant natural resources that hold great potential for agricultural development (MoARD, 2010). Despite having good resource potential there is a growing food shortage in the country due to the poor performance of the agricultural sector. Poor performance of the agricultural sector is evident in the rural farming population's lower standard of living, seen in high levels of poverty, illiteracy and infant mortality (Diao, 2010).

As a result, the country continuously faces food insecurity and to some extent relies on food aid and food imports (Adenew, 2003; Diao, 2010).

In an agriculturally dependent poor economy, it is expected that growth in agricultural production, especially in crop growth, would contribute more to reduce poverty than stronger macro-economic growth (Boccanfuso & Kabore, 2004). The key to growth in agricultural production in Ethiopia lies in increasing the productivity and efficiency of smallholder farmers (Owour, 2000). Due to the importance of agricultural productivity, the Ethiopian government has given substantial policy emphasis to increasing productivity of smallholder farmers through the Agricultural Development Led Industrialization (ADLI) strategy (Diao, 2010). The ADLI strategy emphasises the role of adoption and intensification of yield enhancing technological inputs such as fertilisers and improved seeds to increase crop productivity (Diao, 2010).

6.1.2 *PROBLEM STATEMENT AND RESEARCH OBJECTIVES*

Despite the fact that Ethiopia has abundant agricultural resource potential and is following a consistent agricultural policy to boost productivity, the country could not achieve the expected productivity increment resulting in food insecurity and poverty remaining at high levels (CSA, 2011b). In response to the agricultural development strategy pursued, studies by Mulat (1999) and Arega and Zeller (2005) indicated substantial improvements in the adoption and use of fertiliser, improved seeds and related inputs, but maize yields have not shown a substantial improvement. One of the reasons for low maize productivity could be due to the presence of technical inefficiencies in production. Therefore, information about farm level technical efficiencies of smallholder farmers is important in improving the productivity of the smallholder maize farmers (Alene & Hassan, 2003).

In Ethiopia, empirical studies on the technical efficiency of smallholder maize production are limited and the few existing studies indicate the presence of technical inefficiencies. Among the studies, Alene and Hassan (2003) have examined the technical efficiencies associated with maize production in Western Ethiopia where the estimated efficiency is 76%. Similarly, Geta *et al*. (2010) has examined the technical efficiency of maize production in Southern Ethiopia and obtained an efficiency estimate of 40%. The technical efficiency estimates of maize production provides good indications of efficiency in the zones studied, but they could not provide a comprehensive estimate of the technical efficiency of the country. Furthermore, Arega and Zeller (2005) and Bachewe (2009) explored technical efficiencies of multiple grain crop production by using a single aggregate index value and obtained technical efficiencies of 79% and 40%, respectively. These studies also could not provide separate technical efficiency estimations for maize production because of the use of a single aggregate index value for the crops. From the literature, it was found that there was no comprehensive study of technical efficiency of smallholder maize production that involved the main maize producing regions of Ethiopia namely: Amhara, Oromia and SNNP regions.

Therefore, the main objective of the study is to identify factors affecting the technical efficiency of smallholder maize farmers in selected regions of Ethiopia. The main objective will be reached through the completion of the following sub-objectives:

i. Estimating technical efficiency of smallholder maize farmers using Stochastic Frontier Analysis (SFA) which estimates a production frontier against which the farmers' actual production is evaluated to quantify their technical efficiency.

ii. Identifying and analysing the socio-economic and farm management factors that affect the technical inefficiency of smallholder maize farmers using the SFA in order to better understand the constraints that prevent farmers from producing the maximum potential output.

6.1.3 *LITERATURE REVIEW*

When discussing the economic performance of producers, the two commonly used concepts are productivity and efficiency (Fried *et al.*, 2008). Productivity is a measure of physical output produced from the quantity of inputs used (Latruffe, 2010). Variations in productivity across producers or across time are attributed to differences in the following: production technology, scale of operation, operating efficiency and operating environment (Fried *et al.*, 2008:8).Productivity is one means of improving output growth as output can be increased either by increasing productivity of inputs or through expansion of farm sizes in production (FAO & OECD, 2012). Growth in output that is achieved by increasing agricultural productivity is a sustainable means of output growth without the need to expand farm sizes

(FAO & OECD, 2012). Increased agricultural productivity and the resulting increase in output contribute to poverty reduction and to broader economic development (Mellor, 1999).

Efficiency, on the other hand, is the degree of success producers achieve in allocating the inputs at their disposal and the outputs they produce in an effort to meet certain objectives (Kumbhakar & Lovell, 2000). Not all producers are equally efficient in utilising their inputs to achieve a potential yield due to performance variations among the producers. Efficiency can be examined in terms of technical, allocative or economic efficiency (Fried *et al*., 2008). Technical efficiency is a ratio of the actual production to optimal production (Green, 1993), while allocative efficiency is the ability of a producer to use inputs in an optimal proportion, given their respective prices (Coelli *et al*., 2005). Economic efficiency is a combination of technical efficiency and allocative efficiency (Farrell, 1957).

Measuring and analysing technical efficiency in crop production assists in determining the scope of raising the productivity of inefficient producers (Uaiene, 2008). Knowledge of the level of technical efficiency contributes to the realisation of policy goals such as achieving food security, poverty alleviation and growth and development through the improving performance of inefficient producers (Mupanda, 2009). Technical efficiency can be measured using either a parametric or non-parametric approach. The former uses an econometric technique of estimation while the latter uses mathematical programming (Sarafidis, 2002). Developments in the technique of efficiency measurement are influenced by the early works of Debreu (1951), Koopmans (1951), Shephard (1953) and Farrell (1957).

In empirical work, the two most popular techniques of efficiency measurement are DEA and SFA. DEA is a non-parametric technique of efficiency measurement based on mathematical programming and it was first introduced by Charnes *et al*. (1978). DEA is widely applied in literature mainly in operational research. However, DEA’s main limitation is that there is no provision for statistical noise and all the deviations from optimal frontier are considered as inefficiencies (Fried *et al*., 2008). SFA is an alternative efficiency measurement technique which was first introduced by Aigner *et al*. (1977) and Meeusen and van den Broeck (1977).

SFA is a parametric technique of efficiency measurement that is based on econometric estimation which requires specification of functional forms to estimate production frontiers. The SFA model measures efficiency by accommodating statistical noise in the estimation of technical efficiency (Kumbhakar & Lovell, 2000). For the estimation of technical efficiency and examining the determinants of technical inefficiency using SFA, there are two approaches; a two-stage and a single-stage approach (Kumbhakar & Lovell, 2000).In early studies, the two-stage approach was applied where first technical efficiency is estimated, and then the estimated technical efficiency is regressed against the determinants of technical inefficiency. The two-stage estimation is based on the OLS method and suffers from inconsistency of assumptions about the distribution of the inefficiency error terms (Kumbhakar & Lovell, 2000). More recent studies employed a single-stage approach in which both the production frontier and the technical inefficiency model equations are estimated simultaneously (Kumbhakar *et al*., 1991; Battesse & Coelli, 1995).

The SFA model was preferred to DEA because of the ability of the model to separately accommodate the effects of statistical noise from that of technical inefficiency (Sarafidis, 2002). SFA is more applicable in crop efficiency analysis because of the probability that the data could be affected by statistical noises arising from random shocks such as changes in drought, frost, flood, etc. (Hordofa *et al*., 2008). A single-stage SFA model was used to measure technical efficiency and to identify the determinants of technical inefficiency in the maize production studied. FRONTIER version 4.1 software that was developed by Coelli (1996) is used for the simultaneous estimation of production frontier and technical inefficiency model parameters.

6.1.4 *STUDY AREA PROFILE AND DATA*

Ethiopia is located in the north eastern part of the horn of Africa with a total surface area of 1.12 million square kilometres (Mengistu, 2006). The country is structured into a federation of nine ethnic based administrative regions and two centrally chartered city administrations (Sori, 2009). The nine regions are Tigray, Afar, Amhara, Oromia, Somali, Benishanful-Gumuz, Southern Nations, Nationalities and Peoples (SNNP), Gambela and Harari while the two city administrations are Addis Ababa and Dire Dawa. The study area included Tigray, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNP, Harari and Dire Dawa. Afar and Gambela regions were not included because the information relevant to the study was not adequately obtained for these two regions. Due to the presence of extremely varied topography, there is wide variation in agro-ecology, climate, soil, vegetation and settlement patterns among the study areas in the country (Camberiln & Philippon, 2001).Maize is produced in almost all regions of Ethiopia, but the three largest producers are Oromia (61%), Amhara (20%) and SNNP (12%) (Schneider & Anderson, 2010).

Crop production in Ethiopia is rainfed smallholder farming systems (CSA, 2012a). There are two cropping seasons for temporary crops, Meher and Belg. Meher is the main cropping season that accounts for 97% of total crop production (Alemayehu *et al*., 2012). Maize is produced in both seasons, but Meher accounts for 90.5% while Belg accounts for 9.5% of the total maize production annually (Alemayehu *et al*., 2012).

The data used for the study is a secondary data set obtained from the Central Statistical Agency of Ethiopia for maize production performed during Meher season of 2011/12. The data was collected as part of the Rural Socio-economic Survey of the country. In the process of sample selection, the CSA set larger quotas for the most populous regions. Based on the quotas, the percentage of the sample composition of each region in the study was as follows: Oromia (24%), Amhara (24%), SNNP (22%), Tigray (15%), Benishangul-Gumuz (six percent), Harari (five percent), Somali (two percent) and Dire Dawa (two percent). The total number of observations used is 438. From the descriptive statistics of the data, it was observed that the sampled households are characterised by lower input usage, weak socio-economic conditions and poor farm management practises which can potentially influence productivity of maize production.

6.1.5 *METHODOLOGY*

Chapter four described the methodological procedures used to achieve the sub-objectives. SFA was used to estimate the level of technical efficiency and to identify and analyse factors affecting the technical inefficiency of smallholder maize farmers for the selected regions of Ethiopia.

A Cobb-Douglas production model was used to relate seed use, fertiliser and labour to maize production in the SFA specification. The linear technical inefficiency model consisted of explanatory variables that are hypothesised to affect technical inefficiency. The choices of the variables were determined by the literature reviewed and type of data available (as it is secondary data). The technical inefficiency model's explanatory variables were: age, gender, education, household size, farm size, tenure, oxen, extension, irrigation, credit, off-farm income, seed type, organic fertiliser and soil protection.

The first attempt to estimate the SFA was unsuccessful due to the presence of high multicollinearity among the technical inefficiency model explanatory variables. Multicollinearity refers to linear correlations among explanatory variables in a multiple regression model that can lead to biased parameter estimates. In order to solve the problem of multicollinearity, Principal Component Regression (PCR) was used. Through PCR, the correlated explanatory variables were transformed into a new set of uncorrelated Principal Components (PCs), which are further used to estimate the parameters and significances of the correlated original technical inefficiency model variables(Kline, 1994). The extraction of the Only five PCs that were associated with eigenvalues greater than one are extracted. Significances of the five PCs were determined by incorporating the five PCs in SFA regression. All the five PCs were found significant and the PCs were used to determine the coefficients and significances of the correlated technical inefficiency model variables.

Hypotheses testing were conducted to test for the presence of technical inefficiency effects in the estimated SFA model and to examine whether the technical inefficiency effects are stochastic. For hypothesis testing, the generalised Log Likelihood statistic (λ) was used against the chi-square and the critical values obtained with the degrees of freedom determined by the number of parameter restrictions imposed under the null hypothesis. The hypotheses tests confirmed the presence of technical inefficiency effects in the model and the inefficiency effects are stochastic such that SFA, with the technical inefficiency model, was an appropriate model for efficiency measurement.

6.1.6 *RESULTS AND DISCUSSION*

6.1.6.1 Technical Efficiency Estimation

The Cobb-Douglas production function indicated that maize yield has a positive response to seed and Nitrogen, but negative to labour. The positive coefficients of seed and nitrogen indicate that increasing the use of seed and Nitrogen increases maize production. However, only Nitrogen is statistically significant in explaining maize yield. The significance of Nitrogen implied that increasing the use of Nitrogen application will increase maize production significantly. The sign of labour coefficient is unexpectedly negative implying that the use of additional labour will decrease maize production, but the relationship is statistically insignificant.

Variance ($\pm^{2}$) of the estimated SFA model is 2.06 and highly significant. The significance of the variance indicated the correctness of the specified distributional assumption. The estimated value of ¥ is 0.99 and is significant at a one percent level. The value of¥ implies that about 99% of the random variation in output of maize production is attributed to technical inefficiency and indicates the importance of examining technical inefficiency in production. The estimated mean technical efficiency score for the sample is 77% indicating that on average, the sampled maize farmers are able to obtain only 77% of potential output from the given mix of production inputs and available resources. The finding suggests the presence of a considerable level of technical inefficiency among the studied households. The mean technical efficiency estimated gives an indication that the sampled maize farmers have the potential for increasing their output by about 23% by using the existing resources and technology more efficiently. Given the observed technical inefficiency in maize production, it is possible to improve production by improving the level of technical efficiency. In order to improve the current state of technical efficiency, it is necessary to examine factors affecting technical inefficiency of maize production.

6.1.6.2 Factors Affecting Technical Inefficiency

While examining factors affecting technical inefficiency, a positive sign for the estimated coefficient indicates that the associated variable increases technical inefficiency and *vice versa*. The implication is that a variable that increases technical inefficiency will decrease technical efficiency and *vice versa*. The estimated coefficients of age, gender, household size, oxen, extension, irrigation, credit, seed type and soil protection are negative and significant in that they have a decreasing effect on technical inefficiency. The estimated coefficient of off-farm income is positive and significant with an increasing effect on maize farm technical inefficiency. Education, tenure, farm size and organic fertiliser are not statistically significant determinants of technical inefficiency.

The coefficient of age is negative and highly significant indicating that whenever age of household heads increase, farm technical inefficiency will decrease. The finding supports the possibility of having better resources and experience with increased age that can potentially decrease inefficiency (Fesessu, 2008). Similarly, the coefficient of gender is negative and significant suggesting that male-headed households are more technically efficient than female-headed households. The finding supports the fact that male-headed households could have better access to farm resources such as land and credit than their female counterparts, causing efficiency differences between male and female-headed households. Female household heads' responsibilities for domestic household activities also make male headed farm households more efficient relative to female headed ones (FARA, 2009; AWM, 2009).

The coefficient for household size is negative and significant indicating that whenever household size increases, technical inefficiency will decrease which could be attributed to the contribution of large households to family labour. Similarly, the coefficient of oxen is negative and significant indicating that ownership of adequate oxen decreases maize farm technical inefficiency. The finding is as expected and is consistent with the finding of Geta *et al*. (2010).

Another important variable estimated is credit which has a negative and significant coefficient. The finding confirms the importance of credit in decreasing farm technical inefficiency by increasing the ability of farmers to overcome the financial constraints to buy inputs and make necessary investments. The result is in line with the findings of Alene and Hassan (2003) and Obwona (2006). Off-farm income is another important determinant of the smallholder maize farmers' technical inefficiency. The coefficient of off-farm income is positive and significant indicating that the pursuit of off-farm income will increase farm technical inefficiency. This is due to the possible reason that participation in off farm income decreases farm labour and effort which could potentially lead to inefficiency in the farm work. The finding is similar to the findings of Alene and Hassan (2003) and Baruwa and Oke (2012).

Extension is an important determinant of technical inefficiency with a negative and significant coefficient. Extension therefore decreases technical inefficiency and the result was expected. The finding is consistent with findings of Obwona (2006) and Bachewe (2009).Another important variable is irrigation. The coefficient of irrigation is negative and statistically significant suggesting that the use of irrigation decreases technical inefficiency. The average technical efficiency score of the irrigated farms were much more efficient than the total sample farms where the average TE was 85% for the irrigated farms compared to 77% of the total sample mean TE score. The finding of irrigation is in line with the results reported by Khai and Yabe (2011) and Makombe *et al*. (2011).

Other important variables are seed type and soil protection practises of the farmers which were found to have negative and significant coefficients. The negative sign of seed type indicates that the use of improved seed decreases technical inefficiency among the maize producers. The finding is consistent with the empirical studies of Geta *et al*. (2010) and Maseatile (2011). Similarly the negative coefficient of soil protection confirms the importance of soil protection in decreasing technical inefficiency in maize production. The average technical efficiency of the farmers that used soil protection is nearly 83% which is greater than the mean technical efficiency of the total sample (77%). The result of soil protection is consistent with the finding reported by Geta *et al*. (2010).

6.2 CONCLUSION AND POLICY IMPLICATION

Due to low production and productivity of food crops, Ethiopia is unable to supply the growing food demand of its population. Despite the fact that there are improvements in adoption and utilisation of yield enhancing inputs in maize production, the level of yield did not show the expected productivity increment. In an attempt to investigate the problems causing low maize productivity of smallholder farmers in Ethiopia, the potential determinants of technical efficiency were analysed by studying a sample of farmers selected from most of the maize producing regions of the country.

The results from the study indicated that there is a considerable level of technical inefficiency among the maize farmers that contributed to lowered productivity. The results show that most of the variation in maize production is due to technical inefficiency. The results furthermore indicated that it is possible to improve the current productivity by increasing technical efficiency. The current level of low production efficiency can be addressed through improving the access of farmers to rural credit and extension services, by promoting soil and land conservation practises and by promoting small-scale irrigation schemes. Based on the findings, some policy implications are drawn.

6.2.1 *POLICY IMPLICATIONS*

Access to rural credit is an important factor that can contribute to an improvement in productivity of the smallholder farmers. Credit is an important source of capital for the poor farmers to be able to purchase yield enhancing technological inputs, own an adequate number of oxen for farming and to make land improvements that can potentially increase farm productivity. Micro-finance institutions (MFIs) and rural saving and credit cooperatives (RUSCCOPs) are the primary suppliers of rural credit in Ethiopia (Ameha, 2011). From the literature, the main constraints prevailing in the rural credit service of the country are the limited capacity of credit outreach, shortage of loanable funds, complicated credit application procedures that the farmers undergo to obtain credit and the requirements of high collateral (Yehuala, 2008; IFAD, 2011). Developing the loanable fund of the credit suppliers could improve credit outreach and improve credit access to the farm households. This can be addressed partly by promoting the mobilisation of savings from farm households through better deposit rates which encourage the farmers to save. In addition, promoting the coordination of MFIs to the commercial banks to acquire loanable funds at affordable interest rates and with minimal collateral can help to overcome the problem of loanable fund shortages. Government can promote and facilitate these efforts through the collaborative work of the Ministry of Agriculture and Rural Development (MoARD) and the Ministry of Finance and Economic Development (MoFED).

Extension services have important contributions in improving the current productivity levels through enhancing the management capacity of the farmers. Extension service coverage needs to be expanded so that all smallholder farmers become beneficiaries of the service. In addition to increasing the coverage of extension services, there should be a coordinated system of monitoring and evaluation of service delivery. To overcome the prevailing high levels of soil and land degradation farmers, in conjunction with extension services, need to implement soil conservation practises such as terracing, inter-cropping, planting trees and contour ploughing.

In an attempt to increase maize productivity irrigation has very important role, given the unreliable and erratic rainfall of the country. The role of low cost irrigation and water harvesting schemes should not be overlooked. The application of yield enhancing inputs will work better if used together with sufficient amounts of water required for the crop production. Promotion of infield rainwater harvesting, low cost water harvest irrigation schemes such as constructing of earth dams, river diversions and hand pumps can greatly contribute to increased maize productivity and food security in the country. Besides irrigation, the use of drought resistant seeds should be promoted through the integrated work with seed suppliers and extension services.

6.2.3 *IMPLICATIONS FOR FURTHER RESEARCH*

All the various factors that can influence the technical efficiency of the smallholder maize farmers were not exhaustively explored due to data limitations. Future studies that can address the shortcomings through incorporating all the possible factors in the production frontier and the technical inefficiency model are highly encouraged.

The scope of study is comprehensive through the inclusion of the major maize producing areas. However, regional variations in maize production were not accounted for. The possibility of regional variations could be a possible reason for the high proportion of variance due to technical inefficiencies to the total variance in the estimated model. Future studies that could account for regional variations in maize production would be more informative.

The study has some data limitations. As secondary cross-sectional data is employed, in-depth investigation about some of the variables, especially credit, off-farm income and the household head’s decision-making role was impossible. For example, information regarding credit indicates only that some farmers had received credit and others had not. The data did not provide further information as to whether all the farmers had applied for credit. Similarly, off-farm income does not show if the farmers used the off-farm income for the betterment of the maize production or for other purposes. In addition different variable combinations, such as combinations of improved seeds *versus* traditional seeds, improved seed with chemical fertilisers or without chemical fertilisers were not accounted for. Therefore, future studies that use primary data can provide better insights into the variables involved in a technical efficiency analysis of maize farmers. Panel data based studies can also provide a clear picture of the production efficiency over time.

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APPENDIX A ALTERNATIVE PRODUCTION FUNCTIONS FITTED

Linear Production Function

```
Dependent Variable: YIELD
Method: Least Squares
Date: 04/03/14   Time: 11:33
Sample: 1 438
Included observations: 438
================================================================
        Variable      Coefficient    Std. Error   t-Statistic    Prob.
================================================================
           C            2.561004     0.078195     32.75169     0.0000
         SEED          -0.000752     0.000426    -1.763653     0.0785
           N            0.004402     0.001172     3.756726     0.0002
        LABOUR          5.14E-05     7.24E-05     0.709852     0.4782
================================================================
R-squared               0.033048   Mean dependent var      2.614772
Adjusted R-squared      0.026364   S.D. dependent var      1.504574
S.E. of regression      1.484608   Akaike info criterion   3.637270
Sum squared resid       956.5630   Schwarz criterion       3.674550
Log likelihood         -792.5620   F-statistic             4.944380
Durbin-Watson stat      1.602707   Prob(F-statistic)       0.002190
================================================================
```

Cobb Douglas Production Function

```
Dependent Variable: LOGYIELD
Method: Least Squares
Date: 04/03/14   Time: 11:07
Sample: 1 438
Included observations: 438
================================================================
        Variable      Coefficient    Std. Error   t-Statistic    Prob.
================================================================
           C            0.328004     0.086793     3.779157     0.0002
        LOGSEED         0.043920     0.049188     0.892903     0.3724
         LOGN           0.023953     0.009388     2.551498     0.0111
       LOGLABOUR       -0.019654     0.036290    -0.541570     0.5884
================================================================
R-squared               0.159190   Mean dependent var      0.313842
Adjusted R-squared      0.091170   S.D. dependent var      0.406840
S.E. of regression      0.404981   Akaike info criterion   1.039136
Sum squared resid       71.18011   Schwarz criterion       1.076417
Log likelihood         -223.5709   F-statistic             2.340194
Durbin-Watson stat      1.801217   Prob(F-statistic)       0.072782
================================================================
```

Translog Production Function

Dependent Variable: LOGYIELD

Method: Least Squares
Date: 04/03/14 Time: 11:14
Sample: 1 438
Included observations: 438

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.617984	0.225018	2.746380	0.0063
LOGSEED	0.263064	0.188058	1.398847	0.1626
LOGN	0.091842	0.054552	1.683589	0.0930
LOGLABOUR	-0.453198	0.179556	-2.523990	0.0120
LOGSEED^2	-0.136399	0.073819	-1.847735	0.0653
LOGN^2	0.010341	0.018482	0.559506	0.5761
LOGLABOUR^2	0.059509	0.049594	1.199930	0.2308
LOGSEED*LOGN	-0.002389	0.024812	-0.096269	0.9234
LOGSEED*LOGLABOUR	0.090859	0.097687	0.930098	0.3528
LOGN*LOGLABOUR	-0.023058	0.018641	-1.236961	0.2168

R-squared	0.033936	Mean dependent var	0.313842
Adjusted R-squared	0.013621	S.D. dependent var	0.406840
S.E. of regression	0.404059	Akaike info criterion	1.048056
Sum squared resid	69.87692	Schwarz criterion	1.141257
Log likelihood	-219.5242	F-statistic	1.670528
Durbin-Watson stat	1.820984	Prob(F-statistic)	0.093806