DETERMINANTS OF RESOURCE USE PRODUCTIVITY AND EFFICIENCY OF GHANA'S RICE INDUSTRY

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DECLARATION

I, Emmanuel Donkor, 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.

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DEDICATION

It is my great joy to dedicate this work to my beloved late father Mr. Emmanuel Gyekye Appeaning and mother Susannah Afrakomah for their greatest contributions towards my life particularly in my upbringing.

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For I know the thoughts that I think toward you, says the Lord, thoughts of peace and not of evil, to give you a future and a hope (Jeremiah 29:11).

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ABSTRACT

Rice is one of the staple crops that has been targeted the government as a food security crop for addressing hunger and poverty issues in Ghana. However, the rice industry is performing below the climatic potential due to low productivity and efficiency levels of the rice producers. Therefore, there is high reliance on rice importation to meet the ever increasing demand. Self-sufficiency in rice can be achieved by improving the productivity and efficiency levels of rice production in Ghana. Some studies have been done on efficiency of rice production in Ghana. However, none of these studies attempted to fit a metafrontier and to estimate the technology gap ratio, and technical efficiency relative to the metafrontier. These efficiency measures are necessary to compare the performance of rice production between districts. The study therefore analyses the determinants of productivity and efficiency of rice production in Bawku Municipal and Kassena Nankana East district of Ghana using a metafrontier analysis. The dataset used for the study was obtained from the Ghana Agricultural Production Survey conducted in 2011/2012 cropping season. A sample size of 470 rice farmers comprising 350 from Kassena Nankana East and 120 Bawku farmers were used for the study.

The empirical results show that land, seed, labour and fertiliser have significant positive impacts on rice output in Kassena Nankana East district, indicating that these variables are essential inputs in promoting rice production in the district. Conversely, land, seed and fertiliser have significant positive effects on rice production in Bawku Municipal, suggesting that these inputs are necessary in enhancing rice production in the district. Generally, the variation in rice production for the study areas is primarily as a result of technical inefficiency on the part of the rice farmers. The stochastic frontier analysis further indicates that the average technical efficiency of Kassena Nankana farmers is 76.90% which is higher than that of Bawku Municipal with mean technical efficiency of 59.10%. Some of the variables of influencing the efficiency level of Kassena Nankana farmers are extension contact, access to credit, household size and row-planting. Extension contact, land renting, education and row-planting had significant negative impacts on technical inefficiency of rice farmers in Bawku Municipal while irrigation and market distance have a significant positive influence on technical inefficiency.

The results of the hypothesis test that was performed using the estimated metafrontier indicate that a distinct production frontier exists for both districts implying that separate production frontiers are needed for the two districts. The average technical efficiency scores estimated relative to the metafrontier (TE_m) for Kassena Nankana is 0.525 while the average

TE_m for Bawku is 0.587. Comparing the average TE_m of the two districts relative to metafrontier, Bawku farmers have higher efficiency scores than Kassena Nankana farmers suggesting that Bawku farmers are performing better than Kassena farmers at a regional level. The results furthermore indicate that a regional or national production frontier cannot be estimated and used to advise farmers at a district level. Hence, specific district information is needed to advise farmers on how to improve their productivity and efficiency of rice production.

Key Words: Efficiency, Determinants, Ghana, Metafrontier, Productivity, Rice, SFA, Technology Gap Ratio

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LIST OF ACRONYMS

BM	Bawku Municipal
DADUs	District Agricultural Development Units
DEA	Data Envelopment Analysis
EAs	Enumeration Areas
ECOWAS	Economic Community of West African State
GAPS	Ghana Agricultural Production Survey
GDP	Gross Domestic Product
GFSR	Global Food Security Response
IFPRI	International Food Policy Research Institute
KNE	Kassena Nankana East
MFP	Multiple Factor Productivity
MLE	Maximum Likelihood Estimator
MoFA	Ministry of Food and Agriculture
MRACLs	Multi-Round Annual Crop and Livestock Surveys
MTR	Meta-Technology Ratio
SFA	Stochastic Frontier Analysis
SFP	Single Factor Productivity
SRID	Statistical Research and Information Directorate
TE	Technical Efficiency
TE_m	Technical Efficiency Relative to Metafrontier
TFP	Total Factor Productivity
TGR	Technology Gap Ratio

CHAPTER ONE: INTRODUCTION

1.1. Background to the Study

Ghana is endowed with abundant natural resources such as land, water and good climatic conditions for agricultural production. Although the climatic conditions are favourable for agricultural production, productivity of most crops is far below their climatic potential (Boansi, 2013). For example, the estimated potential yields of crops such as rice, maize and millet are 6.5mt/ha, 6.0mt/ha and 2.0mt/ha respectively (SRID, 2013). MoFA (2013) production estimates indicated that farmers were only able to achieve 42% (2.71mt/ha) of the potential yield for rice, 28% for (1.7mt/ha) maize and 65% of yield potential (1.3mt/ha) for millet.

Agricultural land constitutes 68.1% of Ghana's total land area (MoFA, 2013). About 27.6% of the agricultural land is arable land and 0.11% of the arable land is under cereal crop production (SRID, 2013). Crop production contributes 65% to Ghana's agricultural gross domestic product (29% of the national gross domestic product) (MoFA, 2013). Cereal crops' contribution to the crop production is about 9%. Cereal commodities such as maize, rice and millet have become important crops grown by Ghanaian farmers on small scale. Among these cereal crops, maize production dominates with 64.24% contribution to the total cereal production in Ghana while sorghum, rice and millet contribute 13.85%, 12.58% and 9.33% respectively (GSS, 2012; MoFA, 2013). Rice and maize have been targeted as food security crops for addressing hunger and poverty issues in Ghana (GFSR, 2009; Liane and Abdulai, 2009) since rice and maize are the crops mostly consumed by Ghanaians.

Rice has become an important staple in Ghana, particularly in cities and towns. Rice contributes to 9% of the food requirements of Ghanaian population (Seidu, 2008). Ghana's demand for rice currently stands at 700,000mt (Savitri, 2013). However, the local Ghanaian rice farmers are able to produce only 300,000mt, leaving a deficit of 400,000mt (Savitri, 2013). Rice consumption continues to increase with population growth, urbanisation and changing consumer preferences. However, Ghana's rice sufficiency ratio is only about 30%, leaving a shortfall of 70%. Currently, Ghana spends about US$450 million every year on rice imports to meet the 70% deficit (Savitri, 2013).

This high expenditure on rice importation has become a great concern to the Government of Ghana because of its negative impact on the nation's economic development. Rice importation also exerts pressure on the foreign currency reserves of the country. As an example, almost one third of foreign exchange earned by exporting cocoa is used to pay for imported foods and other agricultural commodities like rice (MoFA, 2013). Therefore, the Government of Ghana desires to reduce rice imports by promoting domestic rice production through productivity and efficiency enhancement measures. Enhancing domestic rice production will reduce Ghana's foreign expenditure on rice importation. Promotion of domestic rice production will also enhance the output and income levels of farmers and eventually improve their standard of living through provision of employments for farmers, processors and marketers.

1.2. The Motivation and Nature of the Research Problem

The performance of Ghana's rice industry is low (Donkoh and Awuni, 2011; Oladele *et al.,* 2011; MoFA, 2011 and Boansi, 2013). Rice producers are not getting maximum returns from the resources committed to production which leads to a decline in per capita food production and low national self-sufficiency ratio of rice (MoFA, 2011 and Boansi, 2013). In 2009, Ghanaian rice producers achieved 36.92% of the potential yield and increased to 42% in 2010 but declined to 41.69% in 2012. The 5% increase in yield between 2009/2010 could be attributed to the introduction of improved rice varieties. For example, in 2009/2010 cropping season, about 2,083.8ha were devoted to the cultivation of improved rice variety like nerica rice (Donkoh and Awuni, 2011; Oladele *et al.,* 2011; MoFA, 2011 and Boansi, 2013). The inability of farmers to obtain the expected yields could be attributed to low efficiency level of resource use (Roetter *et al.*, 2008; Donkoh and Awuni, 2011).

A number of studies have been done on efficiency of Ghana's rice industry but with diverse interests. Some of the studies directed their attention towards adoption of improved rice varieties (see Donkoh and Awuni, 2011; Oladele *et al*., 2011; Wiredu *et al*., 2011 and Ragasa *et al*., 2013) whilst others focused on technical efficiency (see Abdulai and Huffman, 2000; Seidu *et al*., 2004; Seidu, 2008; Seidu, 2012; Donkoh *et al.*, 2013 and Yiadom-Boakye *et al*., 2013). Empirical evidences have proven that efficiency measures for Ghana's rice industry are low. Abdulai and Huffman (2000) indicated that average efficiency of rice farmers in northern Ghana was 63% with profit efficiency ranging between 16% and 96%. Abdulai and Huffman (2000) concluded that about 27% of potential maximum profit was lost as a result of inefficiency. Seidu *et al*. (2004) provided evidence which shows that rice farmers in the Upper East region of Ghana produced on average 34% below maximum output. Yiadom-Boakye *et al*. (2013) observed that farmers in the Ashanti region of Ghana were technically inefficient with low efficiency level of 24%.

Very few studies have attempted to compare the levels of efficiency in rice production between districts. Most of the efficiency studies on rice production usually consider rice production in a single district or pool the data together from different districts and estimate one production function using stochastic frontier analysis (SFA). Nevertheless, production environments and technologies may differ from district to district. There is a limitation to the SFA estimation procedure when technologies are not similar in an industry or when production environments are different. The metafrontier analysis (MFA) is more appropriate when heterogeneous production environments are to be compared. The metafrontier approach can estimate the efficiency of heterogeneous groups based on their distance from a common and identical frontier.

The MFA has been applied by a number of researchers (Mariano *et al*., 2010; Moreira and Bravo-Ureta, 2010) for cross country and regional level technical efficiencies. However, in Ghana, only few studies have attempted to apply the MFA for industry analysis where production technologies are different (see Dadzie and Dasmani, 2010; Onumah *et al*., 2013). There are also few applications of MFA in rice production worldwide (see Villano *et al.,* 2006; O'Donnell *et al.,* 2008; Pate and Cruz, 2007; Boshrabadi *et al*., 2008; Villano *et al.*, 2010). Most of these studies were conducted in Asia with only one study in West Africa. But no efficiency studies on Ghana's rice production have attempted to employ MFA to estimate the production frontier for different districts and estimate metafrontier production function for the rice industry. Consequently, there is very little information available on MFA application in Ghana's rice industry and Africa as a whole. The study therefore contributes to literature by bridging this knowledge gap.

Enhancing farm productivity would help to increase Ghana's per capita food production and self-sufficiency in rice. Again, information derived from the metafrontier analysis would help extension officers to make appropriate recommendations to farmers on how they can increase their rice yields. Fitting the metafrontier for the rice industry would reveal the technological gap between the districts and how far the two districts' stochastic frontiers depart from the metafrontier which the SFA fails to do. Knowledge on the technology gap would provide stakeholders in the rice industry on how technology has advanced in the industry which will help them to devise appropriate strategies to promote agricultural technologies that would enhance farmers' yield.

1.3. The Objectives of the Study

The main objective of the study was to analyse technical efficiency and to make efficiency comparisons across producers for rice production in the Upper East region of Ghana.

1.3.1. The specific objectives

In order to achieve the main objective, some specific objectives were set which include the following:

1) To estimate the technical efficiencies of rice farms in the two districts by fitting stochastic frontier model for each district. The relationship between the rice output and farm inputs would be established using a suitable functional production frontier.
2) To examine the factors affecting technical inefficiency of rice production in each district using the stochastic frontier approach.
3) To estimate the technological gap ratios and technical efficiency relative to the metafrontier. A technological gap is estimated as ratio of the output for the frontier production function for the *k*-th district relative to the potential output by the metafrontier production function. The technical efficiency relative to the metafrontier is the product of the technical efficiency relative to the district and the technology gap ratios for each district.

1.4. The Organisation of the Dissertation

The thesis is structured into six main chapters. The relevant literature related to the research was reviewed in Chapter 2. In Chapter three, the description of the study areas, sources of data, sampling procedure and socio-economic characteristics of the rice farmers were presented. Procedures that were used to address the stated research objectives are explained in Chapter 4, while in Chapter 5, the results of the study were discussed and in Chapter 6, the summary, conclusion and policy recommendations of the study were outlined.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

The chapter provides the reader with an overview of the relevant literature related to efficiency studies. The chapter starts with an introduction to agricultural productivity and its measurements. The subsequent discussion presents the concept of efficiency and its types such as technical, allocative and economic efficiencies. Different approaches of measuring efficiency are discussed, followed by a discussion on empirical application of DEA and SFA in estimating technical efficiency and a discussion of the metafrontier approach and its empirical application. The last section focused on the empirical literature to identify the determinants of agricultural productivity and efficiency.

2.2. Agricultural Productivity and its Measurement

Productivity growth in African agriculture has attracted intensive research over the last five decades as a result of its critical role in promoting economic development and growth (Bruce *et al.*, 2007). Agricultural productivity provides the basis for improving real incomes and welfare of people which results in poverty reduction (Renuka, 2003). Agricultural productivity helps to increase agricultural output sufficiently at rapid rate to meet the high demands for food and raw materials (Ehui and Pender, 2005; Bruce *et al.*, 2007).

Measurements of productivity and efficiency in agriculture have been a subject matter of concern owing to increasing demand for food resulting from population growth (Alene and Hassan, 2003). Population growth has increased the demand for land for agricultural and other purposes. Consequently, scientists are compelled to focus on improving agricultural productivity. The scientists realised that a suitable way of addressing the food insecurity problem is to increase food production per unit of land area (Lenis *et al*., 2010; Mapula *et al.,* 2011; Rangalal, 2013). Therefore, measuring existing agricultural productivity becomes a pre-requisite before any possible amendments can be taken to address food insecurity issues (Alene and Hassan, 2003; Kaur and Shekhon, 2005; Goksel and Altug, 2007; Bingxin and Shenggen, 2009; Lenis *et al*., 2010; Mapula *et al.,* 2011; Rangalal, 2013).

Some scholars have attempted to measure agricultural productivity in diverse ways based on their own perspectives. These scholars classified agricultural productivity measures into two main concepts, namely, partial and total factor productivities. The classification is based on the number of inputs under consideration. The partial productivity measure is defined as the ratio of physical output to a unit of input used in production. The partial productivity measure is sometimes called single factor productivity (SFP). There are three basic measures of partial productivity which include land, labour and capital productivities. The main advantage of estimating the partial productivity measures is that they are crucial indicators of welfare. Thus, they can be used to address a specific welfare issue. For example, labour productivity can be used as an indicator of rural welfare (which is measured as per capita income) and land productivity can be used by policy makers to address national food security issues. Despite the value of single factor productivity measures in addressing specific questions, they are incomplete indicators of agricultural productivity, because they measure the productivity of only single factor of production. Therefore, these partial productivity measures can provide a misleading indication of overall productivity when considered in isolation (Olayide and Heady, 1982; Coelli *et al*., 1998; Hulten *et al*., 2001; Alene and Hassan, 2003; Comin and Gertler, 2006; Bamidele *et al*., 2008).

The weakness of the partial productivity measures inspired other researchers to devise an appropriate way of measuring overall productivity. The newly developed total factor productivity (TFP) or multi-factor productivity (MFP) simply measured the levels and changes in the total agricultural output relative to changes in an aggregated index of multiple inputs (Christensen, 1975). Olayide and Heady (1982) expressed total factor productivity as the ratio of the value of total farm outputs to the value of the total inputs used in farm production. In TFP, farm inputs are aggregated and reflect the overall performance of agricultural production (Diewert, 1976 and Hulten *et al*., 2001). The main shortfall of TFP is that aggregating farm inputs become challenging particularly when price data is unavailable.

Understanding the relationship between productivity and efficiency in production is important. To some degree, farmers are faced with challenges in regard to issues of farm productivity and efficiency in their production process. However, many people fail to understand the difference as well as the interdependencies between productivity and efficiency. Productivity simply considers the rate of production while efficiency deals with level of production in comparison to resources and cost committed into production (Helmut, 2013). Studies have demonstrated that there is a direct relationship between productivity and efficiency which suggests that efficiency improves farm productivity (Coelli *et al*., 1998). Lack of efficiency affects all businesses. Small firms are more likely not to grow due to costs of inefficiencies regardless of the nature of their business.

The next section attempts to explain the concept of efficiency as well as the various types of efficiency.

2.3. The Concept of Efficiency

The seminal work of Farrell (1957) cannot be ignored as far as efficiency is concerned. Farrell (1975) defined efficiency as a firm's success in producing the largest possible output from a given set of inputs. Farrell (1957) further explained that this definition is accepted provided that all inputs and outputs are correctly measured. Coelli *et al*. (1998) indicated that efficiency is a relative concept. Based on this idea, Biffarin *et al*. (2010) conceptualised efficiency as the relative performance of the processes used in transforming given inputs into outputs. Efficiency is important in increasing productivity growth in developing economies where resources are limited (Ali and Chaudhry, 1990). Such economies can benefit greatly by determining the extent to which it is possible to raise productivity or increase efficiency using the existing resource base or technology (Alvarez and Arias, 2004). Therefore, understanding the various types of efficiency is crucial. Economic theory identifies at least three types of efficiency namely, technical, allocative and economic efficiencies. These measures of efficiency are discussed below with particular reference to technical efficiency.

2.3.1. Technical Efficiency

Economic literature defines technical efficiency from two perspectives; pure and relative efficiencies. The pure technical efficiency is also called the Koopmans measure of technical efficiency while relative efficiency is termed as the Debreu-Farrell measure of technical efficiency (Cooper *et al*., 2004; Greene, 2005). The Koopmans measure of technical efficiency indicates that a producer is technically efficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input required an increase in at least one other input or reduction in at least one output (Koopmans, 1951). Relative technical efficiency is when a producer is fully efficient on the basis of available evidence if and only if the performance of other producers do not show that some inputs or outputs can be improved without worsening some of its other inputs or outputs (Cooper *et al*., 2004).

Technical efficiency shows the ability of firms to employ the best practice in an industry, so that no more than the necessary amount of a given set of inputs is used in producing the best level of output (Carlson, 1968). Greene (2005) defined technical efficiency as the relationship between observed production and some ideal or potential production level. That is, the ratio of actual output to the optimal value as specified by a production frontier. Technical efficiency relates to the degree to which a farmer produces maximum output from a given bundle of inputs, or uses the minimum amount of inputs to produce a given level of output (Cooper *et al*., 2004).

2.3.2. Allocative and Economic Efficiencies

Allocative efficiency is also referred to as price efficiency and it reflects the ability of a farm to use inputs in optimal proportions, given respective prices of the inputs (Cooper *et al*., 2004). Farrell (1957) defined allocative efficiency as the choice of an optimum combination of inputs consistent with the relative factor prices. Kalirajan and Shand (1999) explained allocative efficiency as the willingness and ability of an economic agent to equate its specific marginal value product to its marginal cost. Nargis and Lee (2013) defined allocative efficiency as the adjustment of input per output to reflect a given price under a given technology. The concept of allocative efficiency encompasses the idea that society is concerned with not only how an output is produced but also with the balances of inputs given prices.

Economic efficiency is also termed as overall efficiency which is the product of technical and allocative efficiencies (Farrell, 1957). Nargis and Lee (2013) stated that even though economic efficiency is the product of technical and allocative efficiencies, it also indicates the ability of a production unit to produce a well-specified output at minimum cost. An economically-efficient firm should be both technically and allocatively efficient. The next section is a discussion of the techniques used to measure efficiency level

2.4. Efficiency Measurement

Efficiency measurement techniques can be broadly categorised into parametric and non-parametric approaches as shown in Figure 2.1. The parametric approach is subdivided into two groups: frontier methods and non-frontier methods. The frontier method includes the stochastic frontier analysis while the non-frontier method includes simple regression analysis. The non-parametric approach can be also grouped into non-frontier methods and frontier methods. The frontier method encompasses the data envelope analysis while non-frontier method consists of the use of index number. The main difference between the parametric and non-parametric is that the parametric approach specifies a particular functional form for the production or cost function while the non-parametric does not (Vasilis, 2002). Also, the parametric approach relies on econometric techniques which include stochastic frontier analysis and simple regression analysis (Kumbhakar and Bhattacharyya, 1992) while the non-parametric approach uses mathematical programming techniques. The most commonly used parametric approach is the stochastic frontier analysis (SFA) and the non-parametric approach is the data envelopment analysis (DEA). The next sections are devoted to discussing the DEA and SFA.

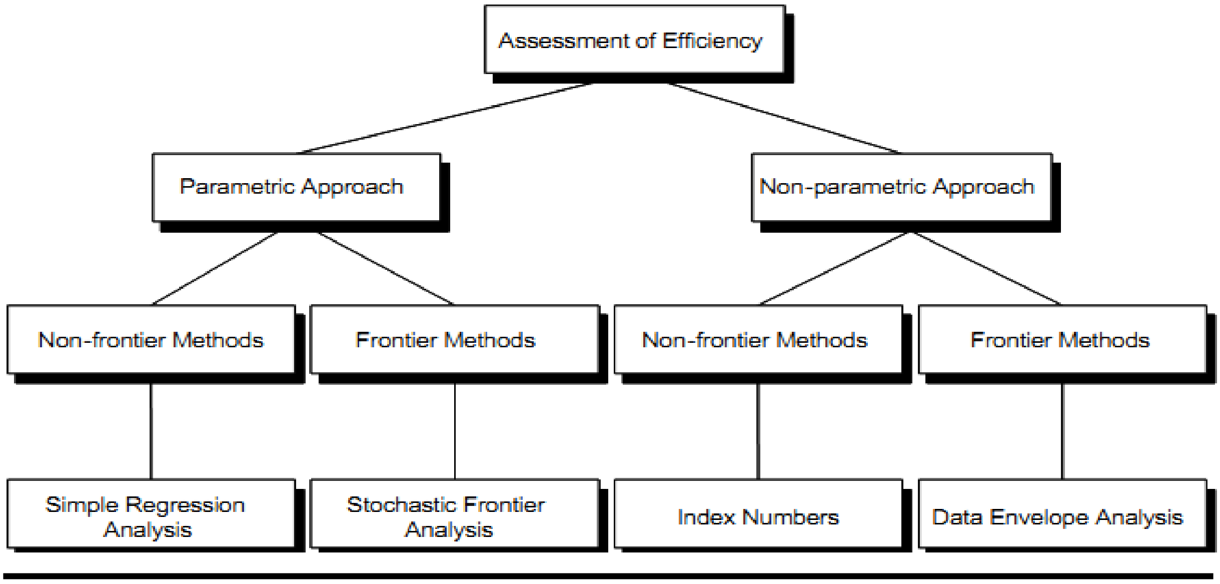

Figure 2.1. Classification of efficiency measurement techniques
Source : Vasilli (2002).

2.4.1. Data Envelopment Analysis (DEA)

Based on Farrell's (1957) seminal work, Charnes *et al*. (1978) were the first to introduce the data envelopment approach to estimate efficiency. Since its introduction, the approach has become the foundation for most subsequent developments in the nonparametric estimation approach of technical efficiency (Charnes *et al*., 1978). The DEA uses mathematical linear programming techniques in order to find the set of weights for each firm that maximises its efficiency scores, subject to the constraints that none of the firms has an efficiency score greater than 100% at those weights (Charnes *et al*., 1978 and Vasilli, 2002). The weights would vary for each firm in such a way that each individual firm's performance compares in the most favourable way with the remaining firms. The model would reject the solution for a particular firm if the set of weights that maximises its relative performance generate scores greater than 100% for any other firm. In this way, DEA builds up an envelope of observations that are most efficient at each set of weights. A firm is said to be inefficient if its score is less than 100% at the estimated set of weights that maximises relative efficiency. For an inefficient firm, at least one other firm will be more efficient given the estimated set of weights. These efficient firms are known as the peer group for the inefficient firm (Vasilli, 2002).

The main strength of DEA is that it does not require a prior specification of the functional form for the production frontier. Furthermore, DEA does not require any specific assumptions about distributions of error terms. The main weakness of DEA is that it attributes any deviation of an observation from the frontier to inefficiency which implies that there is no provision for statistical noise or measurement error in the model (Ray, 2004; Coelli *et al*., 2005; Heady *et al*., 2010).

2.4.2. Stochastic Frontier Analysis (SFA)

The stochastic production frontier approach proposed by Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977) is motivated by the idea that deviations from the production frontier might not be entirely under the control of the firm being studied. Under the interpretation of the deterministic frontier, for example, an unusually high number of random equipment failures, or even bad weather might ultimately appear to the analyst as inefficiency. Worse yet, any error or misspecification of the model or measurement of its component variables, including output could likewise translate into increased inefficiency measures which is an unattractive feature of any deterministic frontier specification. A more appealing formulation holds that any particular firm faces its own production frontier, and that frontier is randomly placed outside the control of the firm. Therefore, measurement error, any other statistical noise, and random variations are added to the deterministic frontier (Battese and Coelli, 1993) and this kind of production frontier is called stochastic frontier. Stochastic frontier analysis (SFA) uses mainly the maximum likelihood estimation technique to estimate the frontier function in a given sample (Vasilli, 2002).

The main strength of SFA is its ability to separate error components (thus, measurement error and statistical noise) from inefficiency components. Separate assumptions are made concerning the distributions of the inefficiency and error components, potentially leading to more accurate measures of relative efficiency (Farrell, 1957; Battese and Coelli, 1993). However, the stochastic frontier model is not devoid of any problem. The main weakness is that there is generally no a priori justification for the selection of any particular distributional form for the inefficiency component of the error term (Greene, 1990).

Some authors (see Coelli *et al*., 2002; Ogundari, 2008; Aung, 2011; Shamsudeen *et al*., 2011; Abatania *et al*., 2012, among others) have tried to employ SFA and DEA to estimate technical efficiency in their empirical studies. The review of these empirical studies is discussed in the section below.

2.4.3. Empirical Application of DEA and SFA in Efficiency Estimation

The application of the DEA in estimating technical efficiency is becoming common in agricultural research. Coelli *et al*. (2002) applied DEA to estimate technical, allocative and scale efficiencies of rice cultivation in Bangladesh. They estimated the average technical, allocative and scale efficiencies for dry season rice production to be 69%, 81% and 95% respectively. Rios and Shively (2005) examined the relationship between farm size and efficiency measures for coffee farms in Vietnam using a two-stage DEA approach where technical efficiency was estimated with a linear programming techniques and the estimated technical efficiency scores were regressed on farm size and other socio-economic characteristics of the farmers. The result shows that on average, large farms were more technically efficient than smaller farms. The mean technical efficiencies for large and small farms were 89% and 42% respectively. Abatania *et al*. (2012) applied the DEA to estimate the farm household technical efficiency in Northern Ghana. They estimated the technical efficiency to be 77%.

Other studies (see Ogundari, 2008; Aung, 2011; Shamsudeen *et al*., 2011; Seidu, 2012; Donkoh *et al*., 2013; Yiadom-Boakye *et al*., 2013) employed SFA to estimate technical efficiencies due to DEA's inability to decompose the error term into measurement error and inefficiency effect. Ogundari (2008) analysed technical efficiency of small scale farmers in Nigeria using the translog stochastic frontier approach. The average technical efficiency was 75% which suggests that 25% of rice yield was lost due to inefficiency. Aung (2011) employed the Cobb-Douglas stochastic frontier to estimate technical efficiency of rice farms in Myanmar. The average technical efficiency was estimated to be 84%, implying that 16% of potential maximum output was lost owing to technical inefficiency.

The SFA has been applied in Ghanaian agricultural sector. Shamsudeen *et al.* (2011) applied the Cobb-Douglas stochastic frontier analysis to examine the technical efficiency of groundnut production in Ghana. They estimated the technical efficiency to be 70%. Seidu (2012) used translog stochastic frontier analysis to analyse the technical efficiency of smallholder paddy rice farms in the Upper East region of Ghana. The rice farmers were found to be technically inefficient with average efficiency level of 66%. Donkoh *et al*. (2013) applied the translog stochastic frontier analysis to estimate the technical efficiency of rice farms under irrigation scheme in the Upper East region of Ghana. They estimated the average technical efficiency to be 81%. Similarly, Yiadom-Boakye *et al*. (2013) used the Cobb-Douglas stochastic frontier analysis to examine gender effect on resource use and technical efficiency among rice farmers in Ashanti of Ghana. They found that the females were producing at high inefficiency level. The overall average technical efficiency (24%) was found to be relatively low.

It is also necessary to provide the brief discussion on inefficiency in agricultural production and how it has been empirically estimated in the next section the concept of inefficiency in agricultural production is discussed.

2.4.4. Explaining Inefficiency

Jondrow *et al*. (1982) indicated that inefficiency measures the shortfall of output from its maximum possible value given by a stochastic frontier. Erkoc (2012) suggested that inefficiency is the failure of firms to produce at the "best-practicing" frontier. Therefore, inefficiencies cause resource productivity to fall below its potential. Literature has identified two main basic procedures of estimating inefficiencies in production. They include the two-stage and single stage methods. The two-stage method is normally employed in the DEA estimation approach of technical efficiency (Larson and Plessman, 2009). Firstly, the efficiency scores are estimated using a linear programming approach. The second stage involves regressing the efficiency scores on variables that are expected to influence efficiency where a censored model (Tobit) is employed due to the fact that efficiency scores assume values between zero and one (Jondrow *et al*., 1982). Past research (Aye and Mungatana, 2010) used DEA to calculate the efficiency scores and used the Tobit regression to analyse the factors affecting efficiency. In most efficiency studies where two-stage procedure was used, efficiency scores were used as a dependent variable (Larson and Plessman, 2009; Duy, 2012; Piya and Yagi, 2012). Piya and Yagi (2012) applied a similar approach but in the second stage, multivariate regression model was employed to examine the factors that influence efficiency because all the efficiency scores were greater than zero.

Furthermore, empirical studies (Aigner *et al*., 1977; Meeusen and van den Broeck, 1977; Kalirajan, 1991; Sharma *et al*., 1996; and Nyagaka *et al*., 2009) have used the two-stage method in examining inefficiency with the SFA. The two-stage procedure involves estimating the technical efficiency scores using the SFA. The second stage specifies the technical efficiency scores or inefficiency scores (thus, one minus technical efficiency scores) as a function of farm specific variables using either the Tobit or multivariate regression model depending on whether the predictor is censored or not. Aigner *et al*. (1977), Meeusen and Van den Broeck (1977), Kalirajan (1991), Sharma *et al*. (1996) and Nyagaka *et al*. (2009) applied the two-stage SFA to analyse determinants of technical efficiency. In the second stage, the efficiency scores were regressed on some socio-economic and institutional variables using a two-limit Tobit model because technical efficiency scores ranged between zero and one depicting the upper and lower limits respectively. A similar approach was employed by Nyagaka *et al*. (2009). The two-stage method is easy to apply. There is however a major drawback. Most of the SFA models assume that efficiency is independently identically distributed while a second stage regression assumes that efficiency is dependent (Caudill and Ford, 1993 and Wang and Schmidt, 2002). Caudill and Ford (1993) and Wang and Schmidt (2002) showed that this violation of the assumption renders biased estimates that can be very severe.

To overcome this problem of biased estimates, Huang and Liu (1994) and Battese and Coelli (1995) proposed a single-stage method. In a single-step procedure, the parameters of the production function are simultaneously estimated with those of an inefficiency model in which inefficiency effects are specified as a function of other variables (Amaza *et al*., 2006; Chirwa, 2007). Arnade and Trueblood (2002) indicated that the one-step procedure relies on computationally intensive estimation technique which cannot always distinguish between types of inefficiency. The single-stage method is mainly used in the stochastic frontier estimation of technical efficiency.

Sometimes production environment is heterogeneous and therefore, SFA and DEA might not be able to estimate the efficiency in this environment accurately. A metafrontier analysis which is an extension of SFA and DEA is appropriate in this case. Therefore, a brief discussion is presented in the next section on the metafrontier to provide an overview of what metafrontier analysis seeks to do.

2.4.5. Metafrontier Analysis

Stochastic frontier analysis and data envelopment analysis can sometimes produce inaccurate results if data samples from different production environments are considered. To address this heterogeneity problem, Battese *et al*. (2004) introduced the metafrontier approach which quantifies the efficiency of heterogeneous groups based on their distance from a common and identical frontier. The metafrontier analysis is an extension of the SFA and the DEA. The metafrontier analysis was first developed by Hayami (1969), and Hayami and Ruttan (1970) and latter, Battese and Rao (2002), Battese *et al*. (2004) and O'Donnell *et* *al*. (2008) built upon the metafrontier approach introduced by Hayami (1969) and Hayami and Ruttan (1970).

Metafrontier function is a common underlying production function that is used to represent the input-output relationship of a given production sector (Lau and Yotopoulos, 1989). The basic meta-production function concept proposes an assumption that all groups in an industry have potential access to the same technology. Each producer may decide to operate on a different part of the metafrontier depending upon circumstances such as the natural endowments and the economic environment (Lau and Yotopoulos, 1989). A meta-technology gap ratio (MTR) is derived from the metafrontier which is defined as the ratio of a specific farmer's output from a particular group to the meta-frontier output with the same inputs (Saeedian *et al*., 2013). Higher MTR denotes less technology gap between the individual frontier and metafrontier. MRT assumes values between zero and one. When MTR is equal to one, then the estimated individual frontier is placed on metafrontier. The MTR gives the productivity potential for the rice production given the maximum potential in the rice industry as a whole (as represented by metafrontier function). The MTRG is also significant in explaining the ability of farmers in one locality to compete with other in different area within the rice industry.

There are few studies (see Battese *et al*., 2004; Mehrabi *et al*., 2006; Mehrabi *et al*., 2007; Mehrabi *et al*., 2008; Villano *et al.*, 2010; Farnaz and Bakhshoodeh, 2013) that have applied the metafrontier approach to estimate technical efficiency particularly in the rice sector. In the agricultural sector, Mehrabi *et al*. (2006) applied the metafrontier approach to estimate the technical efficiency of wheat farmers in the Kerman province with translog production function. Mehrabi *et al*. (2007) and Villano *et al.* (2010) also employed Battese *et al*. (2004) procedure to compute technical efficiencies of different varieties of agricultural crops. The results stressed the need to account for differences in frontiers imposed by different tree varieties. Mehrabi *et al*. (2008) examined technical efficiency and environmental-technological gaps in wheat production in Kerman province of Iran. They observed that wheat farms differed in technical efficiencies, environmental-technological gaps and input use. Mehrabi *et al*. (2008) also observed that environmental-technological gap ratios varied greatly between wheat farms and across regions. The result of the study showed that average technical efficiencies were similar across regions but differed in the extent of variability among farms within each region.

Villano *et al*. (2010) examined factors that contribute to metafrontier production by most farmers in Iran at the long run. The study concluded that physical conditions, environmental constraints, access to capital and production cycle span were the most important indicators that should be considered, if farmers desire to reach the metafrontier. Saeedian *et al.* (2013) applied the concept of metafrontier to examine the association between meta-technology ratios (MTR) and varietal differences of date palms. The results demonstrated that the estimated average values of technical efficiency for pooled frontier, varietal group frontiers and metafrontier across all data were 0.56, 0.54 and 0.0014 respectively. Farnaz and Bakhshoodeh (2013) applied the metafrontier approach to estimate technical efficiency and sustainability-technology gap ratio. They categorised the study areas into three namely, sustainable, relatively sustainable and unsustainable. The result of the study indicated that technical efficiency and sustainability-technology gap ratio of relatively sustainable regions are higher than those of the unsustainable regions. It was concluded that farmers in those areas could reduce the gap between technology and agricultural sustainability levels through achieving meta-technology that is compatible with sustainable agriculture.

Manoj *et al*. (2013) applied DEA metafrontier approach to compare the technical efficiencies and technology gap ratios of irrigated and rainfed rice farming systems. The study concluded that irrigation shifts the rice sector production frontier to a higher level. In addition, Manoj *et al*. (2013) employed a second stage bootstrapped truncated regression which showed that efficiency differences between two regions were explained by the timely availability of the water to a significant extent. The study suggested that future sectoral policies should be designed to address efficiency enhancing factors such as irrigation, quality seed, land ownership and scale and female labour participation.

2.5. Factors Affecting Agricultural Productivity and Efficiency

The aim of this section is to provide a discussion on the determinants of agricultural productivity and efficiency. The determinants are group into production factors and inefficiency factors. The inefficiency variables are socio-economic and institutional factors that affect farm management operations. The discussion begins with the production factors and followed by the inefficiency variables.

2.5.1. Production Factors

In this section, literature on factors affecting production of rice are reviewed. Factors of production are technical factors that promote agricultural productivity. The factors of production include fertiliser application, labour, access to high quality rice seed, pesticides application and land.

2.5.1.1. Fertiliser Application

To maximise the gain in productivity of rice farmers in favourable environments, farmers need to apply mineral fertilisers. However, the distribution of fertilisers, access and affordability by small holders remain a fundamental policy challenge in most African countries. Due to the high cost and limited accessibility to fertilisers by smallholders, rice yield levels are not maintained due to declining soil fertility levels (Seidu, 2008). Productivity of rice systems can be increased by enhancing the efficiency of fertiliser use (Buah *et al*., 2011). Even though, yield responses and incentives for fertiliser application in irrigated rice production in Sub-Saharan Africa appear to be similar to that of Asia, the average fertiliser application rate in Sub-Saharan Africa was only 13kg/ha in 2008, as against developed countries of 94kg/ha (Africa Rice, 2009). The low average level of fertiliser application rate demonstrates a considerable scope for potential yield increase (Buah *et al*, 2011).

Empirical study by Bashir *et al.* (2010) indicated a positive relationship between fertiliser use and wheat yield. Bashir *et al.* (2010) indicated that yield of wheat would increase by 0.114% when fertiliser use increased by 1%. Similarly, previous studies (see Abdulai and Huffman, 2000; Ogundari *et* al., 2010; Seidu, 2012; Donkoh *et al*., 2013; Yiadom-Boakye *et al*., 2013) observed a positive relationship between rice output and fertiliser. However, Aung (2011) observed a contradictory result which shows that fertiliser application had a negative effect on rice farmers in Myanmar. Aung (2011) failed to give possible reasons for the unexpected effect of fertiliser.

2.5.1.2. Access to High Yielding Rice Seed

Seidu (2008) observed that the release and cultivation of early maturing and high yielding lowland and/or upland rice varieties moved rice production in the Lawra district in the Upper East region of Ghana into new frontiers (Seidu, 2008). These improved rice varieties have contributed to increasing rice productivity in the last two years (Buah *et al.,* 2011). Sibiko *et al.* (2013) found that seed had a significant positive effect on bean productivity. Sibiko *et al.* (2013) realised that a percentage increase in the quantity of seed sown increased bean yield by 38.5%. Mariano *et al*. (2010) also showed that Philippine farmers who planted high-quality rice seeds obtained 10% rice output higher than those who used the local seeds. Some studies have also established a positive association between the use of improved crop varieties and productivity (see Amaza *et al.*, 2006; Shehu and Mshelia, 2007; Tanko and Jirgi, 2008; Yusuf *et al*., 2009; Adeyemo *et al*., 2010; Mbam and Edeh, 2011; Piya and Yagi, 2012).

2.5.1.3. *Pesticide Application*

One of the factors that can contribute to total crop failure is the occurrence of diseases and pests. High percentage losses in rice production are attributed to the attack of pests such as birds, mammals and insects. These pests attack rice at various stages of development. Farmers also encounter infestation of fungal diseases such as blast (*Pyriculla oryzae*) which reduce yield drastically (Kranjac-Berisavljevic *et al.,* 2003). Some studies (Bashir *et al.*, 2010; Payi and Yagi, 2012) have been conducted on the effects of pest and disease control on crop yields including rice yields. For example, Bashir *et al.* (2010) observed a positive relationship between the use of plant protection and yield. Bashir *et al.* (2010) observed that as the use of plant protection on farms increased by 1%, wheat yield would increase by 0.0154%. Similarly, Payi and Yagi (2012) observed a significant positive effect of use of agro-chemicals such as herbicides and insecticides on rice yield in Nepal. These inputs had a greater impact on increasing rice production. Ogundari *et al.* (2010) found that herbicides application influenced positively rice output in Nigeria. Contrarily, Ndayitwayeko and Korir (undated) found that pesticide application in rice production showed a significant negative effect on rice yield. Ndayitwayeko and Korir (undated) indicated that a percentage increase in pesticide application decreased rice production by 23%. Ndayitwayeko and Korir (undated) attributed the negative and unexpected sign of pesticides to over-application of the pesticides on rice fields to control diseases**.**

2.5.1.4. *Labour*

Labour plays a critical role in agricultural production especially in the rice sector which is labour intensive. In most parts of Sub-Saharan Africa, labour forces are needed for land preparation activities, seeding, weeding, pest control, harvesting and transportation. Labour is mostly measured in man-days in most empirical studies. Agricultural labour is categorised into family and hired labour. Family labour is provided by farmers' household while hired labour is an extra labour that farmers pay to work on their farms. The improvements in efficiency of human labour resource have affected productivity. Empirical evidences (see Akinbile and Akinwale, 2006; Saka and Lawal, 2009; Seidu, 2008, 2012; Ismatul and Andriko, 2013; Yiadom-Boakye *et al*., 2013) indicate that labour significantly influences agricultural productivity and efficiency. For example, Ismatul and Andriko (2013) observed that labour had a significant positive effect on rice production. Ismatul and Andriko (2013) found that if labour use increased by 10%, rice production would increase by 5.51%. Similar findings were observed by Akinbile and Akinwale (2006), Ogundari *et al*. (2010), Seidu (2008: 2012) and

Yiadom-Boakye *et al*. (2013) who established a significant positive relationship between labour use and rice yield. Conversely, Saka and Lawal (2009) observed that labour decreased the productivity of rice farmers in southwest Nigeria but the author failed to provide reason for the negative effect of labour on rice output.

2.5.1.5. Land Area

The area of land under cultivation plays a significant role in agricultural production particularly in the rice sector. Ogundari *et al*. (2010) found that land area had a significant positive effect on rice output in Nigeria. Ogundari *et al*. (2010) further stated that land showed the greatest elasticity implying that land is an important input in the rice production process. Similarly, Mariano *et al*. (2010) showed that land was the highest contributor to rice production in Philippines with elasticity of output ranging from 0.50. Islam *et al.* (2012) mentioned that increasing land area under rice cultivation in Bangladesh would contribute significantly to increasing rice output. Other similar other studies (Abedullah *et al*. 2007; Ogundari *et al*., 2010; Donkoh *et al*., 2013; Yiadom *et al*., 2013) established a significant positive relationship between rice output and land area implying that an increase in land area promotes rice production.

2.5.2. Inefficiency Factors

The factors that contribute to inefficiency are of interest since the inefficiency effects are needed to determine the level and variability of production. Inefficiency in production can be the result of institutional and socio-economic factors. The following factors were found in literature to influence the level of technical efficiency.

2.5.2.1. Institutional Factors

The institutional factors that influence efficiency of rice production include land tenure, access to market, access to credit, access to extension services and education.

2.5.2.1.1. Land Tenure

Empirical studies have shown that land tenure systems influence agricultural efficiency. Some studies (Iqbal *et al*., 2001; Anyaegbunam *et al*., 2010; Abdulai *et al*., 2011; Oladele *et al.,* 2011) have shown that farmers operating under fixed-rent tenancy are more likely to increase productivity than owner-operators. These studies explained that tenants who pay rents tend to use relatively more productive resources which have the potential of increasing productivity and hence, increases farm profit which aids the tenants to pay land rent. Other researchers (Gavian and Ehui, 1999; Ali, 2009) have observed a significant negative effect of sharecropping on agricultural productivity. Gavian and Ehui (1999) and Ali (2009) explained that sharecropping system discouraged farmers from investing intensively in productivity-enhancing measures due to the fact that crop outputs are shared between them and land owners.

2.5.2.1.2. Education

Education either increases prior access to external sources of information or enhances the ability to acquire information through experience with new technology. That is, it may be a substitute or a complement to farm experience in agricultural production (Weir and Knight, 2000). Schooling enables farmers to learn new farm technologies more efficiently (Baerenklau, 2005). Education which was measured in terms of number of years of schooling exerted a positive effect on the technical efficiency of swamp rice farmers in Nigeria (Idiong, 2007). Idiong (2007) argued that education enhances the acquisition and use of information on improved technology. Similarly, Tanko and Jirgi (2008) observed a significant positive effect of education on rice farmers' technical efficiency by decreasing the degree of inefficiency. Duy (2012) mentioned that education decreased technical inefficiency of rice production. According to Duy (2012), education enhances the acquisition and utilisation of information on improved technologies as well as their entrepreneurship.

Bravo-Ureta and Evenson (1994), and Ajibefun and Aderinola (2003) reported a weak association between agricultural productivity and education for eastern Paraguay and southwest Nigeria respectively. Azhar (1991) supported this finding by indicating that elementary education (4-6 years of schooling) did not have much effect on agricultural productivity in traditional farm settings. Mohammed *et al*. (2013) found education to negatively influence technical efficiency. Mohammed *et al.* (2013) explained that educated households are less efficient if education increases farmers' returns from non-farm activities, thereby reallocating attention or management from farm to non-farm activities.

2.5.2.1.3. Access to Market

Empirical studies (see Bagamba *et al*., 2007; Aung, 2011; Aye and Mungatana, 2012; Duy, 2012) found that proximity to market affects technical efficiency. Proximity to market increases farmer's access to factor inputs which enable farmers to buy and apply inputs on time as well as selling their farm products. Bagamba *et al*. (2007) observed that households located nearer factor markets showed a higher technical efficiency than those located in remote areas. According to Bagamba *et al*. (2007), proximity to factor market increased farmer's ease of accessing inputs and extension trainings from which they could attain information and skills for better crop management to raise productivity. Farmers who have poor access to markets have less opportunity to engage in profit maximising activities compared to those farmers who had access to markets and are located near cities (Aung, 2011).

Aye and Mungatana (2012) indicated that market distance was positively related to the technical inefficiency of farms. They indicated that the farms located closer to the markets are technically less inefficient than the farms located away from the market. They further explained that farther markets might not only increase production cost but also affects farming operations, especially timing of input application. Duy (2012) indicated that households in remote areas were more likely to have lower technical efficiency levels and rice yields. Poor communication and transport facilities may lead to lower efficiency levels of households further away from market centres. Other studies found similar results (DeSilva *et al*., 2006; Larson and Plessman, 2009). Conversely, Mohammed *et al*. (2013) found that distance to the input market negatively affected technical efficiency. They indicated that an increase in distance to the market by one kilometre would lead to a decrease in farm's technical efficiency by 0.8%. They further attributed it to the fact that farms were located far from the market and hence, more costs were incurred to transport farm inputs from the market to the farm.

2.5.2.1.4. Access to Credit

Farmers' may be unable to raise sufficient funds to invest in farm technology (because of lack of capital, limited access to credit, or temporary cash flow problems). Limited and untimely availability of credit to farmers affect timely delivery, availability of essential services and application of inputs (Adeyemo *et al.,* 2010). These funds would be needed to pay extra labour require in technology adoption during peak-periods of normal field operations (Mbam and Edeh, 2011). Nurgartono (2005) indicated that access to financial markets facilitated the adoption of technology such as fertiliser and pesticides. Nuryartono (2005) further explained that additional funds from credit markets can be used to invest in rice production, principally by adopting new technologies. Nuryartono *et al*. (2005), Stefan *et al.* (2011) found access to microfinance to increase efficiency. Nuryartono *et al*. (2005), Stefan *et al.* (2011) indicated that those farmers who did not have agricultural microfinance tended to have higher technical inefficiency level than their peers. Nuryartono *et al*. (2005), Stefan *et al.* (2011) attributed this to shortage of working capital due to the increasing price of inputs as well as the low returns to farm produce resulted in high inefficiency. Nuryartono *et al*. (2005), Stefan *et al.* (2011) also explained that credit helps farmers to increase farm revenue while lack of credit decreases the efficiency of the farmers by limiting their adoption of high yielding varieties and ability to acquire information for increased productivity. Duy (2012) indicated that access to credit reduced technical inefficiency and that farmers who had credit access were more likely to increase technical efficiency in rice production. On the other hand, Seidu (2008) observed that credit amount used by farmers did not have any significant contribution to technical efficiency of rice farmers in the northern region of Ghana but no possible reason was provided by the author.

2.5.2.1.5. Extension Services

There is a wide gap between potential and actual crop yields observed by smallholder farmers in developing countries, primarily because of poor extension services delivery (Seidu, 2012), institutional and cultural constraints and the farmers' long history of adaptation to traditional practices. These limitations restrict farmers' ability and willingness to fully adjust their input levels (Xu and Jeffrey, 1998; Yusif *et al.,* 2009). Extension services had a significant positive effect on efficiency of rice production in Northern Ghana (Seidu, 2008). Seidu (2008) explained that with the assistance of extension agents, farmers are able to use modern techniques in rice production which involves land preparation, planting, application of agrochemicals and harvesting. Hence, farmers are able to reduce inefficiencies which tend to increase productivity.

National rice output of Nigeria increased due to active extension service (Adeyemo *et al.,* 2010). Kalirajan (1991) explained that in southern India, farmers' limited access to extension services and misunderstanding of farm technologies were the main contributors to the disparity between the actual and potential yields among farmers. In Zimbabwe, access to agricultural extension services increased farm productivity by 15% (Owens *et al*., 2001). In Kenya, the value of crop productivity per acre for farmers who received extension services increased productivity by 80%. In Tanzania, farmers who received agricultural education through farmer field school increased their farm productivity by 23%. These statistics prove the relevance of effective and efficient extension services in enhancing agricultural productivity and efficiency. Some other studies have also proven a significant positive relationship between extension services and agricultural productivity (Ajibefun and Aderinola, 2003; Tanko and Jirgi, 2008; Onyenweaku and Ohajianya, 2009 and Piya and Yagi, 2012).

2.5.2.2. Socio-economic Characteristics

In this section, the effects of socio-economic variables that influence efficiency in agricultural production are presented. The socio-economic variables include age, gender and household size.

2.5.2.2.1. Age

There are diverse arguments and discussions concerning the correlation between age and agricultural productivity. Some researchers (Tolga *et al*., 2009 and Dhehibi *et al*., 2011) argued that age can be used as a proxy for farming experience and therefore older farmers can operate efficiently. However, others believe that younger farmers are more productive and willing to adopt new technology because of their less risk averse nature (Ayoola *et al*., 2010 and Wiredu *et al*., 2010). For instance, Tolga *et al*. (2009) observed that age had a significant negative impact on technical efficiency. The result of the study showed that younger farmers were more efficient than older ones. They attributed this result to the fact that older farmers are more likely to have contacts with extension agents but been less willing to adopt new practices and modern inputs. Similarly, Ayoola *et al*. (2010) observed a negative influence of age on rice production which supports the assertion that older rice farmers have less vigour for farming. Conversely, Wiredu *et al*. (2010) used age of farmers as a proxy for farming experience in rice production and observed a positive effect on rice yield. Wiredu *et al*. (2010) indicated that experience in rice cultivation can represent accumulated knowledge in rice production which can be useful for proper management of the rice fields to ensure higher yields. Similarly, Dhehibi *et al*. (2011) observed that age was positively correlated to total factor productivity of cereal production in Tunisia.

2.5.2.2.2. Gender

Due to cultural and religious disparities, gender plays a significant role in enhancing agricultural productivity in Africa. For instance, Msuya *et al*. (2008) established a positive association between rice yield and gender. They found that male farmers were more efficient in rice production. The possible reason could be probably due to the fact that rice production is very laborious and therefore men are more likely to engage in rice production. Wiredu *et al*. (2010) found a similar result that gender was an important determinant of yield among the rice farmers. Wiredu *et al*. (2010) explained that rice yields increased when farms are managed by male farmers. Yiadom et al. (2010) observed that inefficiency was less for male farmers than the female counterparts. This finding is also consistent with Due and Gladwin (1991), and Gladwin and McMillan (1989) who emphasised that the relative inefficiency of women rice farmers is due to limited access to agricultural extension and finance that disproportionately affect them.

2.5.2.2.3. Household Size

Most of the households in farming communities in West Africa are relatively large. These households provide farmers with family labour for agricultural production. Evidences from some studies (Msuya *et al*., 2008; Mariano *et al*. 2010) have demonstrated that household size contributes greatly to rice productivity. For example, Msuya *et al*. (2008) observed that household size positively influenced rice production. They further explained that households with big families are more technically efficient because they strive to achieve higher output to meet the subsistence requirements. Large families have a greater labour endowment needed implement management decisions which therefore improves timeliness of agricultural production. Conversely, Mariano *et al*. (2010) found that large household size tended to increase inefficiency in rice production in Philippines. This finding suggests that farmers with larger household sizes tend to dissipate most of their resources on the upbringing and education of their children rather than investing in rice production.

2.6. Summary and Conclusion

Agricultural productivity growth has attracted intensive research over the last five decades. An improvement in productivity is sure to improve the welfare of the people of Africa. Increased efficiency is an important factor of productivity growth especially when resources are scarce and waste of inputs should be avoided. Producing maximum outputs using minimum inputs is a purely technical problem. Efficiency literature identifies a number of efficiency types to improve productivity, namely technical, allocative and economic efficiency. This study focuses on technical efficiency since farmers should first aim at producing maximum output using minimum inputs. Once a wasteful use of resource is overcome (technical efficiency is obtained), a farmer can continue to identify optimal input combinations (allocative efficiency). A number of estimation techniques are suggested in the literature that allows for the estimation of technical efficiency. The most commonly used techniques are the non-parametric mathematical programming approach namely, the data envelopment analysis (DEA) and the parametric stochastic frontier analysis (SFA). Both techniques have advantages and disadvantages. The choice of DEA and SFA relies on the specific characteristics of the problem. This research would use SFA to estimate farmers' production frontier and technical efficiency. SFA is able to account for statistical noise (i.e. measurement error and random errors). The SFA model used in the study is Battese and Coelli's (1995) single-step procedure that allows for the estimation of a production frontier and the sources of inefficiency in a single step. Information about the sources is necessary indicators of which aspects of farm characteristics can be addressed to improve technical efficiency.

Although SFA provides very useful information on technical efficiency and the sources of inefficiency, it is unable to account for the effect of heterogeneous technologies. Data collected from two localities require the estimation of two separate production frontiers because of heterogeneous technologies. Comparisons between the two localities can only be made if a common production frontier is known. Through metafrontier analysis, a meta-production function is estimated which envelops the estimation of the production frontiers of the heterogeneous technology sets. The metafrontier is therefore a common production frontier that can be used for comparison purposes. The meta-technology gap ratio (MTR) estimated from the metafrontier is an indication of how well the farmers in one locality are doing relatively to the common production frontier.

CHAPTER THREE: DATA AND CHARACTERISTICS OF THE RESPONDENTS

3.1. Introduction

In this chapter, an overview of the study areas (Kassena Nankana East and Bawku Municipal of the Upper East region of Ghana) in terms of geographical location, climatic environments and rice production is presented. The discussion focused on the procedures for data collection and the sampling techniques employed in the study. Agricultural production including rice cultivation is also discussed. The characteristics of the respondents sampled for the study is subsequently discussed. The farmers' characteristics are grouped into socioeconomic, institutional and technical factors employed by rice farmers in their production. Socioeconomic characteristics include age, gender, marital status, education, farming experience and land tenure systems while the institutional variables include access to credit, extension services, irrigation and proximity to market centre. The technical factors are production factors such as farm size, fertiliser, pesticides, labour and quantity of seed employed during production.

3.2. Study Area

3.2.1. Location and Physical Environment of Ghana

Ghana is located within West Africa and lies within latitude 4^{o} 44'N and 11^{o} 11'N and 3^{o} 11'W and 1^{o} 11'E longitude as shown in Figure 3.1. The total land area of Ghana is approximately 238500km^2 (Tara, 2013). The country shares boundaries with Cote-d'Ivoire to the west, and Togo to the east and to the north with Burkina Faso. The overall topography is low and gently undulating with slopes of less than one percent. Despite the gentle slopes, approximately 70% of the land is susceptible to significant erosion (Aquastat-Ghana, 2005; Tara, 2013).

Figure 3.1. Ghana within West African Countries (ECOWAS).
Source: Adapted from Google Map (2014).

For administrative purpose, Ghana is divided into 10 regions. These regions are Greater Accra, Central, Western, Eastern, Volta, Ashanti, Brong Ahafo, Northern, Upper East and Upper West as shown in Figure 3.2. Greater Accra is the administrative capital of Ghana. Northern, Upper East and Upper West regions are considered as northern part of Ghana while the remaining seven regions are regarded as southern part.

Figure 3.2. Administrative Map of Ghana.
Source: Adapted from Google Map (2014)

The Upper East region of Ghana is located in the north-eastern corner of the country between longitude 00^{o} and 10^{o} W and latitudes 100^{o} 30 N and 110^{o} N. The Upper East region is bordered to the west by the Upper West region and the south by the Northern region. The total land area of the Upper East is about 2.7% (8842km^{2}) of Ghana's total land area. The land is relatively flat with a few hills to the east and southeast, and the soil is shallow and low in fertility, organic matter content and coarse textured (MoFA, 2013). The Upper East region is divided into eight districts for administrative purpose. These districts include Bawku Municipal, Bawku West, Bolgatanga Municipal, Bongo, Builsa, Garu-Tempane, Kassena Nankana East and Talensi-Nabdam as illustrated by Figure 3.3. Among the eight districts, Kassena Nankana East and Bawku Municipal are predominant in rice production.

Figure 3.3. Kassena Nankana East and Bawku Municipal within Upper East Region of Ghana.
Source: Adapted from Google Map (2014)

Bawku Municipal lies at the southern part of the Upper East region while Kassena Nankana East lies at the most western region of the Upper East region. Bawku Municipal constitutes 14% (1674km^2) of the total land area of the Upper East region while the total land area of Kassena Nankana East accounts for 19% (1215.05km^2). The landscape of these two districts is generally undulating, with isolated hills rising up to about 300m (MoFA, 2013). The next section will discuss the climate of the Upper East region.

3.2.2. Climate of Upper East Region of Ghana

The average monthly rainfall distribution pattern of the Upper East region of Ghana from 2002 to 2010 is shown in Figure 3.4. Upper East region experiences two seasons, namely, rainy and dry seasons.

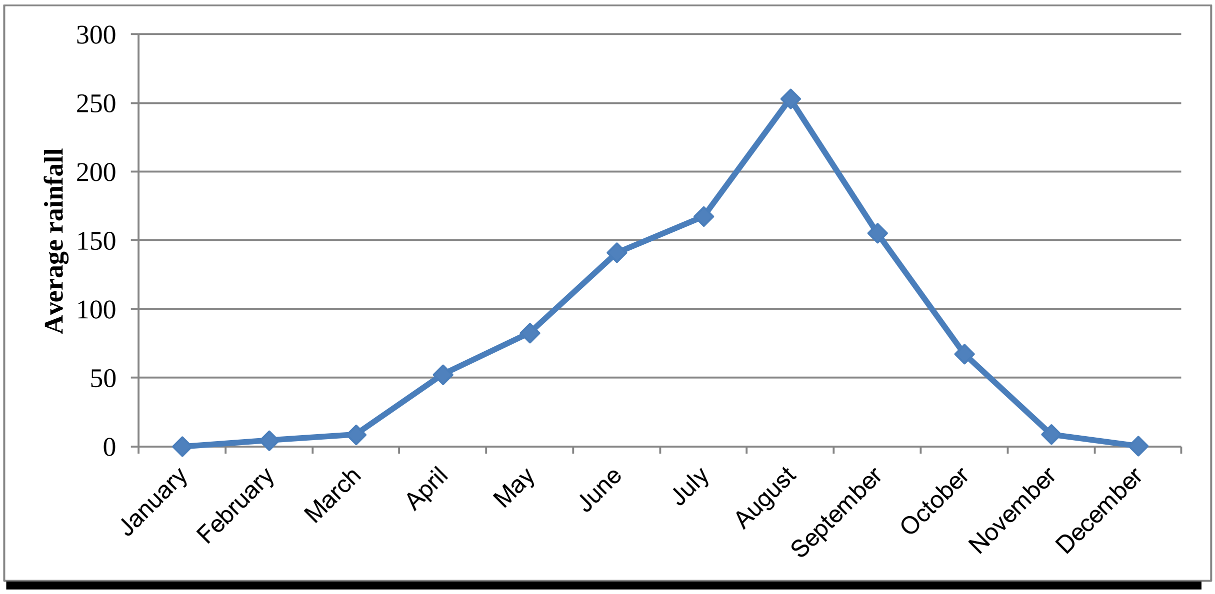

Figure 3.4. The Average Monthly Rainfall Distribution (2002-2010) of the Upper East Region of Ghana.
Source: Meteorological Services Department, Accra (2011).

The region has one major rainy season which starts in April and ends in October. The amount of rainfall tends to rise from 52mm in April to a maximum of 253mm in August. The major farming activities take place during the rainy season since crop production in the region relies solely on rainfall. The dry season starts from November with an average rainfall of 8mm (Figure 3.4). The Upper East region has an annual average rainfall of 921mm. The rainfall distribution in the region ranges between 645mm and 1250mm. The dry season is associated with dry harmattan winds with low humidity and temperatures making the area suitable for the growing of horticultural crops like tomatoes, pepper, onions, watermelons, okro and other leafy vegetables (MoFA, 2013).

The region is generally hot and dry, with a minimum temperature of 15^{o}C (December to February) and a maximum temperature of 45^{o}C (March to April). The relative humidity ranges between 30% and 80% in the dry and rainy seasons respectively (MoFA, 2013). Bawku Municipal and Kassena Nankana East experience one major rainy season from April to October just like the entire region. The average annual rainfall of Kassena Nankana East is 950mm, which is quite higher than that of Bawku Municipal, with an average annual rainfall of 850mm. In terms of temperature, Kassena Nankana East has an average annual temperature of 42^{0} C, which is also greater than that of Bawku Municipal which has an average annual temperature of 35^{0}C (MoFA, 2013).

3.2.3. Agriculture in Ghana

Agriculture contributes to about 29% to Ghana's gross domestic product (GDP) (MoFA, 2013). About 80% of the economically active population is engaged in agriculture (MoFA, 2012). Approximately, 2.74 million households are engaged in farming as a source of livelihood (Boansi, 2013). The livelihood of people in Ghana is influenced by the climatic conditions within which they live (MoFA, 2012). The traditional use of the rainy season for crop production and the dry season for harvesting and building of storage facilities is still a practice, since crop production is dependent on rainfall. The smallholder farms in Ghana account for about 80% of the total agricultural output (MoFA, 2013). About 90% of the farming holdings are less than two hectares in size (Roetter *et al*., 2008). Agricultural land constitutes 68% (162180km^2) of Ghana's total land area (MoFA, 2013). This agricultural land consists of the pasture, forest and arable lands. Twenty eight percent (454104km^2) of the agricultural land is arable land. Out of the 454104km^2 of arable land, 76% (34620km^2) is under food crop production, namely, cereals (maize, rice, millet and sorghum) and roots and tubers (cassava, yam and cocoyam). Cereal crops are produced on 47% of arable land under food crop production, while roots and tubers make up the remaining 53% (MoFA, 2013).

3.2.4. Rice Production in Ghana

Rice was one of the major commercial food crops in the 17th and 18th centuries, and was an important cereal crop after millet and maize. During these centuries, rice was cultivated more than yam and cassava (Kranjac-Berisavljevic, 2003). Rice was cultivated mostly by subsistent farmers in these centuries. The farmers cultivated rice under the bush-fallow system and shifting cultivation, in which rice was grown between 2 – 4 years on the same piece of land, until the soil fertility had reduced drastically. A fresh piece of land was acquired, and the pattern repeated. The original plot was left to fallow and cropped again after 10 – 15 years of rest, in which the productivity of the soil would have been restored. Although the system was inefficient in terms of land and labour use, it was capable of sustaining the population without noticeable adverse effects on the land. Due to high population growth, the fallow periods have been reduced to 1 – 2 years with corresponding decline in yields (Kranjac-Berisavljevic, 2003; Seidu *et al.,* 2004; Marcela and Ashitey, 2011). Currently, rice production is still important but its production has declined and the country is insufficient in rice.

The rice production levels of the various regions of Ghana are presented in Table 3.1. Rice is grown in all the ten regions. However, rice production is predominant in Northern, Upper East and Volta regions (MoFA, 2012) since climatic conditions in these regions are more favourable for rice production.

Table 3.1. Regional rice production level (2009/2010)

Region	Area (ha)	Production (mt)	Yield (mt/ha)
Western	15218	20088	1.32
Central	4158	5073	1.22
Eastern	7310	12427	1.70
Greater Accra	2005	2947	1.47
Volta	20460	60766	2.97
Ashanti	9614	12498	1.30
Brong Ahafo	3709	5786	1.56
Northern	72841	190115	2.61
Upper West	4200	7014	1.67
Upper East	39834	111137	2.79
Total	179349	427845	

Source: Statistical Research and Information Directorate, MoFA (2010)

The largest rice production area is the Northern region with 72841ha under production (40% of the total production area). The second largest production area is the Upper East with 22% (39834ha) of the total production area followed Volta with 11% (20460ha). Total rice production in Ghana for the 2009/2010 production season was 427845mt. The Northern region produced 84% (190115mt) of the total rice output while the Upper East region contributed 11137mt (26%) and Volta contributed 60766mt (14%) to total rice production. Although the Northern region is the biggest rice producer in absolute terms, on a per hectare basis, the Northern region is out performed by Volta and the Upper East regions. On average, the rice yield for the Volta region is 2.97mt/ha making Volta the most productive region. The second most productive region is the Upper East region at 2.79mt/ha, followed by the Northern region at 2.61mt/ha.

3.3. Data Collection and Site Selection

The survey data was obtained from a recent Ghana Agricultural Production Survey (GAPS) conducted by the Ministry of Food and Agriculture in collaboration with the International Food

Policy Research Institute (IFPRI) in the year 2011. The GAPS data was collected from farming households in all ten regions of Ghana by means of a structured questionnaire. Ghana Agricultural Production Survey (GAPS) was a pilot project which aimed at improving the quality of data held by the national agricultural statistics system. GAPS tends to achieve this objective by broadening and deepening the Multi-Round Annual Crop and Livestock Surveys (MRACLs) that the Ghana's Ministry of Food and Agriculture already assesses, through its District Agricultural Development Units (DADUs). MRACLs covers agricultural production, giving estimates of field area and yields of important crops, among other topics.

The survey data for the Kassena Nankana East and Bawku Municipal of the Upper East region of Ghana was used for the study. These two districts were selected because greatest numbers of rice producers were located in these two districts. The GAPS questionnaire captured relevant input-output data of farmers within the rice production environment. The output data are rice output in kilograms while, input data include the quantity of fertiliser in kilograms, amount of labour (hired and family labour were aggregated) in mandays, quantity of seeds applied in kilograms, and expenditure on pesticides in Ghana Cedis (Ghana's currency). Other information of the rice producers like socioeconomic and institutional variables was also captured in the GAPS questionnaire. The socioeconomic variables include age, gender, household size, and education while the institutional factors included extension contact, credit access, distance to nearest market centre, access to irrigation water and land tenure systems.

3.3.1. Sampling Technique and Size

Ghana Agricultural Production Survey (GAPS) employed a multistage sampling technique to select the respondents for the survey. The multistage sampling involved two sampling stages. In the first stage, two districts were selected randomly from each of the 10 regions in Ghana, using the district's farming population (MoFA/IFPRI, 2011). The total districts sampled for the survey amounted to 20. In the second stage, 40 enumeration areas (EAs) were selected randomly from each district summing up to 800 EAs. Ten farmers were selected from each of the 800 EAs, using a full list of all the farmers in the various districts as a sample frame. In total, 400 farmers were selected from each district which sums up to 8000 farmers. Since the study focuses on rice production in the Upper East region of Ghana, the data from Kassena Nankana East and Bawku Municipal were used. Four hundred and seventy (470) rice farmers were extracted from the two districts for the study. The sample size comprises 350 rice farmers from Kassena Nankana East and 120 from Bawku Municipal.

3.4. Characteristics of the Rice Producers

A brief description on the surveyed households in the study area is presented in this section.

3.4.1. Rice Production

To get information on rice production in the study areas, the survey questionnaire captured the quantity of total rice in kilograms harvested from the rice field. Rice output is needed to estimate the production frontier and technical efficiency scores of the rice farmers in the study areas. The average rice yield for the districts was calculated by dividing the average rice output by the average farm size. The summary statistics of the rice output and rice yield are provided in Table 3.2.

Table 3.2. Summary descriptive statistics of rice output and yield

Variable	Kassena Nankana (N = 350)		Bawku Municipal (N = 120)		Pooled sample (N = 470)	
	Average	Std	Average	Std	Average	Std
Rice output (kg)	1055.3	1484.2	766.20	556.70	981.46	971.80
Rice yield (kg/ha)	799.5	1337.1	806.53	927.83	804.47	962.18

Rice producers from Kassena Nankana East obtained higher rice output of 1055.30kg while Bawku Municipal rice farmers had rice production level of 766.20kg. In terms of rice yield, Bawku rice farmers produced a greater rice yield (806.53kg/ha) than farmers from Kassena Nankana who had rice yield of 799.50kg/ha. Although the total output for Kassena Nankana was greater, the yield for Kassena Nankana was less than for Bawku Municipal. The pooled data shows that the rice producers harvested on average a total rice output of 981.46kg with a standard deviation of 971.80kg. The standard deviation indicates that there was high variability of rice output obtained by the rice producers. The average rice yield for the pooled sample was 804.47kg/ha and the standard deviation was 962.18kg/ha.

3.4.2. Technical Factors

A brief discussion on the technical factors employed by the rice farmers in their production in the study areas is provided in this section. The technical factors include farm size, seed, fertiliser, pesticides and labour. These technical factors are used as the explanatory variables during estimation of the stochastic production frontier. The section begins with a discussion on farm size and the rest of the factors are discussed subsequently**.**

3.4.2.1. Farm Size

Farm size refers to the total land area used for production of rice and was measured in hectares. The responses of the rice producers with respect to their farm size are summarised in Table 3.3 using average, minimum (Min), maximum (Max) and standard deviation (Std).

Table 3.3. Farm size cultivated by the rice producers

Variable	Min	Max	Average	Std
Kassena Nankana (ha) (N = 350)	0.32	8.40	1.22	1.00
Bawku (ha) (N = 120)	0.32	3.20	0.95	0.60
Pooled sample (ha) (N = 470)	0.32	8.40	1.22	1.11

The rice farms in Kassena Nankana (1.22ha) on the average were quite larger than that of Bawku Municipal (0.95ha). The majority of the rice farmers of the pooled sample cultivated on average 1.22ha of land with a minimum of 0.32ha and a maximum of 8.40ha (Table 3.3.). The survey data indicates that generally, the rice farmers in the Upper East region of Ghana are operating on a very small farm size. The small farm size could be probably attributed to the nature of land tenure systems in the Upper East in which farmlands are distributed among family members. The small farm size can hinder mechanisation and commercialisation of rice farms that can contribute to improving national self-sufficiency in rice. The finding is consistent with a study by Seidu (2008), who observed that rice farmers in the northern Ghana were cultivating an average farm size of 2ha. MoFA (2010) report also confirmed that about 90% of farm holdings in Ghana were less than 2ha in size.

3.4.2.2. Quantity of Seed Planted, Adoption of Improved Varieties and Seed Planting Techniques

Information on the adoption of improved rice varieties was obtained by asking the farmers to indicate whether they plant improved rice varieties or local varieties. The adoption of improved varieties was measured as a dummy variable with 1 indicating adoption of improved varieties and 0 otherwise. The percentage of the rice producers who adopted the improved rice varieties in the two study areas as well as the pooled sample is illustrated in Figure 3.5.

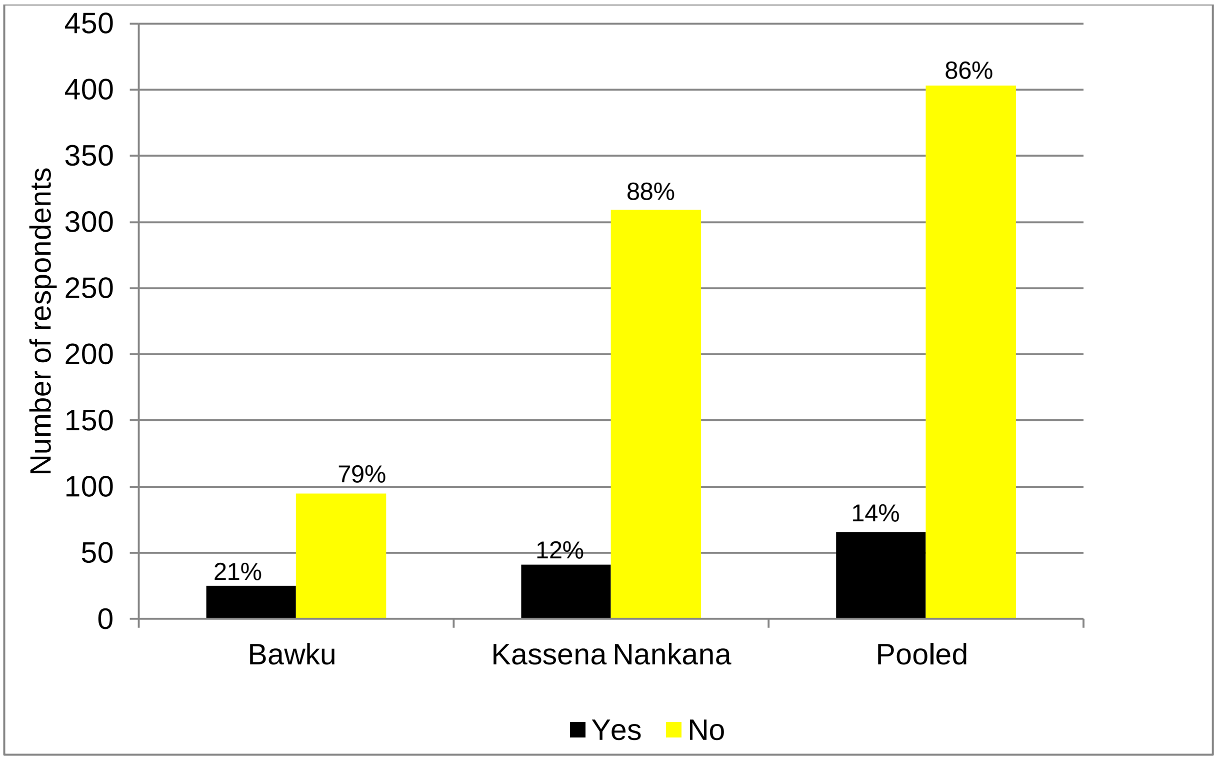

Figure 3.5. Adoption of improved rice variety among the farmers

Most farmers still use traditional seed varieties during production. Twenty one percent (21%) of the rice farmers in Bawku Municipal planted improved rice varieties while only 12% of those in Kassena Nankana East grew improved seed varieties. The pooled data shows that 14% of the rice farmers adopted improved rice varieties, while the majority (86%) grew local rice varieties. The adoption of improved rice varieties is greater for Bawku Municipal than Kassena Nankana. Nevertheless, the adoption of improved rice varieties that are able to generate higher yields is very low in the study areas.

The method of planting can influence the efficiency of rice production. Row-planting for example, can enhance the application of agro-chemicals and make harvesting becomes easy. Even though the broadcasting method is relatively less laborious and quicker, the rice plants become haphazardly grown on the field which leads overcrowding of rice plants. Overcrowding increases competition for water and nutrients among rice plants. Figure 3.6 presents the methods of planting adopted by the rice producers. The figure shows that 45% of the pooled sample planted their rice seeds in rows (which is an improved planting technology) while the remaining 55% used broadcasting. Furthermore, the majority (53%) of

Kassena Nankana farmers planted their seeds by broadcasting while 47% adopted row-planting technology. Similarly, in Bawku, 61% used broadcasting to plant their rice seeds while 39% employed row-planting. Generally, the adoption of the improved planting technology (row-planting) is low.

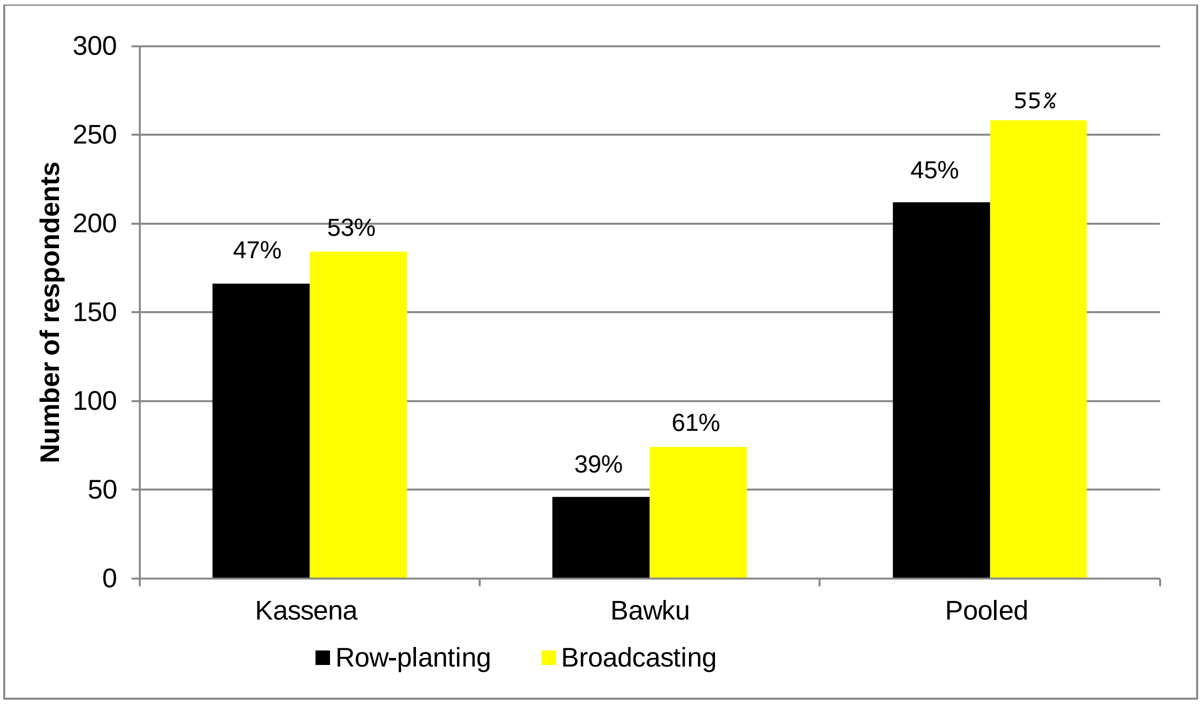

Figure 3.6. Methods of planting

Level of production depends on the quantity of seeds used on the farm. Over application can result in low yield due to increased competition for limited resources. The quantity of rice seed planted for Kassena Nankana, Bawku and the pooled sample is given in Table 3.4. The data on quantity of seed are provided in terms of average, minimum, maximum and standard deviation. The survey data in Table 3.4 shows that the rice farmers in Kassena Nankana applied on the average 67.34kg/ha of seed; which is 17.11kg/ha more than what the Bawku farmers applied. The pooled data indicates the rice farmers planted on the average 62.97kg of rice seed on a hectare of land.

Table 3.4. Quantity of rice seed planted by the rice farmers

Variable	Mini	Maxi	Average	Std
Kassena Nankana (kg/ha) (N = 350)	16	420	67.34	54.77
Bawku (kg/ha) (N = 120)	16	160	50.23	29.15
Pooled sample (kg/ha) (N = 470)	16	420	62.97	50.04

3.4.2.3. Pesticide Use

The survey questionnaire recorded whether farmers used pesticides or not. The results of the pesticide application by the rice farmers are illustrated in Table 3.5. Forty one percent (41.43%) of the rice farmers in Kassena Nankana applied pesticides on their rice fields, while only 1.67% of the farmers in the Bawku Municipal sprayed pesticides to control diseases and pests. Out of the 470 rice farmers, 43.19% applied pesticides on their rice field, while 31.28% did not use any pesticides. The survey results showed that pesticide application was generally low in the study areas. Low pesticide application could be attributed to financial constraints since most of the respondents were poor farmers or lack of access to credit.

Table 3.5. Pesticide application

Location	Pesticide use	Frequency	Percent (%)
Kassena Nankana (N = 350)	Yes	145	41.43
	No	205	58.57
Bawku Municipal (N = 120)	Yes	2	1.67
	No	118	98.33
Pooled sample (N = 470)	Yes	147	31.28
	No	203	43.19

The rice producers who applied pesticides were questioned on how much they spend on pesticides. The expenditure on pesticides was recorded in Cedis (Ghanaian currency). Descriptive statistics for expenditure on pesticides are given Table 3.6. On average, the rice producers from Bawku Municipal spent the most on pesticides. Spending on pesticides in Bawku Municipal amount to ₵Gh 4.35/ha while spending in Kassena Nankana was ₵Gh 2.87/ha. On average, spending on pesticides for the pooled sample amounted to ₵Gh 3.25/ha.

Table 3.6. Summary statistics of expenditure on pesticides

Variable	Observation	Minimum	Maximum	Average	Std
Bawku Municipal (Cedis/ha)	350	0.93	320	4.35	29.36
Kassena Nankana (Cedis/ha)	120	0.50	190	2.87	12.87
Pooled sample (Cedis/ha)	470	0.42	320	3.25	12.50

Note: US$ 1 = Gh₵ 3.10

3.4.2.4. *Fertiliser Use*

Efficient fertiliser use can increase the productivity of rice systems. During the survey, farmers were asked if they use chemical fertiliser and how much they apply. The discussion on fertiliser use first focused on whether farmer used chemical fertiliser. Farmers who mentioned that they did not use chemical fertiliser, did not apply organic fertiliser as well. Figure 3.7 shows summary of the responses obtained by rice farmers. Out of the 350 rice farmers from Kassena Nankana, only 41% employed chemical fertiliser while in Bawku Municipal, 31% applied chemical fertiliser. Sixty one percent (61%) of the pooled sample did not apply any chemical fertiliser on their rice field, while 39% used fertiliser on their rice farms. The survey data shows that application of fertiliser was low in the study areas. The low support of fertiliser use could be due to financial constraints. Although, the government of Ghana subsidises fertiliser prices, farmers can still not afford fertiliser.

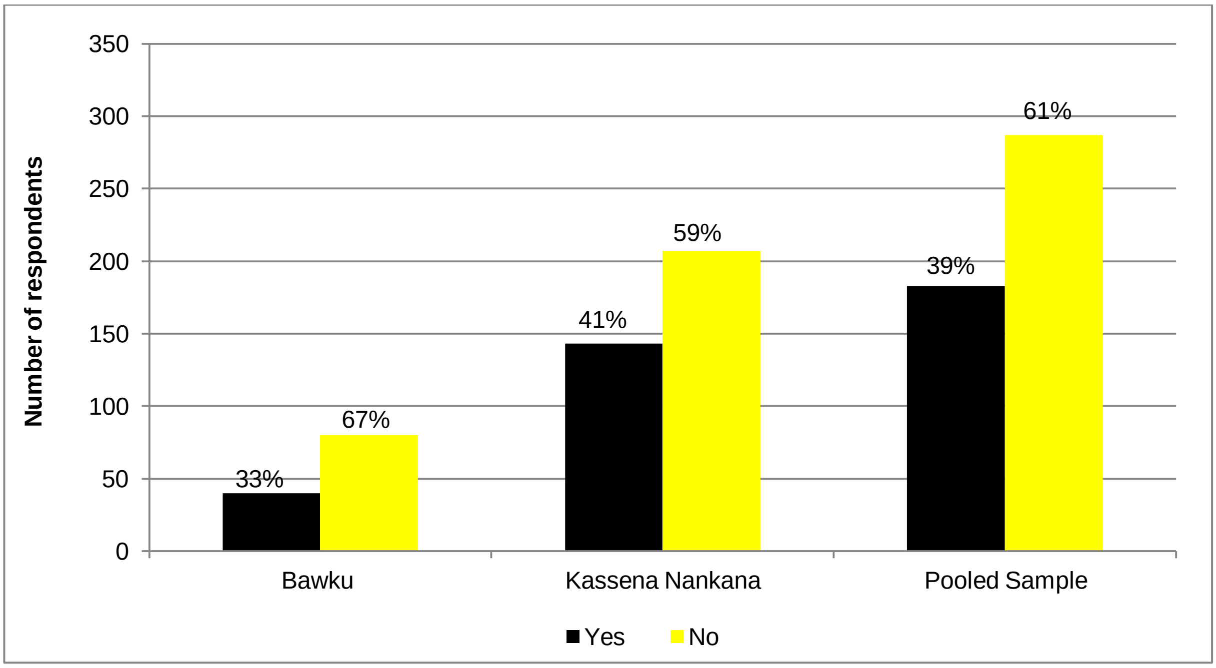

Figure 3.7. Fertiliser use among rice producers across the study areas

The quantity of fertiliser applied by the rice producers in the study areas is summarised in Table 3.8.

Table 3.7. Summary statistics of fertiliser quantity used by rice farmers

Variable	Minimum	Maximum	Average	Std
Kassena Nankana East (N = 350)	15.63	400	117.07	75.09
Bawku Municipal (N = 120)	25	550	144.89	92.50
Pooled Sample (N = 470)	15.63	550	119.46	79.85

The survey data indicates that rice farmers in Bawku Municipal applied on average, the most fertiliser quantity at 144.89kg/ha with a minimum of 25kg/ha and a maximum of 550kg/ha. There was higher variability in fertiliser application among farmers in Bawku Municipal than those in Kassena Nankana East. The rice producers in Kassena Nankana East applied 117.07kg/ha of fertiliser with a minimum of 15.63kg/ha and a maximum of 400kg/ha. The rice farmers applied average fertiliser quantity of 119.46kg/ha with minimum of 15.63kg/ha and maximum of 550kg/ha (Table 3.8). The standard deviation was 79.85kg/ha indicating high variability in fertiliser application among rice producers.

3.4.2.5. Labour Use

Rice production is labour intensive particularly during land preparation, which makes labour an important input for the farmers in the study areas. The amount of labour used by the rice producers in the two districts is presented in Table 3.8.

Table 3.8. Quantity of labour input used by the rice producers

Variable	Minimum	Maximum	Average	Std.
Kassena Nankana manday/ha (N = 350)	17.89	780.00	207.10	136.84
Bawku (manday/ha) (N = 120)	56.67	802.50	259.38	165.10
Pooled sample (manday/ha) (N = 470)	17.89	802.50	220.45	146.19

The results in Table 3.8 show that the rice farmers from Kassena Nankana East employed more labour (207.10mandays/ha) than those in Bawku Municipal who used 259.38mandays/ha. From the pooled sample, the average labour used by the rice farmers was 220.45mandays/ha.

3.4.3. Socio-economic Characteristics of the Rice Producers

A discussion on the socioeconomic characteristics of the respondents include gender, educational level, age, household size and farming experience is presented in this section.

3.4.3.1. Gender

The gender distribution of the rice farmers in the study areas is shown in Figure 3.8. The majority of the Bawku Municipal rice producers were female (53%) while the majority of Kassena Nankana rice producers were male (53%). On evaluation of the pooled sample, it was found that the majority of the producers were male (51%).

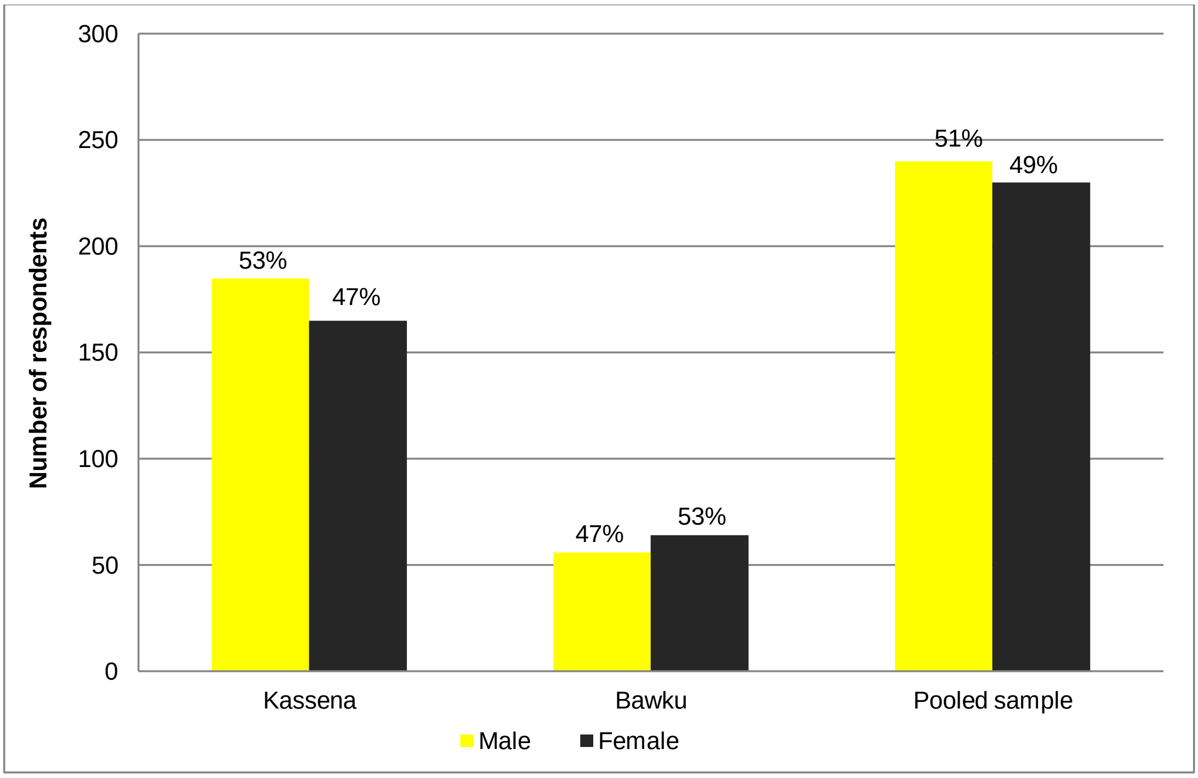

Figure 3.8. Gender of rice producers across study areas

3.4.3.2. Educational Level

The educational level of the rice producer's was categorised into no education, primary, junior high, senior high and tertiary education. Primary education indicates that the respondent has 6 years of formal schooling, junior high is 9 years, while senior high and tertiary are 12 years and 16 years respectively. The frequency of the farmers who had attained these levels of education is provided in Figure 3.9.

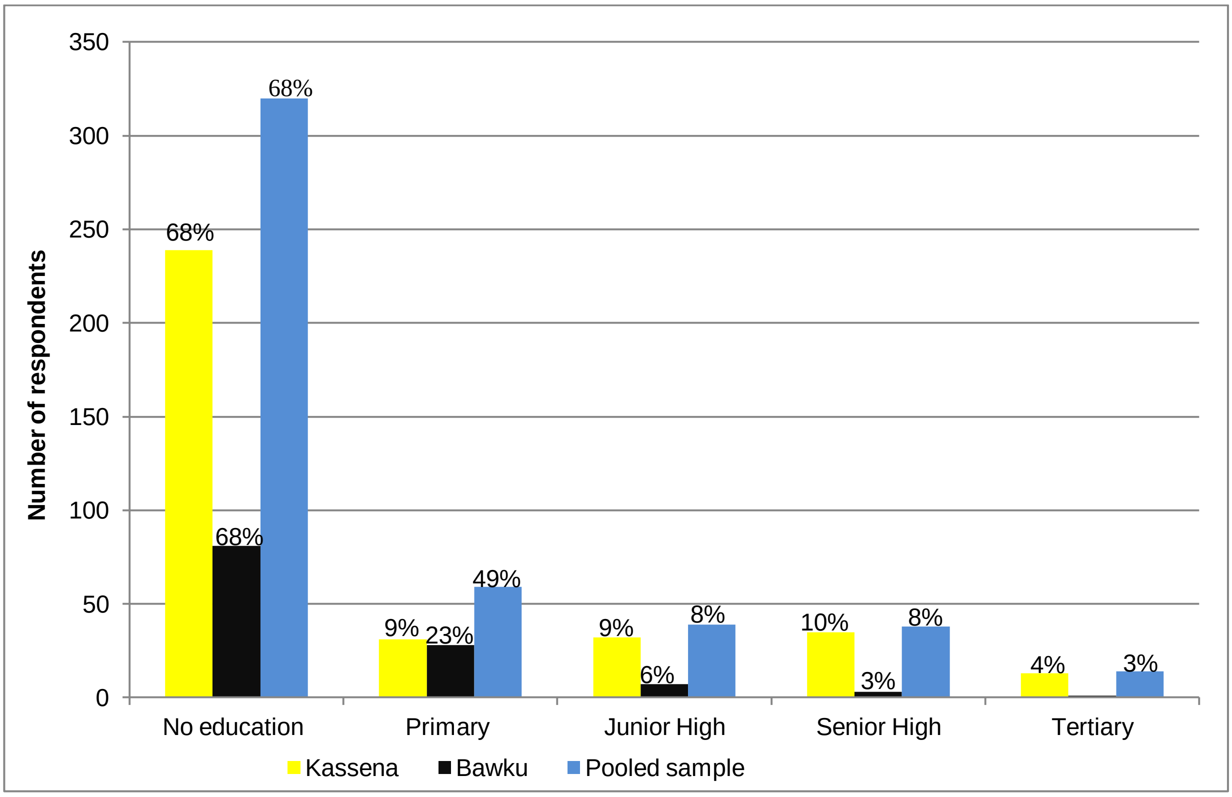

Figure 3.9. Educational level distribution of rice farmers across study areas.

The survey results show that 68% of rice producers in Kassena Nankana had no formal education, 9% reached primary education, 9% obtained junior high education while 10% had senior high and only 4% attained tertiary education. The majority (68%) of farmers in Bawku Municipal had not been to formal school, followed by 23% who had primary education, while 6% attained junior high education and 3% got senior education. Out of the 470 rice farmers selected for the survey, 68% had not attained any formal education while 49% had primary education and 8% junior secondary education. Eight percent (8%) had attained senior secondary while 3% had tertiary education (Figure 3.9). In the Upper East region of Ghana, the standard of education is generally low as compared to that of the national (GSS, 2012). Low educational level can affect technology transfer since rice production involves a lot technology.

3.4.3.3. Age, Household Size and Farming Experience

The descriptive statistics in terms of average, minimum (min) and maximum (max) of the socioeconomic characteristics of the rice producers such as age, household size and farming experience are presented in Table 3.9.

Table 3.9. Descriptive statistics of socioeconomic characteristics of the rice farmers

Variable	Kassena Nankana (N = 350)			Bawku Municipal (N = 120)			Pooled sample (N = 470)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
Age	34.56	19	90	30.75	16	90	33.59	15	90
Household size	5.25	1	21	5.87	1	15	5.41	1	21
Farming experience	6.90	1	41	6.18	1	42	6.71	1	42

Rice farmers in Kassena Nankana were older than Bawku Municipal rice farmers. The average age of the farmers was 34.56 years in the Kassena Nankana district, and 30.75 years in the Bawku Municipal. The pooled data shows that most of the rice farmers were young with an average age of 33.59 years. The minimum age was 19 years with a maximum age of 90 years. The results demonstrate that rice farmers in Kassena Nankana had more experience (6.90 years) in rice production than those in the Bawku Municipal (6.18 years). Table 3.9 also shows that most of the farmers from the pooled sample had engaged in the cultivation of rice for about 6.71 years with a minimum and a maximum of one (1) year and 42 years respectively. On average, Bawku farmers had a larger household size of 6 people while the average household size for Kassena Nankana was 5 people. The average household size of the pooled sample was five (5) people with a minimum and a maximum of one (1) and 21 people respectively. The large household indicates that there is availability of labour for agricultural production in the study areas.

3.4.4. Institutional Factors

The section provides the institutional variables of the rice producers sampled for the study. The institutional factors obtained from the study are extension contact, credit access, distance to nearest market centre and land tenure systems. These institutional factors provide farmers with technical and financial assistance that enhance their rice production. The institutional factors are briefly discussed below beginning with access to extension services.

3.4.4.1. Extension Services

The rice farmers' access to extension services in the study areas is illustrated in Figure 3.10.

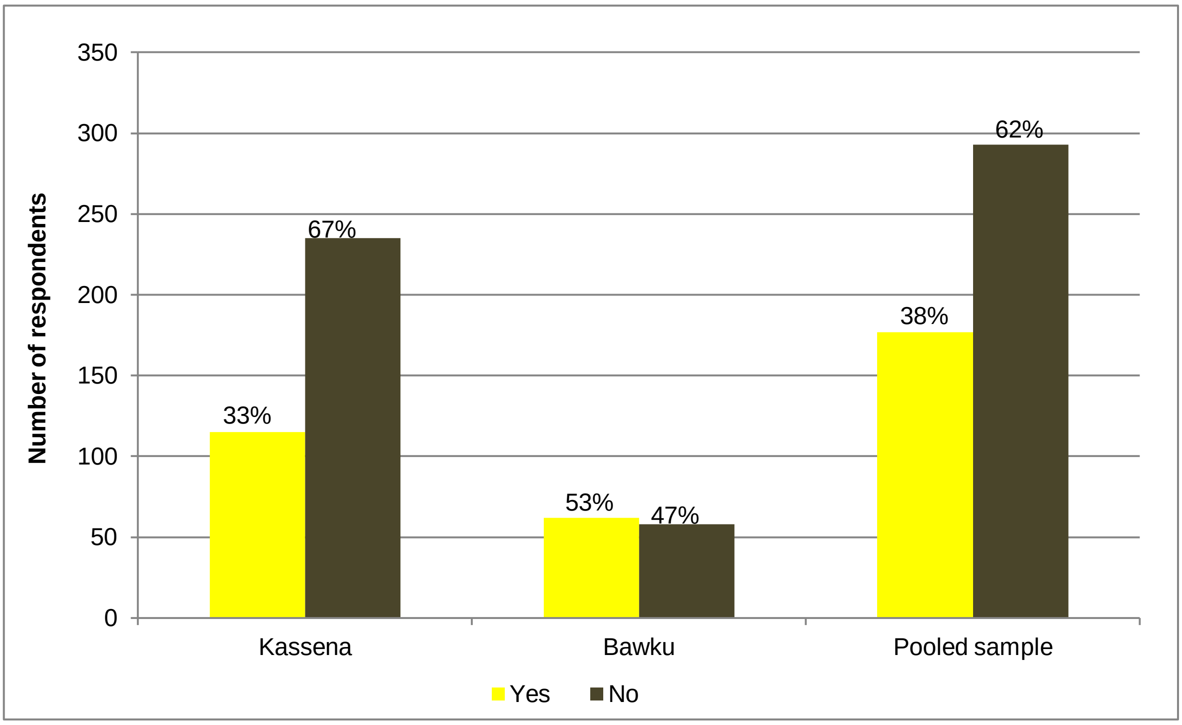

Figure 3.10. Extension services access of respondents across study areas

Sixty seven percent (67%) of the farmers in the Kassena Nankana did not have access to extension service, while in Bawku Municipal; the majority (53%) had access to extension service. The pooled sample shows that 62% of the farmer did not receive any extension service with respect to their rice production, while 38% had access to extension service. Agricultural extension service is mainly delivered by the Ministry of Food and Agriculture in Ghana. Extension service is funded by the government of Ghana under the office of the Ministry of Food and Agriculture. Lack of extension officers is due to budget constraints by the government is the cause of low number of extension officer compared to number of farmer ratio (1:1500) in the northern parts of Ghana (MoFA, 2011). Inability of farmers to receive extension services is due to inadequate number of agent which can have an effect on rice production since extension agents provide useful information on inputs use and technology advancements to farmers.

3.4.4.2. *Access to Credit*

Agricultural finance plays an important role in agricultural production. Agricultural finance is required to purchase farm inputs such as agro-chemicals, improved seeds, farm machinery, and land, among others. However, due to the risky nature of agricultural production, many rural banks are unwilling to support farmers with credit. Figure 3.11 shows farmers' access to credit in the study area.

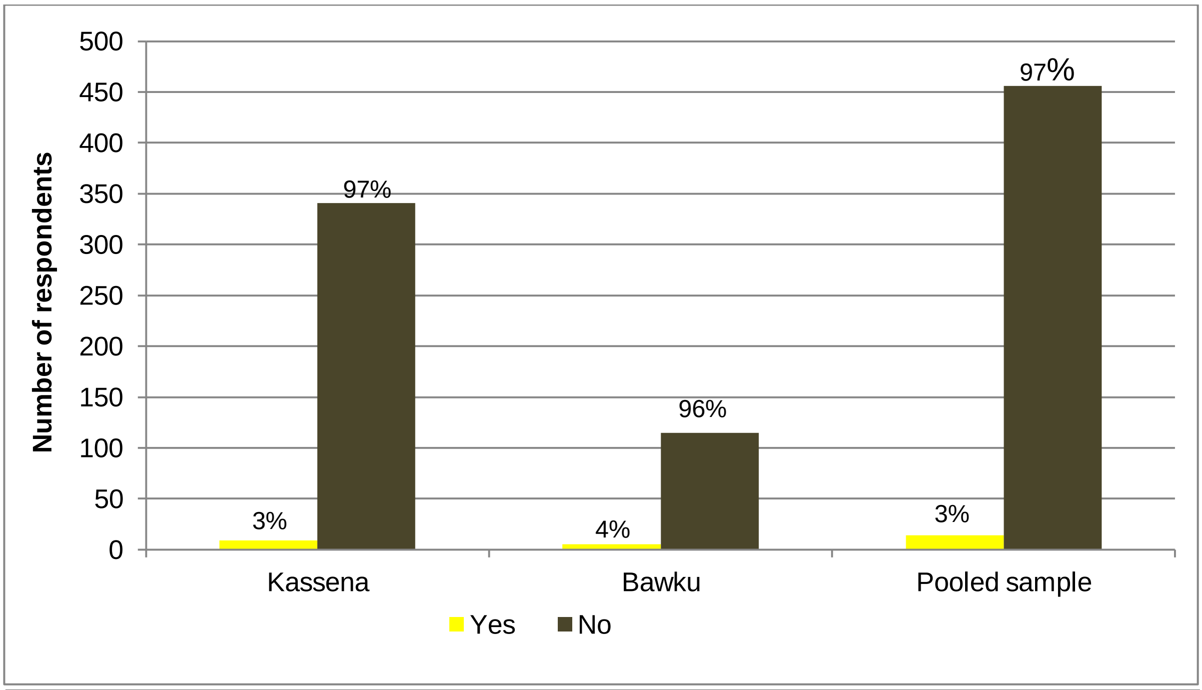

Figure 3.11. Farmers' access to credit across the study areas

Ninety seven percent (97%) of the rice farmers from Kassena Nankana did not have access to any credit, while three percent (3%) had access to credit. The distribution of access to credit in Bawku Municipal was not different from Kassena Nankana. Only four percent (4%) of the rice farmers in Bawku Municipal had access to credit, while three percent (3%) of the Kassena Nankana rice farmers had access to credit. The pooled sample showed that only three percent (3%) of the farmers had accessed credit, while the majority (97%) did not have access to any microfinance. Most of the rural banks are located far away from the rural areas. However, those available in some farming communities are costly to access, and the terms and conditions such as collateral do not favour poor rural farmers who are unable to meet these stringent requirements.

3.4.4.3. Proximity to Market Centre

Proximity to market centre was measured as distance (in kilometres) from the farmer's house to the nearest market centre. Results of rice producer's proximity to market centre are summarised in Table 3.10.

Table 3.10. Distant to nearest market centre

Variable	Observation	Minimum	Maximum	Average	Std
Kassena Nankana (km)	350	1	54	7.66	6.20
Bawku Municipal (km)	120	1	40	8.20	7.47
Pooled sample (km)	470	1	54	7.80	6.84

Rice producers in Kassena Nankana district travelled shorter distance (7.66km) to the nearest market centre than those in Bawku Municipal (8.20km). The pooled sample indicates that the rice farmers were 7.80km away from the nearest market centre with a minimum and a maximum of one kilometre (1km) and 54km respectively. Longer distance to market centres implies that farmers would incur high cost in transporting their commodities to the market as well as transporting farm inputs from the market to their houses or farms.

3.4.4.4. Land Tenure Systems

Land tenure systems indicate how rice producers acquire land for rice production in the Kassena Nankana and Bawku Municipal. The questionnaire considered three land tenure systems: owned land, fixed-rent and sharecropping. The percentages and frequencies of the three land tenure systems are shown in Figure 3.12.

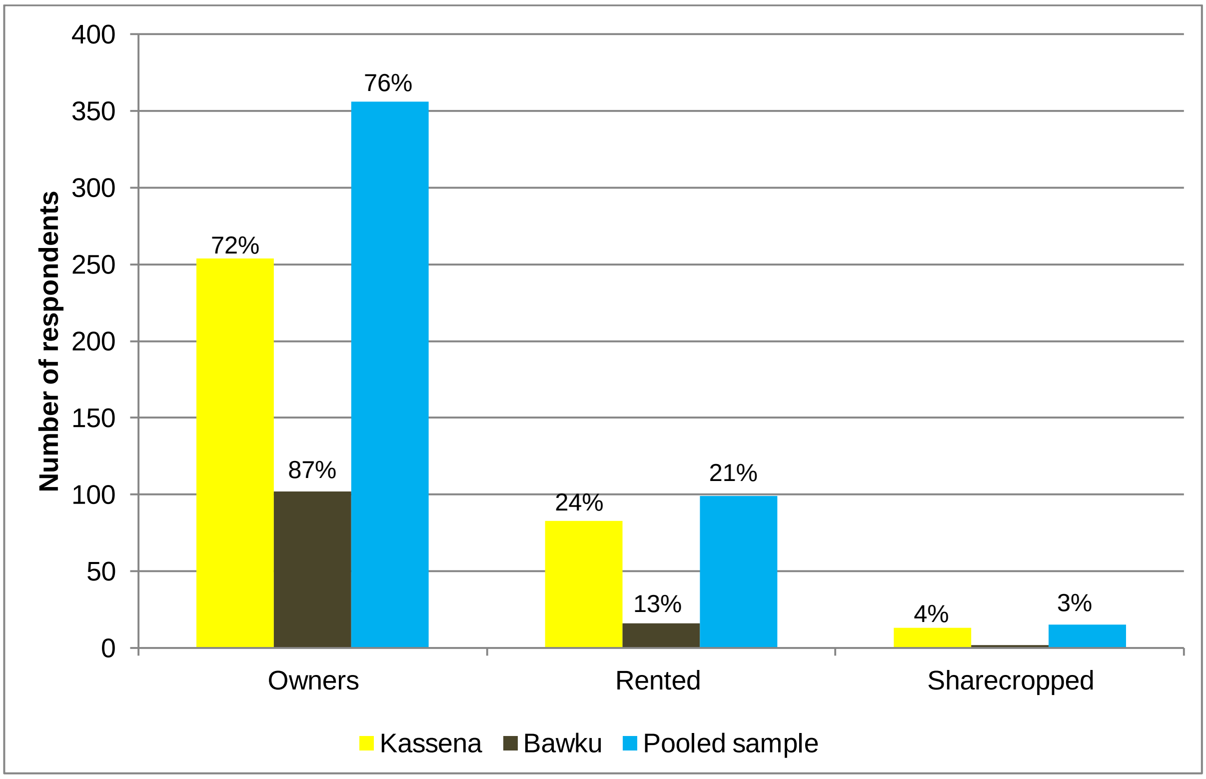

Figure 3.12. Land tenure systems distribution of respondents across study areas

The results in Figure 3.12 indicate that 72% of rice farmers in Kassena Nankana owned their farmlands, 24% rented and only 4% engaged in a sharecropping arrangement while 84% of rice producers in Bawku Municipal owned their farmland, 13% rented and only 3% engaged in sharecropping system. The results also show that 76% of the pooled sample farmed on their own farmlands while 21% rented the farmland and three percent (3%) operated on sharecropping.

3.4.4.5. Access to irrigation water

Irrigation water plays a critical role in rice production particularly in the era of climate change. The distribution of the farmers' access water for irrigation is provided in Figure 3.13.

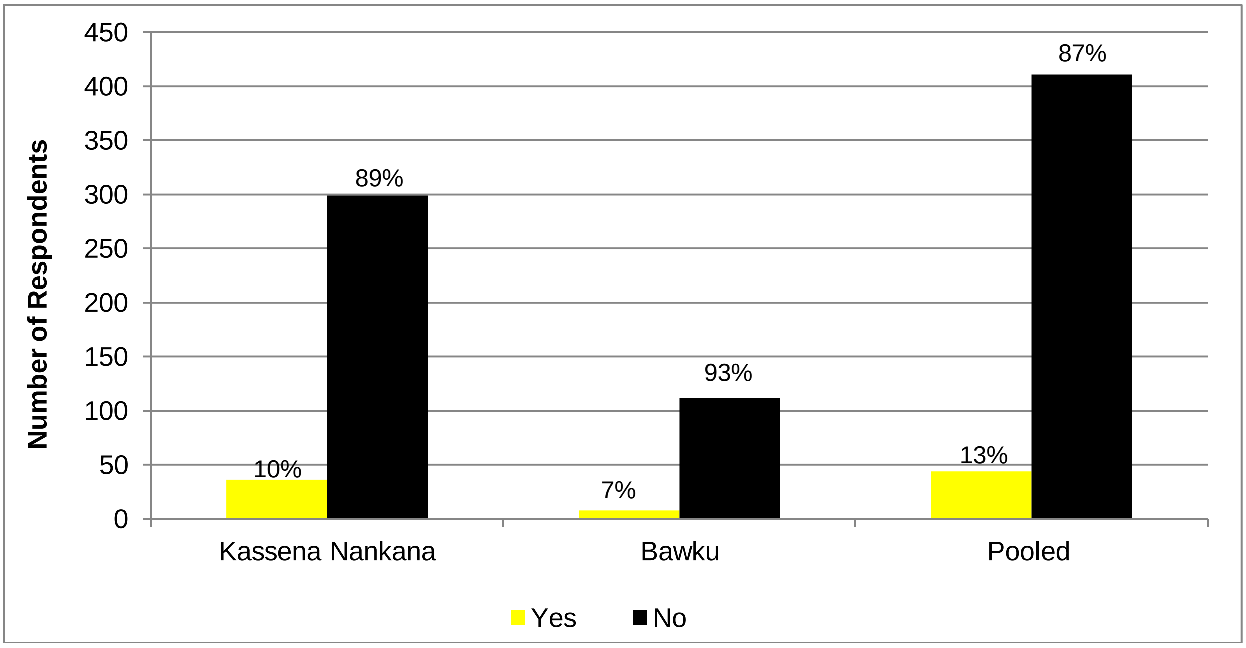

Figure 3.13. Farmers' access to irrigation of respondents across study areas

Higher number (10%) of rice farmers in Kassena Nankana had access to water irrigate their rice field than farmers in Bawku Municipal with only 7% of the rice producers having access to water for irrigation. The results in Figure 3.13 indicate that 87% of the rice farmers from the pooled sample did not have any source of water to irrigate their rice field rather than rain water while only 13% had water source to irrigate their rice fields. The sources of water used by farmers to irrigate their rice fields in the study areas were dams or ponds and streams or rivers. The survey results indicate that the farmers in the study areas have inadequate access to water irrigation water.

3.5. Summary and Conclusion

On average, rice output harvested in Kassena Nankana East was higher than in Bawku Municipal. In terms of resource use, rice farmers in Kassena Nankana East cultivated relatively larger areas, used more labour and applied more seed compared to the farmers in Bawku Municipal. The farmers in Bawku Municipal used more fertiliser and spent more on pesticides. The adoption of technologies between the two districts is also different, although, marginally so. Farmers in Bawku Municipal are more prone to adopt improved seed varieties while farmers in Kassena Nankana are more prone to adopt row-planting technique.

Most of the females in Bawku Municipal had greater interest in rice production than the males, but the males dominated in rice production in Kassena Nankana. Generally, there was low educational level among the rice producers, and the educational levels in both districts were the same. The study also revealed that young people showed interest in rice cultivation, but the farmers in the Bawku Municipal were quite younger than those in Kassena Nankana East. The Kassena Nankana East rice producers had more experience in rice production than those in the Bawku Municipal. Even though the household size in both districts were very close, Bawku rice farmers had relatively larger households. Access to extension services was very low in the two districts. However, rice farmers in Bawku Municipal had more comparative advantage in terms of accessing extension services than Kassena Nankana East rice farmers. Access to credit was very low in both districts, and the situation in both districts was not different. In terms of proximity to market centres, Kassena Nankana East rice producers were closer to market centres than rice farmers in Bawku Municipal. The majority of the farmers in Kassena Nankana and Bawku cultivated on their own farmlands. Access to irrigation water was low for the farmers in the study areas. However, there was higher number of farmers who had access to irrigation water in Kassena Nankana than Bawku Municipal.

CHAPTER FOUR: PROCEDURES

4.1. Introduction

In this chapter, the procedures used to achieve the research objectives are presented. The study used the stochastic metafrontier analysis which consists of two main estimation steps:

1. First, a stochastic frontier model was used to estimate the production frontiers and the technical efficiency of rice production for both Bawku Municipal and Kassena Nankana district. During the estimation of the production frontiers, an inefficiency model was estimated using a single estimation procedure. The inefficiency model helps one to identify the factors that influence efficiency of production.
2. The second step consists of the estimation of a metafrontier. The individual frontiers estimated in step one cannot be used to compare the efficiency of the two districts due heterogeneous technologies. The estimated metafrontier pools the individual frontiers to determine a single frontier consisting of the best rice producers in the two districts. Technology gap ratios and technical efficiency scores relative to the metafrontier are then estimated. These measures are comparative efficiency measures used to compare the performance of rice production in the two districts using a common technology available.

This chapter is structured into five sections. The second section introduces the stochastic frontier model used to estimate the production frontier and inefficiency models. The metafrontier production function together with the technology gap ratio is described in the third section. The testing of hypotheses formulated in the study is presented in the fourth section. The last section concludes the chapter.

4.2. The Stochastic Frontier Model

4.2.1. The Stochastic Frontier Model Specification

Analysis of productivity and efficiency has attracted particular attention in developing countries due to the importance of agricultural productivity growth in promoting economic development (Ogundari, 2008; Ogundari *et al*., 2010). The concept of productive efficiency was suggested by Debreu (1951) and Farrell (1957) using a production frontier. The production frontier represents the maximum output attainable from a given set of inputs using existing technology (Greene, 2003). A farm's production level relative to the production frontier is considered to be a measure of efficiency of the farm. Greene (2003) and Coelli *et al*. (2005) indicated that productive efficiency can be estimated with different approaches namely, stochastic frontier analysis and data envelopment analysis.

Farrell (1957) proposed the development of a relative production frontier which can be used to determine and compare productivity and efficiency of producers. Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977) developed a technique to estimate a deterministic production frontier that can decompose the error term into random error and non-negative inefficiency term. This kind of production frontier was called stochastic production frontier. The stochastic production frontier is appropriate for agricultural production which is influenced greatly by random shocks (such as natural disasters, weather, among others) that are not under the control of the farmers. These random shocks can influence the shape and position of the production frontier (Ogundari *et al*., 2010).

The stochastic frontier model was used in the study to estimate the production frontiers and the technical efficiency levels of the rice farms in the two study areas. FRONTIER version 4.1 (c) computer program (Coelli, 1996) was used to simultaneously estimate the production frontier and the inefficiency model for the two districts. The model included hypothesised efficiency variables in the inefficiency error component so as to determine which factors are important in promoting efficiency. In specifying the stochastic frontier model, Ogundari *et al*. (2010) indicated that it is necessary to choose the functional form well in a study because the choice of functional form can influence the estimated efficiency results. In this study, a number of functional forms were explored including linear, semi-log, Cobb-Douglas and translog. Among these functional forms, the Cobb-Douglas function was found to be the best fit for the data. The Cobb-Douglas production function used in the study to estimate the production frontiers and technical efficiency levels was specified as:

$$\ln R_i = \beta_0 + \sum_{j=1}^{5} \beta_j \ln x_{ij} + \varepsilon_i \quad i = 1, 2, ..., N \qquad (1)$$

R_i denotes rice output for the i-th rice farm for the each district. x_i denotes the farm inputs used by the i-th rice farm for each district. β_j denotes the coefficients of the farm inputs for each district. β_0 represents the constant term. ε_i denotes the total deviation which is decomposed in two independent elements, a random error component (V_i) and the technical inefficiency term (U_i) and is mathematically expressed as:

$$\varepsilon_i = V_i - U_i \quad (2)$$

where V_i represents a symmetric two sided normally distributed random error that accounts for the random effects outside the farmers control (for example, weather, natural disasters, omitted variables, measurement error and other statistical noise) (Coelli *et al*., 2005). The systematic random error component (V_i) is assumed to be independently and identically distributed with zero mean and variance, σ_V^2 $(0, \sigma_V^2)$ (Battese and Broca, 1997). U_i denotes the asymmetric non-negative random error component that measures technical inefficiency. The non-negative variable, U_i is assumed to be independently and identically distributed truncations (at zero from below) of the N (m_i, σ_U^2) distribution, where $m_i = Z_{ij}\delta_j$. δ_j is a vector of parameters to be estimated and Z_{ij} is a vector of variables that may influence inefficiency of the rice farmers (Greene, 2003; Coelli *et al*., 2005).

Variance parameters such as sigma-squared (σ^2) and gamma (γ) are also estimated. The gamma value is used to determine the presence of inefficiency in the production data, while the sigma squared value is used to check if the distributional assumption of the inefficiency effect is correctly specified. The variance parameters of the model were specified as:

$$\sigma^2 = \sigma_U^2 + \sigma_V^2, \quad (3)$$

$$\gamma = \sigma_U^2 / \sigma^2 \text{ and } 0 \le \gamma \le 1 \quad (4)$$

where σ^2 represents the overall variance of error terms while the gamma parameter (γ) explains the impact of inefficiency on output (Stefan *et al*., 2011). A gamma value of 0.9 would indicate that 90% of the variation in rice production would be the result of technical inefficiency (Coelli *et al*., 1998; Ogundari, 2008). The gamma value can therefore be used as an indicator for the presence of inefficiency in the data.

Given the specification of the Cobb-Douglas stochastic frontier model in equation (1), the technical efficiency (*TE$_i$*) of the i-th rice farm with respect to each district production frontier can be defined as the ratio of the mean output for the i-th farmer, given the values of the farm inputs (x_i) and its technical inefficiency effect (U_i) to the corresponding mean output if there were no technical inefficiency in production (Battese and Coelli, 1988). From the above definition, TE_i can be expressed mathematically as:

$$TE_i = \frac{R_i}{R_i^*} = \frac{f(x_{ij};\beta_j)e^{(U_i - V_i)}}{f(x_{ij};\beta_j)e^{(V_i)}} = e^{-U_i} \quad (5)$$

Battese and Coelli (1988) derived the best predictor of technical efficiency which can be specified as:

$$TE_i = E[\exp(-U_i)] \quad (6)$$

So that $0 \leq TE_i \leq 1$ and are inversely related to technical inefficiency (Coelli, 1988). The variables included in the production frontier model are defined in the next subsection.

4.2.2. Description of variables included in the Production Frontier Model

Five (5) independent variables (farm inputs) were included in the Cobb-Douglas stochastic production frontier model. Table 4.1 provides the description of the variables included in the rice production frontier (for the two districts) together with their expected signs.

Table 4.1. Description of the farm inputs and output included in the production frontier

Variable	Description	Expected sign
R = Rice output	Total quantity of rice output in kilogram	
Production Function		
X_1 = seed	The quantity of seed (kg) planted on total land area	+
X_2 = Fertiliser	The total quantity of chemical fertiliser (kg) applied on total land area	+
X_3 = Labour	The quantity of labour used (in mandays) on total land area	+
X_4 = Pesticides	The amount of money (Ghana Cedis) spent on pesticides for the total land area	+
X_5 = Land	Land area under rice cultivation in hectares	+

The positive signs for the inputs (seed, fertiliser, labour, pesticides and land) imply that the variables are expected to increase the productivity level of rice farms indicating that an increase in one of these variables should increase the level of rice output. The next section presents the specification of the technical inefficiency model.

4.2.3. The Technical Inefficiency Model

4.2.3.1. Specification of the Technical Inefficiency Model

The inefficiency model was used to identify sources of variation in technical efficiency among rice farmers in the two districts. The inefficiency model would help one to determine the factors that improve the efficiency levels of the farmers in the two districts. The inefficiency model was specified as:

$$U_i = \delta_0 + \sum_{j=1}^{11} \delta_j Z_{ij} + \xi_i \qquad i = 1, 2, \ldots, N \tag{7}$$

where U_i denotes the technical inefficiency of the i-th rice farm in each district. Z_{ij} is a vector of explanatory variables associated with the inefficiency effect. The explanatory variables are related to institutional, socioeconomic and technological factors. δ_0 and ξ_i refer to the constant term and the error term respectively. δ_j denotes a vector of unknown parameters to be estimated. The variables included in the inefficiency model are described in the next section.

4.2.3.2. Description of Variables Included in the Technical Inefficiency Model.

Eleven (11) explanatory variables were included in the inefficiency model. The description of the inefficiency variables together with their expected signs are summarised in Table 4.2. The negative signs of the variables in the technical inefficiency model indicate that the associated variables reduce inefficiency in rice production while positive signs imply that the variables increase inefficiency. Since the model use inefficiency as the dependent variable it is expected that variables with a negative sign would increase technical efficiency while variables with a positive signs would reduce technical efficiency of rice production in the study areas. The next section discusses the estimation of the metafrontier function.

Table 4.2. Definition of the inefficiency variables

Variable	Description	Expected sign
Institutional		
Z_1 = Extension contact	1, if farmer had contact with extension agent and 0 otherwise	-
Z_2 = Credit access	1, if farmer had access to credit and 0 otherwise	-
Z_3 = Distance to market	Distance (km) from farmer's house to the nearest market	+
Z_4 = Access to irrigation water	1, if farmer had access to irrigation water and 0 otherwise	-
Z_5 = Land renting	1, if farmer rented the farmland and 0 otherwise	-
Socioeconomic		
Z_6 = Age	Years	-
Z_7 = Education	Number of years of formal schooling	
Z_8 = Household size	Number of people in the household	-
Z_9 = Farm size	Land area under rice cultivation	-
Technological		
Z_{10} = Row-planting	1, if farmer planted rice seeds in rows and 0 otherwise	-
Z_{11} = Improved rice variety	1, if farmer planted improved rice seed variety and 0 otherwise	-

4.3. Metafrontier Model

The stochastic frontier analysis assumes that production environments and technologies used by farmers are similar. However, in the case where production environments and technologies are different, the use of a single production frontier to analyse productivity and efficiency would result in inaccurate results due to heterogeneity in technology. To address this heterogeneity problem, Battese and Rao (2002), Battese *et al*. (2004) and O'Donnell *et al*. (2008) proposed the metafrontier model. The metafrontier model estimates the efficiency of heterogeneous groups based on their distance from a common and identical frontier. The metafrontier function originated from the idea of meta-production developed by Hayami (1969), and Hayami and Ruttan (1970). The metafrontier production function is illustrated graphically in Figure 4.1.

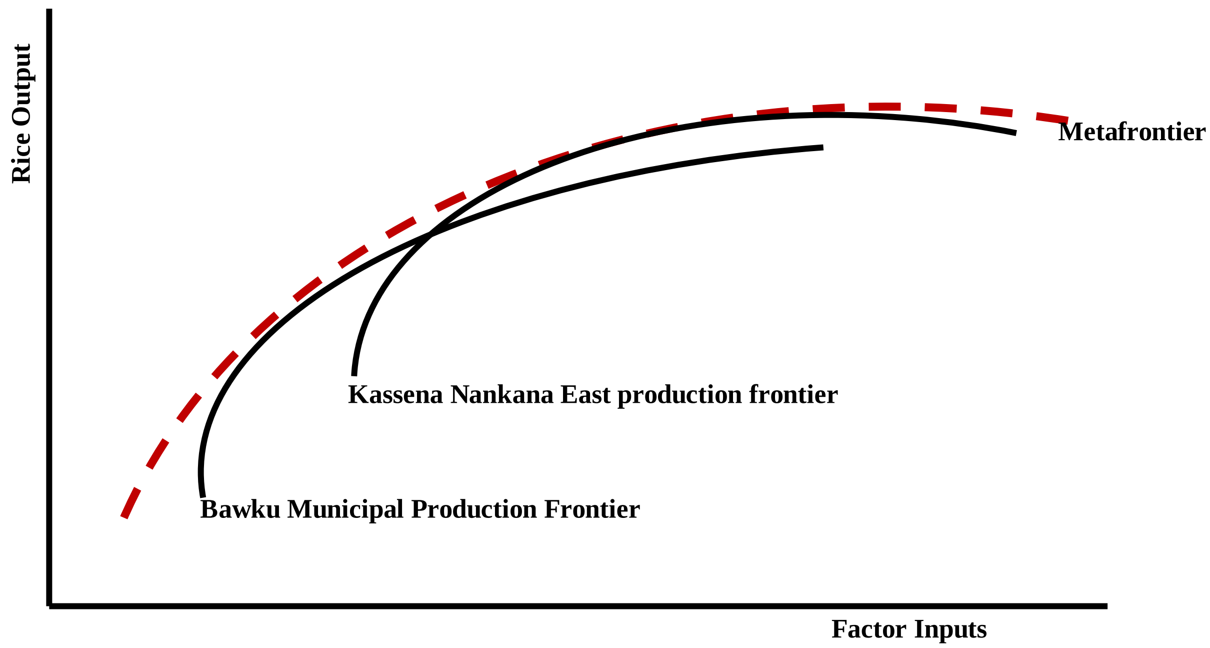

Figure 4.1. Illustration of Metafrontier.

Source: Adopted from Mariano *et al*. (2010)

The individual production frontiers indicate the state of technology regarding the transformation of inputs into rice output with respect to those two districts. The production frontiers for Kassena Nankana and Bawku Municipal envelops together to form the metafrontier function as indicated by the dotted line in Figure 4.1. The metafrontier function reflects the state of technology at the regional level or the rice industry as a whole. The distance from the individual frontiers to the metafrontier measures the technology gap ratio. The specification of the metafrontier model is presented in the next subsection.

4.3.1. Estimation of Metafrontier Model

The metafrontier frontier model was used to estimate a metafrontier function and technology gap ratio as well as technical efficiency relative to the metafrontier. The technology gap ratio and the technical efficiency relative to the metafrontier would be used to compare the efficiency of the farmers in the two districts.

The metafrontier production function takes the same functional form (Cobb-Douglas) as the production frontier for the two districts. Following Battese and Rao (2002), Battese *et al*. (2004) and Rao *et al*. (2005), the metafrontier production function was specified as:

$$\ln R_i^* = \beta_0^* + \sum_{j=1}^{5} \beta_j^* \ln x_{ij}^* \quad i = 1, 2, ..., N \qquad (8)$$

The asterisk sign (*) is used to indicate that the rice output (R_i^*) and inputs (x_{ij}^*) for two districts were pooled together to estimate the metafrontier. β_0^* denotes the constant term for the metafrontier. β_j^* denotes vector of parameters of the metafrontier function such that:

$$x_i\beta^* \geq x_i\beta \tag{9}$$

β denotes a vector of parameters of the individual district stochastic frontiers. The parameters (β^*) of the metafrontier function were estimated by minimising the summation of the differences between the metafrontier function ($\ln f(x_i, \beta^*)$) and the stochastic frontier for the pooled sample ($\ln f(x_i, \hat{\beta})$). The optimisation problem can be expressed mathematically as:

$$\text{Minimise} \sum_{i=1}^{N} |[\ln f(x_i, \beta^*) - \ln f(x_i, \hat{\beta})]| \tag{10}$$

subject to

$$\ln f(x_i, \beta^*) \geq \ln f(x_i, \hat{\beta}) \tag{11}$$

The solution to the above optimisation problem is equivalently obtained by minimising the objective function ($\bar{x}\beta^*$), subject to the linear restrictions of equation (11), where $\bar{x}$ is the row vector of means of the element of the x_i – vectors for all farms in the data set. The estimates of the stochastic frontiers for the different districts ($\hat{\beta}$) are assumed to be fixed for the linear programming problem (Battese *et al*., 2004). SHAZAM 9 was used to solve the linear optimisation problem in order to obtain the parameters (β^*) for the metafrontier. The estimation procedure for the technology gap ratio and the technical efficiency relative to the metafrontier is presented in the next subsection.

4.3.2. Estimation of Technology Gap Ratio

The technology gap ratio measures the ratio of the output for the frontier production function for each district relative to the potential output that is defined by the metafrontier function, given by the observed inputs (Battese and Rao, 2002; Battese *et al*., 2004; Villano *et al*., 2010). The values for the technology gap ratio ranges between zero and one. The technology gap ratio is relevant in explaining the technological gap faced by farmers in the two districts when their performances are compared with the regional technology. The technology gap ratios for the two districts were computed as:

$$TGR_i = \frac{e^{x_i\beta}}{e^{x_i\beta^*}} \tag{12}$$

where TGR_i is the estimated technology ratios of each district. $e^{x_i\beta}$ denotes the deterministic production frontier for the individual district frontier while $e^{x_i\beta^*}$ represents the metafrontier.

Comparing technical efficiency of farmers where production frontiers vary among locations is possible only if there is a common reference for all the farmers upon which their efficiency scores are estimated. For technical efficiency scores relative to the districts, the references (production environment and technology) are different. Therefore, using this technical efficiency as a performance comparison between these two districts can be misleading. Taking the metafrontier as a reference, the performance of the rice farmers in the two districts can be compared. The technical efficiency relative to the metafrontier is a more appropriate comparative performance measure. The technical efficiency relative to the metafrontier for each district illustrates the efficiency of each district using a similar technology in the region. The technical efficiency relative to the metafrontier is the product of the technical efficiency relative to the individual frontiers and technology gap ratios. The technical efficiency relative to the metafrontier is expressed mathematically as:

$$TE_i^* = TE_i \ \text{x} \ TGR_i \tag{13}$$

TE_i^* is the technical efficiency of each district relative to the metafrontier. The various hypotheses formulated in the study are presented and explained in the next section below.

4.4. Hypothesis Testing

Hypothesis testing was used to test for the presence of technical inefficiency, non-stochastic effect of the technical inefficiency term, relevance of explanatory variables to explain the variation in technical inefficiency for the Kassena Nankana and Bawku Municipal, and the appropriateness of the use of the metafrontier. The hypotheses put forward for the study are as follows:

1. H_0: $\gamma = \delta_0 = \delta_1 = ... = \delta_{11} = 0$ (14)

The null hypothesis specifies that no technical inefficiencies exist in rice production in the two districts. This hypothesis was used to check if there was inefficiency of rice production in the study areas and also to determine if there was need to specify an inefficiency model.

2. H_0: $\gamma = 0$ (15)

The null hypothesis states that the technical inefficiency effects are non-stochastic. The hypothesis was used to test for the presence of inefficiency in the rice production data since the modelled production function reduces to a simple Ordinary Least Squares (OLS) if no inefficiencies exist.

3. H_0: $\delta_1 = ... = \delta_{11} = 0$ (16)

The null hypothesis indicates that the coefficients of the variables in the inefficiency model do not jointly influence technical inefficiency of rice production in the study areas. Should the null hypothesis be rejected, a production function and inefficiency model should be fitted as opposed to a production function which includes all the explanatory variables.

4. H_0: $f(x_{ij}, \beta_j^{Pool}) = f(x_{ij}, \beta_j^{KNE}) = f(x_{ij}, \beta_j^{BM})$ (17)

The null hypothesis states that farmers in Kassena Nankana, Bawku Municipal as well as the pooled sample are using similar technologies and that the district production frontiers are the same for all the farms. Accepting the null hypothesis implies that the two districts are homogenous and that a single production function can be fitted to estimate the productivity and efficiency of the two districts. Rejecting the null hypothesis would mean that the two districts are heterogeneous in the technology applied and two production frontiers should be fitted to estimate productivity and efficiency of the two districts. Furthermore, if the researcher wishes to make comparisons between the two heterogeneous districts a metafrontier should be estimated to allow for a common frontier to which comparisons can be made.

All hypotheses were carried out using generalized likelihood-ratio (LR) test. The test statistics (λ) is defined as:

$$\lambda = -2[L(H_0) - L(H_a)] \tag{18}$$

where $L(H_0)$ and $L(H_a)$ are the values of the log likelihood functions for unrestricted (H_0) and the restricted (H_a) models (Coelli, 1995). The test statistics have an approximately asymptotic chi-square or mixed chi-square (χ^2) distribution with degrees of freedom equal to the number of parameters specified to be zero in the null hypothesis (Kodde and Palm, 1986) therefore the Kodde and Palm chi-square distribution tables are used. The estimated test statistics are compared to the Kodde and Palm (1986) critical values at a five percent significance level. The null hypotheses are rejected if the χ^2 statistic estimated exceeds the χ^2 critical value.

4.5. Summary and Conclusion

Stochastic frontier analysis was used to fit a rice production frontier for Kassena Nankana and Bawku Municipal in Ghana. Frontier 4.1 (Coelli, 1996) was used to estimate a production frontier and a technical inefficiency model simultaneously. The technical inefficiency model can help identify the factors that contribute to inefficiency. Five farm inputs namely, seed, fertiliser, pesticides, land and labour were included in the stochastic frontier models while 11 inefficiency variables (extension contact, credit access, distance to market, access to irrigation water, land renting, age, education, household size, farm size, row-planting and improved rice variety) were included in the inefficiency models. The technical efficiency scores would be predicted based on the stochastic frontier model fitted for each of the districts.

The use of stochastic frontier model to fit production frontier and estimate technical efficiency under heterogeneous production environments and technologies would result in inaccurate results. To address this heterogeneity problem, a metafrontier model is estimated to fit a common frontier to which comparisons can be made. The metafrontier model estimates the efficiency of heterogeneous groups based on their distance from a common and identical frontier. The estimated parameters from the production frontier for the two districts are used together with the pooled data to estimate the metafrontier. The Shazam 9 software uses a linear programming approach in the estimation of the metafrontier. Comparative efficiency measures such as the technology gap ratio and technical efficiency relative to the metafrontier are predicted from the metafrontier function for the two districts. The technology gap ratio defines the distance between the estimated production frontiers and the metafrontier. The technical efficiency relative to the metafrontier is the product of the technical efficiency relative to the individual frontiers and technology gap ratios.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1. Introduction

The results for the production frontiers and technical efficiency scores for the individual districts (Bawku Municipal and Kassena Nankana East) are presented and discussed in the first section along with the results for the hypothesis tests that were performed during the estimation of the production frontiers. The sources of variation in technical inefficiency for the two districts are presented and discussed in the second section. The results of the metafrontier function including the hypothesis tests performed using the metafrontier, the technology gap ratio and technical efficiency scores relative to the metafrontier are presented and discussed in the third section. The chapter conclusion is presented in the last section.

5.2. Production Frontiers and Technical Efficiency Estimated for the Two Research Districts

5.2.1. Stochastic Production Frontier Results

The first objective of the study is to estimate the technical efficiency of the rice producers in the study areas using a stochastic production frontier. The maximum likelihood estimates for the stochastic production frontiers for the study areas together with diagnostic statistics are provided in Table 5.1. The dependent variable was rice output (kg) which was regressed against the farm inputs.

Table 5.1. MLE estimates of Cobb-Douglas production frontiers for Kassena Nankana East and Bawku Municipal

Variable	Parameter	Kassena Nankana East			Bawku Municipal		
Rice output (*R*)		Coefficient	t-value	Prob	Coefficient	t-value	Prob
Constant	β_0	5.080***	7.257	0.000	5.384 ***	114.803	0.000
Inseed (X_1)	β_1	0.335**	2.120	0.035	0.430***	5.584	0.000
Infertiliser (X_2)	β_2	0.046***	3.286	0.001	0.104***	13.000	0.000
Inpesticide (X_3)	β_3	-0.006	-0.188	0.852	0.016	0.356	0.728
Inland (X_4)	β_4	0.416**	2.568	0.011	0.628***	14.952	0.000
Inlabour (X_5)	β_5	0.104*	1.891	0.058	0.009	0.130	0.898
Diagnostic Statistics							
Sigma square	$\sigma^2 = \sigma_U^2 + \sigma_V^2$	0.270***	6.750	0.000	0.490***	5.833	0.000
Gamma	$\gamma = \sigma_U^2 / \sigma^2$	0.568***	7.474	0.000	0.990***	4950	0.000
Ln (likelihood function)	*LF*	-168.826			-47.324		
Number of observation	*N*	333			120		

***, ** and * denote 1%, 5% and 10% significant levels respectively.

The diagnostic statistics include sigma-squared, gamma and log likelihood function values. The estimated sigma-squared values for Kassena Nankana and Bawku Municipal are 0.270 and 0.490 respectively. These sigma-squared values are all significant at a 1% level, indicating that the one-sided error term dominates the symmetry error suggesting a good fit and the distributional assumption is correctly specified. The gamma parameter (γ) measures the total variation of output from the frontier which is attributed to technical inefficiency. The gamma values (0.568 and 0.990) for both Kassena Nankana and Bawku Municipal respectively are highly significant at a 1% level. From the empirical results, the gamma value (0.990) for Bawku Municipal is higher than that of Kassena Nankana with a gamma value of 0.568. The gamma value for Bawku Municipal (0.990) indicates about 99% of the variability in rice output of Bawku Municipal is due to technical inefficiency while only 1% of the variation is explained by random shock and measurement error. This result indicates that the impact of technical inefficiency in Bawku Municipal may be very high. However, for Kassena Nankana about 56.80% of the variation in rice output is explained by technical inefficiency while 43.20% of the variation is due to random shocks and statistical noise. Generally, the variation in rice production for the study areas is primarily as a result of technical inefficiency on the part of the rice farmers. The implication is that the average production function which has no technical inefficiency effects is not an adequate representation of the data (Battese *et al*., 1996).

The next discussion is on the estimated stochastic frontiers for the two districts. The discussion first begins with the stochastic frontier results for Kassena Nankana before turning to that of Bawku Municipal.

The estimated coefficients of the variables in the stochastic production frontier for Kassena Nankana given in Table 5.1 showed the expected positive signs except pesticide which shows a negative sign. The variables with positive signs indicate that rice output is positively related to those variables while negative sign shows that an increased use of the input (pesticides) will reduce rice output. The negative effect of pesticides may be due to fact that farmers in Kassena Nankana are not applying appropriate type of pesticides which tended to affect the rice crop. However, pesticide use is not significant in the estimation of the production frontier indicating that pesticide does not contribute to rice production. Of the variables that have a positive correlation with rice production, land and seed are significant at 5%, while fertiliser and labour are significant at 1% and 10% respectively. The inputs that are important for rice production are therefore, land, seed, fertilizer and labour. From Table 5.1, the elasticity (denoted by the coefficients) of land had the greatest significant impact on rice output followed by seed, labour and fertiliser.

In Bawku Municipal, all the variables have the expected positive signs. The variables with the positive signs imply that they positively influence rice output when their quantities are increased. Seed, fertiliser and land are significant at the 1% level while pesticides and labour are not significant even at 10% indicating that labour and pesticides are not significant inputs for rice production in Bawku Municipal. Evaluating the elasticity of the inputs, land had the greatest elasticity followed by seed and fertiliser. The elasticity represents that a percentage change in output resulting from a proportionate change in an input.

The empirical results demonstrate that land is a critical factor in promoting rice production in the study areas since the elasticity of rice yield with respect to land is found to be the highest for the two districts. The findings of the study corroborates with that of Seidu (2012) and Islam *et al*. (2012) who found land to be positively related to rice output in Ghana and Bangladesh respectively. Abedullah *et al*. (2007), Ogundari (2008), Seidu (2008) and Yiadom *et al* (2013) found that seed and fertiliser had a significant influence on rice output in Pakistan, Nigeria and Ghana respectively.

5.2.2. Technical Efficiency of the Rice Farmers in the Study Areas

Based on the estimated production frontiers, the technical efficiency scores for the rice producers in the two districts were calculated. The technical efficiency scores are represented in Figure 5.1 as a cumulative density function (CDF). The CDF shows the technical efficiency scores as a continuous distribution in order to evaluate the technical efficiency scores.

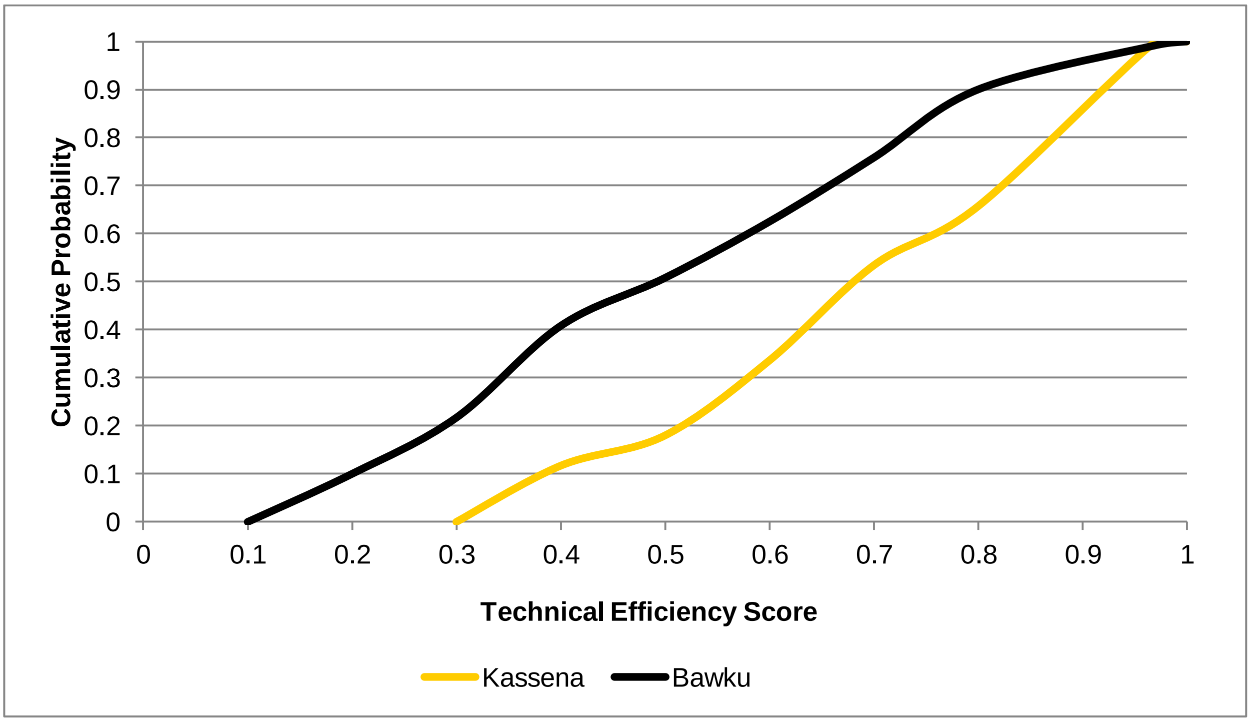

Figure 5.1. Cumulative Probability of Technical Efficiency Scores

The cumulative probability indicates that there is a wide gap between the efficiency of farmers in the two districts regarding the lowest and highest estimated technical efficiency. About 50% of the sample in Kassena Nankana had technical efficiency levels between 0.68 and 0.97 while in Bawku Municipal, the same 50% of the sample obtained technical efficiency scores ranging from 0.49 to 1.00. The results indicate that most of the rice producers in Kassena Nankana are using farm inputs efficiently with the available technology in the district.

The summary statistics of technical efficiency scores among rice producers in Kassena Nankana and Bawku Municipal are presented in Table 5.2.

Table 5.2. Summary statistics of the technical efficiency scores of the farmers in Kassena Nankana East and Bawku Municipal

Statistic	Kassena Nankana East	Bawku Municipal
Average	0.769	0.591
Minimum	0.291	0.089
Maximum	0.965	1.000
Standard deviation	0.176	0.237

The minimum and maximum technical efficiency for Kassena Nankana are 29.10% and 96.50% respectively. The average technical efficiency of 76.90% for Kassena Nankana indicates that on average there is a potential for rice farmers in Kassena Nankana to expand their production by about 23.10% by operating at full technical efficiency level. The rice producers can achieve full efficiency level by utilising existing farm resources and technologies.

The technical efficiency level of Bawku rice farmers ranges from 8.90% to 100%. Bawku Municipal farmers obtained an average technical efficiency of 59.91% suggesting that on average the scope of Bawku rice farmers to increase the level of efficiency using available farm resources and technologies is about 40.09%. The general implication of the results is that there is large potential for rice farmers in the study areas to increase rice production by improving their technical efficiency levels.

The average technical efficiency scores of Kassena Nankana (76.90%) and Bawku Municipal (59.10%) are higher than the findings of Seidu (2012) and Yiadom *et al*. (2012) who observed that the average technical efficiency of rice producers in Upper East and Ashanti regions of Ghana were 53% and 25% respectively. However, Donkoh *et al.* (2013) obtained relatively higher technical efficiency of 81%. Furthermore, the average technical efficiency scores of the rice producers in the study areas are fairly consistent with rice studies in other African and Asian countries. Tijani (2006) and Ogundari (2008) estimated the technical efficiency of rice farmers in Nigeria to be 86% and 75% respectively. Danhounsi *et al*. (2013) found the technical efficiency of rice producers in Benin to be 70%. The average technical efficiency found by Abedullah *et al*. (2007) among rice farmers in Pakistan was 91%. Rahman *et al*.

(2012) and Islam *et al*. (2012) found the technical efficiency of rice producers in Bangladesh to be 88% and 89% respectively.

One can infer that the rice producers are operating below the production frontier suggesting that there is still room for rice farmers in the study areas improve their efficiency level to reach the frontier threshold in order to meet high rice consumption in the Ghana. The technical efficiency levels of the farmers in the two districts differ from each other suggesting that location plays a significant role in explaining efficiency. The results indicate that fitting different production frontiers for the two districts is necessary in order to provide specific policy recommendations that are required to improve the performance of the farmers in each district.

5.2.3. Hypothesis Testing

A generalised likelihood ratio is used to test for the presence of technical inefficiency and; if there is need to include the hypothesised explanatory variables in the inefficiency model. The parameters are derived from the frontier estimations. The hypotheses formulated in the study, the calculated test statistic, the Kodde and Palm critical value and the decisions are provided in Table 5.3.

Table 5.3. Results of testing of hypotheses

Null hypothesis	Location	Test statistic	Degree of freedom	Critical value[a]	Decision
1. H_0: $\gamma = \delta_0 = \delta_1 = ... = \delta_{11} = 0$	Kassena Nankana	110.60	12	20.410	Reject H_0
	Bawku Municipal	53.52	12	20.410	Reject H_0
2. H_0: $\gamma = 0$	Kassena Nankana	27.84	1	2.706	Reject H_0
	Bawku Municipal	30.14	1	2.706	Reject H_0
3. H_0: $\delta_1 = ... = \delta_{11} = 0$	Kassena Nankana	100.62	11	19.045	Reject H_0
	Bawku Municipal	28.10	11	19.045	Reject H_0

[a]The critical values were obtained from the Kodde and Palm Chi-square Table.

The first null hypothesis, $H_0: \gamma = \delta_0 = \delta_1 = ... = \delta_{11} = 0$, tests for the presence of technical inefficiencies in rice production of the two districts. The null hypothesis assumes that technical inefficiency effects are not present in rice production. From Table 5.3, the estimated test statistics for the Kassena Nankana and Bawku Municipal are 110.60 and 53.52 respectively, which are greater than the critical value of 23.069 at a 5% level. Therefore, the null hypothesis is rejected. The rejection of the null hypothesis implies that there is technical inefficiency in the rice production in the study areas and hence, the use of stochastic frontier analysis is justified.

The second null hypothesis, $H_0: \gamma = 0$, states that the technical inefficiency effects are non-stochastic. Under $\gamma = 0$, the stochastic frontier model reduces to the conventional average response functions in which explanatory variables in the inefficiency model are included in the production function. The null hypothesis is rejected at a 5% level since the test-statistics (27.84 and 30.14) for the two districts are greater than the critical value of 2.706. The rejection of the second hypothesis suggests that the technical inefficiency effects are random and therefore, a stochastic production function and inefficiency model should be specified separately.

The third null hypothesis, H_0: $\delta_1 = ... = \delta_{11} = 0$, implies that the coefficients of the variables in the inefficiency model do not jointly influence technical inefficiency of rice production in the study areas. The null hypothesis is rejected at a 5% level due to the fact that the test statistics for Kassena Nankana (100.62) and Bawku Municipal (28.10) are greater than the critical value of 21.742. Rejecting the hypothesis confirms the presence of technical inefficiency and the need to include inefficiency variables in the inefficiency model.

5.3. Factors Determining Technical Inefficiency in Rice Production

The results of the hypothesis tests indicate that there is technical inefficiency in the study areas, suggesting the need to identify the sources of the variation in the technical inefficiency among the rice producers in the study areas. The estimates of the inefficiency model are estimated together with the stochastic frontier using Frontier Version 4.1. The maximum likelihood estimates of the determinants of technical inefficiency of rice production in the study areas together with their corresponding t-values and probabilities are provided in Table 5.4. The results for the inefficiency model of Kassena Nankana are discussed first followed by the factors that determine inefficiency in the Bawku Municipal. It should be noted that the empirical model used technical inefficiency as the dependent variable which is regressed against the explanatory variables. Therefore, the results can be interpreted from a technical efficiency point of view where a positive sign would indicate reduced technical efficiency and a negative sign would show increased technical efficiency.

Table 5.4. Determinants of technical inefficiency for rice production in Kassena Nankana East and Bawku Municipal

Variable	Parameter	Kassena Nankana East			Bawku Municipal		
Technical inefficiency (*ui*)		Coefficient	t-value	Prob	Coefficient	t-value	Prob
Constant (Z_0)	δ_0	1.169***	2.872	0.004	0.092	0.125	0.901
Extension contact (Z_1)	δ_1	-2.621 *	-1.941	0.053	-0.452**	-2.093	0.039
Credit access (Z_2)	δ_2	0.014*	1.750	0.081	0.006	1.120	0.265
Distance to market (Z_3)	δ_3	1.207	0.965	0.335	1.978**	2.497	0.014
Access to irrigation water (Z_4)	δ_4	0.010	0.055	0.956	0.948**	2.488	0.014
Land renting (Z_5)	δ_5	-0.125	-0.962	0.338	-0.598***	-3.181	0.002
Age (Z_6)	δ_6	-0.003	-0.750	0.454	0.002	0.333	0.740
Education (Z_7)	δ_7	-0.003	-0.250	0.803	-0.061*	-1.694	0.093
Household size (Z_8)	δ_8	-0.089***	-3.179	0.002	0.061	1.326	0.187
Row-planting (Z_9)	δ_9	-0.313**	-2.504	0.013	-0.475**	-2.411	0.017
Improved rice variety (Z_{10})	δ_{10}	0.099	0.544	0.587	-0.139	-0.422	0.674
Farm size (Z_{11})	δ_{11}	-0.260	-0.958	0.339	-0.102	-0.434	0.665
Observation	*N*	333			120		

***, ** and * denote 1%, 5% and 10% significant levels respectively.

The empirical results in Table 5.4 show that extension contact, household size, credit access and row-planting are the significant contributors to technical efficiency in rice production in

Kassena Nankana. Extension contact has a negative coefficient with technical inefficiency of rice production in the study area and is statistically significant at a 5% level. The negative effect of extension contact on technical inefficiency implies that as farmer's contact with extension agents increases, they tend to be more technically efficient. Farmers who have contact with extension agents are likely to adopt modern technologies in rice production which include land preparation, planting, application of agro-chemicals and harvesting. The extension agents provide farmers with the necessary information regarding the modern technologies which enable the farmers to use the technology. As a result, farmers are able to reduce inefficiencies which tend to increase the productivity levels. The result is consistent with the findings of Seidu (2008), Adeyemo *et al*. (2010) and Ogundari *et al*. (2010) who observed that extension services promote technical efficiency of rice production. However, Islam *et al*. (2010) and Yiadom *et al*. (2013) indicated that access to extension services did not have any significant influence on technical inefficiency of rice production in Ghana.

Nuryartono *et al*. (2005), Stefan *et al*. (2011) found access to microfinance to increase technical efficiency by reducing inefficiency in rice production. Nuryartono *et al*. (2005) and Stefan *et al*. (2011) further explained lack of credit decreases the efficiency of the farmers by limiting their adoption of high yielding varieties and the ability to acquire information for increased productivity. Contrary to the results by Nuryartono *et al*. (2005) and Stefan *et al*. (2011), in this research, access to credit is positive and statistically significant at a 5% level for Kassena Nankana, suggesting that access to credit tends to reduce efficiency in rice production. A possible reason may be that farmers who received credit did not have the funds on time to purchase the necessary inputs for rice production.

Household size in Kassena Nankana shows the expected negative sign and is found to be statistically significant at a 1% level. The negative effect of household size implies that as farmers' household size increases, technical efficiency in rice production decreases. Large households provide family labour to implement farm management decisions and extra hands to help with production activities. A similar empirical finding was found by Msuya *et al*. (2008) and Seidu (2012) who indicated that large farming households tend to be technically efficient in rice production.

Row-planting has a negative effect on technical inefficiency for Kassena Nankana and is statistically significant at a 5% level. The implication of this result is that farmers who planted their rice seeds in rows are more likely to be technically efficient than those who broadcast. Row-planting tends to make the application of agro-chemicals and harvesting of rice more efficient. Row planting also reduces overcrowding of seedlings as compared to broadcasting resulting in better crop growth and therefore increased efficiency.

Market distance, access to irrigation and improved seed variety decreases technical efficiency while land renting, age and education tend to increase technical efficiency in rice production. However, none of the variables mentioned above is statistically significant and therefore does not result in a significant change in rice production. The next discussion focuses on the factors affecting the technical inefficiency of farmers in Bawku Municipal.

The results from Table 5.4 indicate that extension contact, distance to the market, access to irrigation water, renting of land, education and row-planting have significant effects on technical inefficiency of rice production in Bawku Municipal.

Extension contact negatively influence technical inefficiency of rice production in Bawku Municipal and is statistically significant at a 1% level. This negative effect of extension contact on technical inefficiency indicates that as farmers' contact with extension agents increases, their efficiency level tends to increase. Similar to results for Kassena Nankana, extension agents provide farmers with useful information on modern technologies in rice production including information on land preparation, planting, application of agro-chemicals and harvesting. Consequently, farmers are able to increase efficiency which tends to promote the productivity levels. The result corroborates with the findings of Seidu (2008), Adeyemo *et al*. (2010) and Ogundari *et al*. (2010) who found that farmers' access to extension services increase technical efficiency of rice production.

The coefficient of distance to market shows the expected positive sign for Bawku farmers and is statistically significant at a 1% level, indicating that as distance to market increases, farmers' technical efficiency decreases. Since proximity to market increases farmer's access to factor inputs and income generating activities, it is expected that farmers who are closer to markets would show greater levels of efficiency compared to farmers who are further away from the market. Bagamba *et al*. (2007) and Aye and Mungatana (2012) found that farms located closer to the markets are more technically efficient than the farms located away from the market. Access to irrigation water does not have the expected negative sign for Bawku Municipal and is statistically significant at a 1% level. The positive sign for access to irrigation water suggests that farmers in Bawku Municipal who have access to irrigation water tend to be inefficient which is inconsistent with empirical literature (Seidu, 2012). A probable reason could be that the farmers are over-flooding their rice fields which can negatively affect the growth of the rice plant and consequently reduce the yield.

Land renting is statistically significant at a 1% level and shows the expected negative sign for Bawku Municipal. The negative effect of land renting on inefficiency for Bawku Municipal indicates that farmers who rent their rice farms tend to be more technically efficient in rice production. Tenants who pay rent tend to use their resources more productively which have potential to increase productivity and hence, increase farm profit which aids the tenants to pay land rent. The result is consistent with the findings of Iqbal *et al*. (2001), Anyaegbunam *et al*. (2010) and Abdulai *et al*. (2011) who found that land renting negatively influenced technical inefficiency.

The coefficient of education is statistically significant at a 10% level and shows the expected negative sign for Bawku Municipal. This result suggests that educated farmers in Bawku Municipal are more likely to be more technically efficient in rice production which is consistent with empirical literature that education enhances the managerial skills of farmers (Weir and Knight, 2000; Baerenklau, 2005). Farmers tend to learn new farm technologies as their level of education increases. On the other hand, a study by Mohammed *et al*. (2013) indicated that education negatively influenced technical efficiency. Mohammed *et al*. (2013) explained that educated households are less efficient in agricultural production if education increases farmers' returns from non-farm activities, thereby reallocating attention or management from farm to nonfarm activities.

Row-planting is negatively related to technical inefficiency for Bawku Municipal and is statistically significant at a 5% level. The result implies that farmers who sow their rice seeds in rows tend to be more efficient technically in production compared to the farmers who used broadcasting. Similar to row-planting in Kassena Nankana, row-planting in Bawku Municipal reduces overcrowding of rice plants and hence, competition for nutrients among plants becomes less. Application of agro-chemicals and harvesting of rice becomes more efficient when rice seeds are planted in rows.

Access to credit, age and household size have a positive relationship with technical inefficiency but are insignificant. While rice variety and farms size show a negative relationship with technical inefficiency. None of the variables are significant and therefore are not significant contributors to technical efficiency.

Some similarities exist in the results obtained for Kassena Nankana and Bawku Municipal (i.e. extension contact and row-planting). However, as a rule, the coefficients and variable significance differ between the two districts. Therefore, factors that increase or decrease technical efficiency in the two districts are different. The conclusion is that district specific information is necessary to ensure that farmers receive correct information on the factors that will increase their technical efficiency levels.

5.4. Estimation of the Metafrontier Production Function

5.4.1. The Metafrontier Production Function

The third objective is to fit a metafrontier for the Upper East region of Ghana using the estimated coefficients of the Kassena Nankana and Bawku Municipal. The parameters of the metafrontier function were estimated with a linear programming approach using SHAZAM 9. The estimates of the metafrontier function are presented in Table 5.5. The metafrontier function represents the production frontier for the region (Upper East region) or the rice industry as a whole. Linear programming models do not report standard errors and therefore, variables significance cannot be determined.

Table 5.5. The estimates of the metafrontier production function

Variable	Parameter	Coefficient
Rice output (R^*)		
Constant	β_0	5.080
Lnseed (X_1)	β_1	0.335
Lnfertiliser (X_2)	β_2	0.046
Lnpesticide (X_3)	β_3	-0.006
Lnland (X_4)	β_4	0.416
Lnlabour (X_5)	β_5	0.104

All the coefficients of the variables included in the metafrontier function have the expected positive effects except pesticides which show a negative sign. The positive signs imply that an increase in the farm inputs would increase the rice output at the regional level and the reverse is true. The negative effect of pesticide on the output relative to the metafrontier can be that the rice producers are not applying the appropriate type of pesticides on the crops which affected the crop growth and the yield.

The hypothesis test that justified the estimation of the metafrontier is presented in the next section.

5.4.2. Hypothesis Testing on the Metafrontier

A generalised likelihood ratio test was used to validate the appropriateness of the estimation of the metafrontier model. The results on the hypothesis tests are presented in Table 5.6.

Table 5.6. Results of testing of hypotheses

Null hypothesis	Test statistic	Degree of freedom	Critical value	Decision
4. $f(x_i, \beta^{Pool}) = f(x_i, \beta^{KNE}) = f(x_i, \beta^{BM})$ *	78.84	3	7.045	Reject H_0

*KNE and BM denote Kassena Nankana East district and Bawku Municipal respectively.

The null hypothesis, H_0: $f(x_i, \beta^{Pool}) = f(x_i, \beta^{KNE}) = f(x_i, \beta^{BM})$, implies that farmers in Kassena Nankana, Bawku Municipal as well as the pooled sample are using similar technologies and that the district frontiers are the same for all three samples. The null hypothesis is rejected in favour of the alternative since the test statistic (78.84) is greater than the critical value (7.045). The result justifies the specification of different production frontiers for the two districts since the production environments and technologies are heterogeneous between the two areas.

5.4.3. Technology Gap Ratio (TGR)

The existence of heterogeneous technology and the need for a metafrontier suggest that a technology gap exists between the metafrontier and the district frontiers. The TGR shows by how much the highest output in the region (Kassena Nankana or Bawku Municipal) should increase to achieve the output as given on the metafrontier using the current input set. The TGR values for the two districts are illustrated in a cumulative probability graph in Figure 5.2 to show the frequency distribution of the TGR among the rice producers in the two districts. The cumulative probability distribution graph shows that there is a wide gap between the TGR values for the two districts.

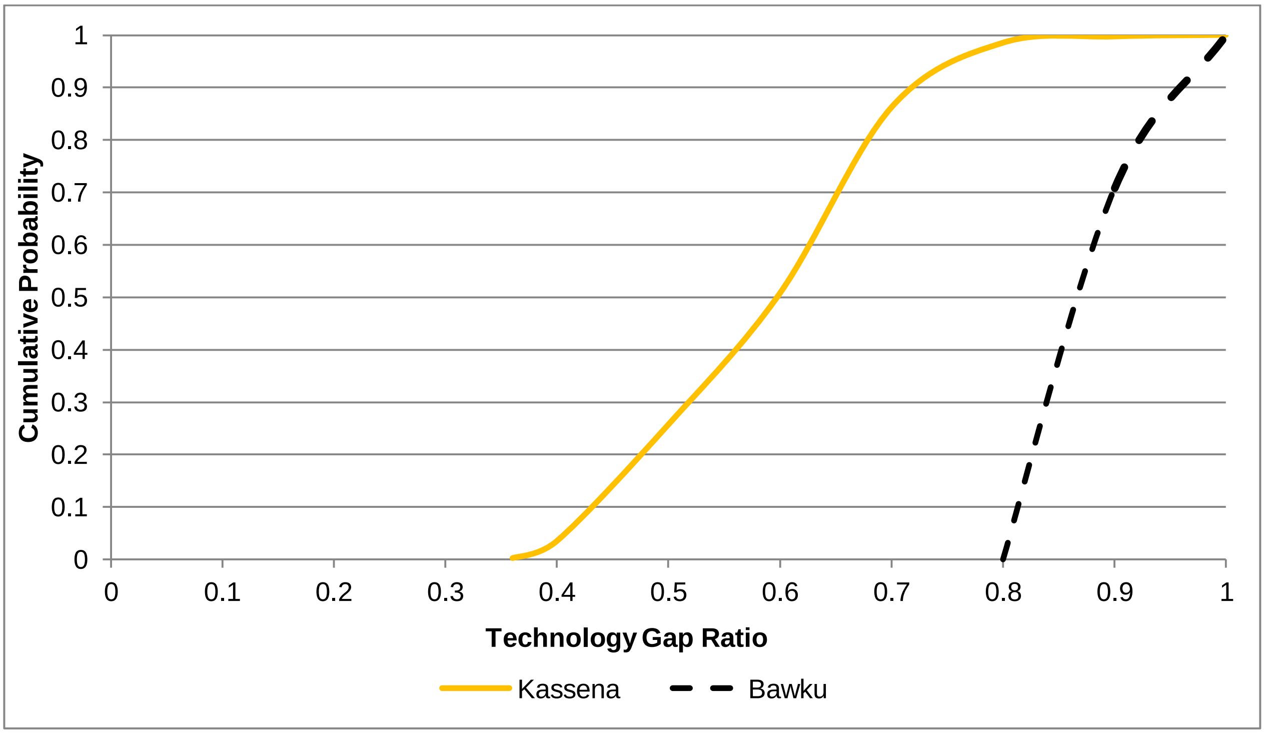

Figure 5.2. Cumulative Probability of Technology Gap Ratio

Figure 5.2 indicates that about 50% of Bawku rice farmers show an estimated TGR of 0.85 or higher while 50% of the farmers in Kassena Nankana have a TGR ranging from 0.60 to 1.00. The results also indicate that 50% of the farmers in Kassena Nankana produce at least 60% or more of the potential rice output given the technology available as a whole. The implication of the results is that the majority of farmers in Bawku Municipal are operating on a production frontier closer to the metafrontier and most of the farmers who operated on the metafrontier are likely to come from Bawku Municipal.

Table 5.7 provides the summary statistics of technological gap ratio and technical efficiency relative to the metafrontier. The summary statistics include the average, minimum, maximum and the standard deviation.

Table 5.7. Summary statistics of technological gap ratio

Variable	Kassena Nankana	Bawku Municipal
Average	0.683	0.994
Minimum	0.363	0.944
Maximum	1.000	1.000
Standard deviation	0.106	0.013

The minimum and maximum TGR for Bawku farmers are 94.40% and 100% respectively, while Kassena Nankana farmers have TGR values that range from 36.30% to 100%. The variation in TGR for farmers in Bawku Municipal is lower compared to that of Kassena Nankana as shown by the standard deviations. The results in Table 5.7 show that Bawku farmers had the highest average TGR of 99.40% which suggests that the farmers are able to produce to about 99.40% of the potential rice yield using the regional technology (meta-technology). On the other hand, Kassena Nankana farmers achieve only 68.30% of the potential rice output using the meta-technology. The implication of the results is that farmers in Bawku Municipal are operating on a production frontier closer to the metafrontier. The TGR result indicates that there are some farmers in both districts who are operating on the metafrontier.

5.4.4. Technical Efficiency Relative to the Metafrontier

The technical efficiencies estimated for the two districts, Kassena Nankana and Bawku Municipal cannot be used to rank the producers between the districts. For these technical efficiency scores, the references (production environment and technology) are different. Therefore, performance comparison between these two districts can be misleading. Taking the metafrontier as a reference, the performance of the rice farmers in the two districts can be compared. The technical efficiency relative to the metafrontier is therefore a more appropriate comparative performance measure. The technical efficiency relative to the metafrontier for each district illustrates the efficiency of each district using a similar technology in the region. The technical efficiency relative to the metafrontier is the product of the technical efficiency of the individual frontiers and technology gap ratios ($TE_m = TE_j \times TGR_j$). A comparison between the distribution of technical efficiency scores for the district's frontiers and relative to the metafrontier is given in Figure 5.3.

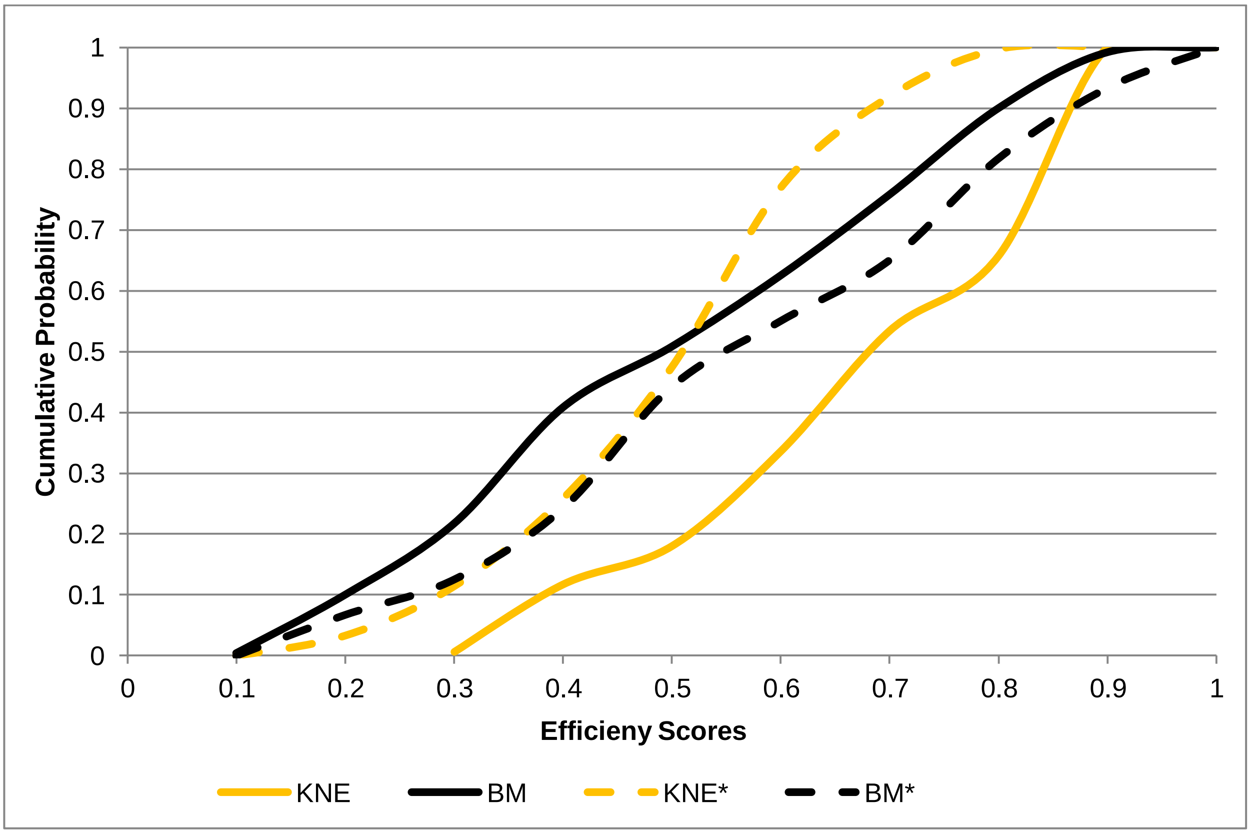

Figure 5.3. Cumulative Probability of Technical Efficiency for the Individual Frontiers and Technical Efficiency Relative Metafrontier.

KNE and BM are used to denote the technical efficiency for Kassena Nankana and Bawku Municipal. The Asterisk sign (*) is used to indicated the technical efficiency relative to the metafrontier.

Technical efficiency in the Bawku Municipal (BM) shown in Figure 3.5 indicates that 50% of the farmers achieve a technical efficiency score of 0.48 or more. Comparing the farmers' performance to metafrontier (BM*) 50% of the farmers achieve a technical efficiency score of 0.55 or more. Bawku farmers are performing better when compared to the regional technology. The Kassena Nankana farmers, on the other hand, are performing poorly, when compared to the regional technology. When evaluating Kassena Nankana performance at a district level (KNE), 50% of the farmers achieve a technical efficiency score of 0.70 or more while 50% of the farmers achieve a technical efficiency score of 0.51 when compared to the metafrontier (KNE*). The improved efficiency estimated for Bawku Municipal (BM*) is due to the higher TGR indicating that the farmers in Bawku Municipal are operating closer to the metafrontier.

The summary statistics related to the technical efficiency relative to the metafrontier are presented in Table 5.8. The results are summarised using average, minimum, maximum and standard deviation.

Table 5.8. Summary statistics of technical efficiency relative to the metafrontier (TE_m)

Variable	Kassena Nankana East	Bawku Municipal
Average	0.525	0.587
Minimum	0.105	0.084
Maximum	0.840	1.000
Standard deviation	0.019	0.003

The minimum and maximum TE_m for Bawku Municipal are 8.40% and 100% respectively. TE_m of 100% implies that at least there are farmers in Bawku Municipal who are operating on the metafrontier using the regional technology. For Kassena Nankana, the technical efficiency relative to the metafrontier ranges from 10.50% to 84%. The implication of this result is that in using the regional technology (meta-technology), Bawku rice farmers are more efficient than rice farmers in Kassena Nankana. However, the majority of the farmers in the two districts are operating below the metafrontier even with the best technology available. The average TE_m for the Bawku farmers is 58.7% which implies that for the farmers in Bawku to operate on metafrontier, they need to increase their production by 41.3% using the technology available at the regional level. On the other hand, Kassena Nankana farmers are able to achieve 52.50% of the potential rice output using the regional technology which suggests that Kassena Nankana farmers should increase their efficiency level by 47.50% in order to operate at the full efficiency level using the regional technology.

5.5. Summary and Conclusion

The results for the stochastic production frontiers indicate that the most important inputs for rice production are land, seed and fertiliser for both Kassena Nankana and Bawku Municipal. Labour is a significant production input only for Kassena Nankana while pesticide application is not significant for either of the districts. The estimated gamma (γ) is 0.568 for Kassena Nankana and 0.990 for Bawku Municipal which indicates that 56.8% and 99% of the variation in rice yield is the result is due to technical inefficiency. The estimated average technical efficiency for Kassena Nankana and Bawku Municipal are 0.769 and 0.591 respectively, suggesting that the farmers can improve their technical efficiency by 23.1% and 40.9% respectively. In conclusion, the gamma (γ) and the estimated technical efficiencies show that there exists room to improve productivity and technical efficiency of the rice farmers in both districts. Upon evaluation of the estimated gamma (γ) and the average technical efficiency score, it can also be concluded that the farmers in Kassena Nankana is more technically efficient than the farmers in Bawku Municipal.

Extension contact, credit access, household size and row-planting are significant factors that influence technical efficiency of rice production in Kassena Nankana. In Bawku Municipal, extension contact, distance to market, access to irrigation water, land renting, education and row-planting are significant contributors to technical efficiency of rice farmers in the district. Extension contact and row-planting are significant factors influencing efficiency in both districts indicating that the issue with extension service and row-planting are common for the two districts. Apart from extension contact and row-planting which are significant for both districts, a clear distinction exists among the factors influencing the efficiency in the districts. It can be concluded from the results that the two districts are faced with different production environments and technologies. Therefore, district specific information is necessary to improve the efficiency of rice production in each district.

The results of the hypothesis test that was performed using the estimated metafrontier indicated that a distinct production frontier exists for both districts. It is therefore, impossible to fit a single production frontier to represent production in the two districts. The average technical efficiency scores estimated relative to the metafrontier (TE_m) for Kassena Nankana is estimated at 0.525 while the average TE_m for Bawku is estimated at 0.587. Comparing the average TE_m of the two districts relative to metafrontier, Bawku farmers have higher efficiency scores than Kassena Nankana farmers suggesting that Bawku farmers are performing better than Kassena farmers at a regional level. The conclusion is that it is of utmost importance to use the correct benchmark when trying to compare the performance of districts. Initially, it may seem as if a district is performing very well compared to other districts. However, when a common goal or benchmark is identified, the district may not perform well as originally thought. The results furthermore indicate that district differences should be taken into consideration when advising the farmers in each district.

CHAPTER SIX: SUMMARY, CONCLUSION AND IMPLICATION

6.1. Introduction to the Study

6.1.1. Background Information

Rice is one of the cereal crops that have been targeted as a food security crop to address hunger and poverty issues in Ghana. Rice contributes to 9% of the food requirements of the Ghanaian population (Seidu*,* 2008). Ghana's demand for rice currently stands at 700,000mt (Savitri, 2013). However, the local Ghanaian rice farmers are able to produce only 210,000mt, leaving a deficit of 490,000mt (Savitri, 2013). The country's rice consumption tends to rise with population growth, urbanisation and changing consumer preferences. However, the country's rice sufficiency ratio is only about 30%, leaving a shortfall of 70%. Ghana spends about US$450 million every year to import rice in order to meet the 70% deficit (Savitri, 2013). The high expenditure on importation is of great concern to the Government of Ghana because of the negative implication on the nation's economy. Therefore, the Government of Ghana desires to reduce rice imports by promoting domestic rice production through productivity and efficiency enhancement measures.

6.1.2. The Motivation and Nature of the Research Problem

The rice industry in Ghana is performing poorly and farmers are not able to obtain maximum returns from resource invested in production. Consequently, there is decline in per capita food production (Boansi, 2013). The inability of farmers to obtain the expected yields could be attributed to low efficiency level (Roetter *et al.*, 2008). Some empirical studies have been conducted on efficiency of rice production in Ghana (Abdulai and Huffman, 2000; Seidu *et al*., 2004; Seidu, 2008; Seidu, 2012; Donkoh *et al.*, 2013 and Yiadom-Boakye *et al*., 2013). These studies failed to provide a comparative efficiency measure between districts in Ghana. Most of the efficiency studies on rice production usually consider rice production in a single district or pool the data from different districts and estimate one production function using stochastic frontier analysis (SFA). Nevertheless, production environments and technologies may differ from district to district which implies that the estimated technical efficiency measures used for comparison across different locations can be misleading. Therefore, the metafrontier analysis

(MFA) is more appropriate when heterogeneous production environments and technologies are to be compared.

There are few empirical studies that have applied the MFA to estimate technical efficiencies across countries and regions. Nevertheless, no efficiency studies on Ghana's rice production have attempted to employ MFA to estimate the production frontier for different districts using a metafrontier production function for the rice industry. Consequently, there is very little information available on MFA application in the Ghana's rice industry and Africa as a whole. The study therefore contributes to economic literature by bridging this knowledge gap. It is expected that significant factors that influence farmers in the two different districts from operating on the production frontier would be revealed. Such information is useful to policy makers, and farmers when deciding which aspect of the human and physical resources need to be targeted in order to enhance farm efficiency and productivity.

The main objective of the study is to analyse technical efficiency and to make comparisons across producers for rice production in the Upper East region of Ghana. The main objective was achieved by estimating the technical efficiencies of the two rice producing districts using a stochastic frontier model for each district's and by identifying the factors that influence variations in technical efficiency in the two districts. The study furthermore estimated a metafrontier model to represent a common frontier to which production in the districts can be compared. The common metafrontier is then used to estimate a meta-technology gap which shows the producers technical efficiency relative to the metafrontier and therefore the districts performance compared to the common metafrontier.

6.2. Literature Review

Increased efficiency is an important factor of productivity growth especially when resources are scarce and waste of inputs should be avoided. Efficiency literature identifies a number of efficiency types to improve productivity, namely technical, allocative and economic efficiencies. This study focuses on technical efficiency since farmers should first aim at producing maximum output using minimum inputs. Once wasteful use of resource is overcome (technical efficiency is obtained), a farmer can continue to identify optimal input combinations (allocative efficiency).

A number of estimation techniques are suggested in literature that is used to estimate technical efficiency. The most commonly used techniques are the non-parametric mathematical programming approach namely, data envelopment analysis (DEA) and the parametric stochastic frontier analysis (SFA). Both techniques have advantages and disadvantages. The choice of DEA and SFA relies on the specific characteristics of the problem. This research would use SFA to estimate farmers' production frontier and technical efficiency. SFA is able to account for statistical noise (i.e. measurement error and random errors). The model used in the study is Battese and Coelli's (1995) single-step procedure that allows for the estimation of a production frontier and the sources of inefficiency in a single step. Information of the sources of variation in technical efficiency is necessary indicators of which aspects of farm characteristics can be addressed to improve technical efficiency.

Although SFA provides very useful information of technical efficiency and the sources of inefficiency, the technique is unable to account for the effect of heterogeneous technologies and production environments. Data collected from two localities require the estimation of two separate production frontiers because of heterogeneous technologies and production environments. Comparisons between the two localities can only be made if a common production frontier is known. Through metafrontier analysis, a meta-production function is estimated which envelops the estimation of the production frontiers of the heterogeneous technology sets. The metafrontier is therefore a common production frontier that can be used for comparison purposes. The meta-technology gap ratio (MTR) estimated from the metafrontier is an indication of how well the farmers in one locality are doing relatively to the common production frontier.

There are a number of studies that estimated productivity and technical efficiency among producers in Ghana using a stochastic frontier analysis. The studies that have analysised efficiency in Ghana include, but is not limited to: Shamsudeen *et al.* (2011), Seidu (2012), Donkoh *et al*. (2013) and Yiadom-Boakye *et al*. (2013). Most of the empirical studies for Ghana and other countries found that fertiliser, labour, land, high yielding seed varieties and use of pesticides determined the production frontier. The socio-economic and institutional variables found to influence technical inefficiency are: land tenure, education, access to market, access to credit, extension services, age, gender and household size.

6.3. Data and Characterististics of the Respondents

6.3.1. Study Area

Ghana is located in West Africa and has a total land area of approximately 238 500km^2 (Tara, 2013). The country shares boundaries with Cote-d'Ivoire to the west, Togo to the east and to the north with Burkina Faso. There are 10 regions in Ghana, namely, Greater Accra, Central, Western, Eastern, Volta, Ashanti, Brong Ahafo, Northern, Upper East and Upper West. Northern, Upper East and Upper West regions are considered as northern part of Ghana while the remaining seven regions are regarded as southern part. The study was done in the Kassena Nankana East district and Bawku Municipal of Upper East region of Ghana. The Upper East region is bordered to the west by Upper West region and the south by Northern region. The total land area of Upper East is about 2.7% (8842km^2) of Ghana's total land area. Bawku Municipal shares boundaries with Bawku West and Garu–Tempane districts to the west and the south respectively, while Kassena Nankana East shares boundaries to the east with Bongo and Bolgatanga districts, and with the Builsa and Sissala districts to the west. Bawku Municipal constitutes 14% (1674km^2) of the total land area of the Upper East region while the total land area of Kassena Nankana East accounts for 19% (1215.05km^2).

Data used for this study was obtained from the Ghana Agricultural Production Survey which was conducted by the Ministry of Food and Agriculture in collaboration with IFPRI in 2011/2012 cropping season. The survey employed a multistage stratified sampling technique to select the respondents. The sample size was 470 rice farmers consisting of 350 Kassena Nankana farmers and 120 Bawku farmers.

6.3.2. Characteristics of the Respondents

On average, rice output harvested in Kassena Nankana was higher than in Bawku Municipal. In terms of resource use, rice farmers in Kassena Nankana cultivated relatively larger areas, used more labour and applied more seed compared to the farmers in Bawku Municipal. The farmers in Bawku Municipal used more fertiliser and spent more on pesticides. The adoption of technologies between the two districts is also different, although, marginally so. Farmers in Bawku Municipal are more prone to adopt improved seed varieties while farmers in Kassena Nankana are more prone to adopt row-planting technique.

Most of the females in Bawku Municipal had greater interest in rice production than the males, while males dominated in rice production in Kassena Nankana. Generally, there was low educational level among the rice producers, and the educational levels in both districts were the same. The study also reveals that young people showed interest in rice cultivation, but the farmers in the Bawku Municipal were quite younger than those in Kassena Nankana. The Kassena Nankana rice producers had more experience in rice production than those in the Bawku Municipal. Even though the household size in both districts were very close, Bawku rice farmers had relatively larger households. Access to extension services was very low in the two districts. However, rice farmers in Bawku Municipal had a greater comparative advantage in terms of accessing extension services than Kassena Nankana East rice farmers. Access to credit was very low in both districts, and the situation in both districts was not different. In terms of proximity to market centres, Kassena Nankana rice producers were closer to market centres than rice farmers in Bawku Municipal. The majority of the farmers in Kassena Nankana and Bawku cultivated rice on their own farmlands. Access to irrigation water was low for the farmers in the study areas; however, there were higher number of farmers who had access to irrigation water in Kassena Nankana than Bawku Municipal.

6.4. Procedures

Stochastic frontier analysis was used to fit a rice production frontier for Kassena Nankana and Bawku Municipal in Ghana. FRONTIER version 4.1 (Coelli, 1996) was used to estimate a production frontier and a technical inefficiency model simultaneously. The technical inefficiency model can help identify the factors that contribute to inefficiency. Five production inputs namely, seed, fertiliser, pesticides, land and labour were included in the stochastic frontier models while 11 inefficiency variables (extension contact, credit access, distance to market, access to irrigation water, land renting, age, education, household size, farm size, row-planting and improved rice variety) were included in the inefficiency models. The technical efficiency scores were predicted based on the stochastic frontier model fitted for each of the districts.

The use of stochastic frontier model to fit a production frontier and estimate technical efficiency under heterogeneous production environments and technologies would result in inaccurate results. To address this heterogeneity problem, a metafrontier model is estimated to fit a common frontier to which comparisons can be made. The metafrontier model estimates the efficiency of heterogeneous groups based on their distance from a common and identical frontier. The estimated parameters from the production frontier for the two districts are used together with the pooled data to estimate the metafrontier. The Shazam 9 software uses a linear programming approach to estimate a metafrontier. Comparative efficiency measures such as the technology gap ratio and technical efficiency relative to the metafrontier are predicted from the metafrontier function for the two districts. The technology gap ratio defines the distance between the estimated production frontiers and the metafrontier. The technical efficiency relative to the metafrontier is the product of the technical efficiency relative to the individual frontiers and technology gap ratios.

6.5. Results and Discussion

The results for the stochastic production frontiers indicate that the most important inputs for rice production are land, seed and fertiliser for both Kassena Nankana and Bawku Municipal. Labour is a significant production input only for Kassena Nankana while pesticide application is not significant for either of the districts. The estimated gamma (γ) is 0.568 for Kassena Nankana and 0.990 for Bawku Municipal which indicates that 56.8% and 99% of the variation in rice output is due to technical inefficiency. The estimated average technical efficiency for Kassena Nankana and Bawku Municipal are 0.769 and 0.591 respectively, suggesting that the farmers can improve their technical efficiency by 23.1% and 40.9% respectively. In conclusion, the γ and the estimated technical efficiencies show that there exists room to improve productivity and technical efficiency of the rice farmers in both districts. Upon evaluation of the estimated γ and the average technical efficiency score, it can also be concluded that the farmers in Kassena Nankana is more technically efficient than the farmers in Bawku Municipal.

Extension contact, credit access, household size and row-planting are the significant factors that influence the technical efficiency of rice production in Kassena Nankana. In Bawku Municipal, extension contact, distance to market, access to irrigation water, land renting, education and row-planting are the significant contributors to technical efficiency of rice farmers in the district. Extension contact and row-planting are significant factors driving efficiency in both districts indicating that the issue with extension service and row-planting are common for the two districts. Apart from extension contact and row-planting which is significant for both districts, a clear distinction exists among the factors influencing the efficiency in the two districts. It can be concluded from the results that the two districts are faced with different production environments and technologies. Therefore, district specific information is necessary to improve the efficiency of rice production in each district.

The results of the hypothesis test that was performed using the estimated metafrontier indicate that a distinct production frontier exists for both the districts. It is therefore impossible to fit a single production frontier to represent rice production in the two districts. The average technical efficiency scores estimated relative to the metafrontier (TE_m) for Kassena Nankana is estimated at 0.525 while the average TE_m for Bawku is estimated at 0.587. Comparing the average TE_m of the two districts relative to metafrontier, Bawku farmers have higher efficiency scores than Kassena Nankana farmers suggesting Bawku farmers are performing better than Kassena farmers at a regional level. The conclusion is that it is of utmost importance to use the correct benchmark when trying to compare the performance of districts. Initially, it may seem as if a district is performing very well compared to other districts. However, when a common goal or benchmark is identified the district may not perform as well as originally thought. The results furthermore indicate that district differences should be taken into consideration when advising the farmers in each district.

6.6. Recommendations and Policy Implications

The results from the study identified a number of factors (i.e. row planting and improved seed varieties) that contribute to the improvement of technical efficiency and productivity in the study area. The bulk of the factors identified can be adressed throught improved extension services, therefore the discussion of the recommendations will focus on the improvement of extension services.

In Kassena Nankana, there is need for the Ministry of Food and Agriculture (MoFA) to intensify its extension services through the training and deployment of qualified extension agents to the district. The extension agents should also be provided with vehicles to enable them to travel to the rice producers in the district. The extension agents, in turn, should educate farmers on efficient input use particularly, land, seed, labour and fertiliser since these inputs had significant positive effects on rice output. Extension officers should encourage farmers to adopt improved technologies in rice production such as row-planting due to the fact that row-planting increased farmers' efficency.

For Bawku Municipal, like Kassena Nankana, extension service delivery should be intensified by training and deployment of qualified extension agents to the districts. These extension agents should provide farmers with information on efficient input use especially, land, fertiliser and seed since these inputs promoted rice output. Extension officers should advise farmers on the adoption of improved technologies in rice production such as row-planting due to the fact that row-planting increased farmers' efficiency. Policy makers should also develop formal and informal educational programmes that will enhance the farmer's ability to retrieve and process information about modern agricultural technologies such as improved planting technology and irrigation, among others. The provision of farmers with these educational programmes will be crucial investment and a good mechanism for improving the efficiency level in rice farming in the district. Land policy for the producers in Bawku Municipal should be aimed at ensuring that tenants have secured rights to use land in order to increase their efficiency level.

The study shows that the technical efficiency scores and the factors influencing the technical efficiency of production in the two districts are different. Furthermore, the hypothesis results on the metafrontier indicates that there is a distinction between the production functions for the two districts, suggesting that there is heterogeneity in the production environments and technologies for the two districts. This result indicates that a regional or national production frontier cannot be estimated and used to advise producers at a district level. District specific information is necessary to advise producers on how to increase their productivity and efficiency in rice production.

The study suggests that the following areas should be considered for further research.

- Further studies should evaluate technical efficiencies for rice producers for all six ecological zones in Ghana since the current study only focused on a single ecological zone. This kind of study will be relevant in developing appropriate policies to increase the efficiency of rice production under each ecological zones which will consequently reduce the high reliance on rice importation.
- The study did not evaluate the timely application of fertilisers during the production process. It is suggested that future research should incorporate the timely use of fertiliser when evaluating technical efficiency of rice production.
- Access to irrigation had negative effect on technical efficiency. It is possible that the producers in the study area are over-applying irrigation water. The data used to in the study only capture irrigation water simply indicated if the producers applied irrigation water or not. Therefore, it is suggested that a further study should be conducted to determine the effect of quantity of irrigation water applied on the efficiency of rice production.
- The study shows that credit access reduces technical efficiency of rice production. The result is contrary to what was expected. It is therefore, important for future research to investigate why access to credit reduces efficiency by investigating the sources of credit, timeliness of access to credit and what the credit is used for.

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