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Efficiency Performance of Rice Farms in Northern Bangladesh: An Application of the Stochastic Frontier and Data Envelopment Analysis (DEA) Mode

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Efficiency Performance of Rice Farms in Northern Bangladesh: An Application of the Stochastic Frontier and Data Envelopment Analysis (DEA) Model

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Certificate

I have the pleasure to certify that the dissertation entitled, "Efficiency Performance of Rice Farms in Northern Bangladesh: An Application of the Stochastic Frontier and Data Envelopment Analysis (DEA) Model," is an original work by Md. Nurunnabi Miah. It is the candidate's own achievement and is not a conjoint work. The dissertation is prepared under my direct supervision and guidance.

I also certify that I have gone through the draft and final version of this dissertation and found it satisfactory for submission to the University of Rajshahi, Bangladesh for degree of Doctor of Philosophy in Economics.

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Declaration

I do hereby declare that this dissertation entitled, "Efficiency Performance of Rice Farms in Northern Bangladesh: An Application of the Stochastic Frontier and Data Envelopment Analysis (DEA) Model," submitted to Rajshahi University, Bangladesh for the degree of Doctor of Philosophy in Economics, is an exclusively original work of mine. No portion of this work referred to in this dissertation in any form has been submitted to any university or any other institution of learning for any degree, diploma or any other similar purposes.

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Dedicated

to my

Lovely wife and

Sweet daughters

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List of Acronyms

BBS	Bangladesh Bureau of Statistics
BES	Bangladesh Economic Survey
BMDA	Barind Multipurpose Development Authority
BNAP	Bangladesh National Agriculture Policy
CCR	Charnes, Cooper and Rhodes
C-D	Cobb-Douglas
COLS	Corrected Ordinary Least Square
CRS	Constant Returns to Scale
CV	Coefficient of Variation
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
EE	Economic Efficiency
GDP	Gross Domestic Product
GNP	Gross National Product
GOB	Government of Bangladesh
HYV	High Yielding Varieties
I-O	Input-Oriented
IRS	Increasing Returns to Scale
MLE	Maximum Likelihood Estimation
Mound	Measurement of Weight (One Mound is equal to 37.32 Kilograms)
NIRS	Non-increasing Returns to Scale
OLS	Ordinary Least Squares
O-O	Output-Oriented
RS	Returns to Scale
Std.Dev	Standard Deviation
SE	Scale Efficiency
SFA	Stochastic Frontier Analysis
SFM	Stochastic Frontier Model
TC	Total Cost
TE	Technical Efficiency
TK.	Bangladeshi Currency ($ 1 = about 80 Bangladeshi Taka)
TRM	Tobit Regression Model
TP	Total Profit
TR	Total Revenue
DTW	Deep Tube Wells
VRS	Variable Returns to Scale
YASB	Yearbook of Agricultural Statistics of Bangladesh

Abstract

This study examines farm level efficiency of the rice producers in Northern Bangladesh by estimating technical efficiency (TE) for the period of aman season 2009-10 and boro season 2010 using farm level cross sectional field survey primary data. Two methods for measuring efficiency are applied, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). Technical efficiency is computed by estimating the Cobb-Douglas stochastic frontier. We also investigate the factors associated with technical inefficiency. Technical inefficiency effects are modeled as a function of age and experience of farmers, years of schooling of the rice producers, size of plots, credit facilities, extension services and land degradation factors in a single stage estimation technique using maximum likelihood method. Technical and Scale efficiencies are derived from solving input-oriented and output-oriented constant return to scale (CRS), variable returns to scale (VRS) DEA models. Tobit inefficiency effects model is used to quantify factors associated with technical and scale inefficiency for both input-oriented and output-oriented CRS and VRS DEA frontiers. We compare the results obtained from both the Cobb-Douglas stochastic frontier and DEA frontiers.

We conduct a survey of 251 rice producers from ten villages of three upazilas of different three districts. We select Tanore upazilla from Rajshahi district, Manda upazilla from Naogaon district and Nachole upazilla from Chapai Nawabganj district of northern Bangladesh. These upazillas and 10 villages are selected by applying purposive and stratified sampling. Finally, a simple random sampling technique is applied to each stratum. The cross sectional primary data are collected from rice producers by using a questionnaire. We collect data mainly on rice output and related inputs, socio-economic characteristics, environmental degradation and other information.

The Cobb-Douglas stochastic frontier results exhibit that the rice producers of our study area in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together average technical efficiency (TE) are 85.17 per cent, 80.42 per cent and 86.85 per cent respectively. The minimum TE scores are 55.73 per cent, 48.73 per cent and 57.51 per

cent in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together and maximum TE scores are 98.22 per cent, 99.93 per cent and 98.50 per cent respectively with standard deviations of 9.23, 13.01 and 8.49 for aman season (S_1), boro season (S_2) and both seasons (S_1+S_2) together respectively.

Both input-oriented and output-oriented CRS and VRS DEA methods give almost similar results in aman season (S_1). The input-oriented DEA frontier results show that the average technical efficiency estimates in aman season (S_1) are 86 per cent and 88 per cent under constant returns to scale (CRS) and variable returns to scale (VRS) assumptions and the average scale efficiency (SE) is 97 per cent. The average values for technical efficiency measures and scale efficiency from the output-oriented CRS and VRS frontiers are 86 per cent, 89 per cent and 96 per cent respectively. The corresponding values for boro season (S_2) from input-oriented DEA methods are 83 per cent, 85 per cent and 97 per cent and from output-oriented DEA methods these value are 83 per cent, 89 per cent and 93 per cent per cent under CRS and VRS respectively. The average values for technical efficiency measures and scale efficiency from the input-oriented and output-oriented CRS and VRS frontier for both aman and boro seasons (S_1+S_2) together are 86 per cent, 89 per cent and 97 per cent and 86 per cent, 89 per cent and 96 per cent respectively.

The efficiency estimates from stochastic frontier analysis (SFA) model for aman season (S_1) are slightly higher than boro season (S_2) as expected. According to stochastic frontier, results technical efficiency (TE) in aman season (S_1) 14.83 per cent, boro season (S_2) 19.58 per cent and both aman and boro seasons (S_1+S_2) together 13.15 per cent, which could be improved if the rice producers could operate at full efficiency levels.

The efficiency estimates of data envelopment analysis (DEA) model from input-oriented CRS and VRS results for aman season (S_1) are slightly higher than boro season (S_2) and similar result exists from scale efficiency (SE) of both aman and boro seasons (.S_1+S_2) together. According to DEA, results of technical efficiency (TE) from input-oriented CRS and VRS in aman season (S_1) shows that 14 per cent and 12 per cent could be increased and 17 per cent and 15 per cent could be increased in boro season (S_2). The corresponding values for both aman and boro seasons (S_1+S_2) together are 14 per cent and 11 per cent, which could be enhanced if the farmers could operate at full efficiency levels.

Inefficiency effects model shows that age and experience of farmers, years of schooling of farmers, land size, credit facilities, quality extension services are inversely related to inefficiency of farms in both aman and boro seasons. Environmental factor, such as land degradation is the most statistically significant factor effecting technical inefficiency. This implies that land degradation is not only reducing output from given inputs but also causing sub-optimal cost minimizing input decisions. Policies should be taken to reduce land fragmentation, to increase rural credit facilities and the quality extension services, and also to reduce factors which cause land degradation. As a result, these will increase rice production and rice producer's income and hence bring the welfare of farmers.

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Chapter 1

Introduction

1.1. Introduction

Agriculture is the principal economic activity and the basic sources of employment, income and export earnings in Bangladesh. It plays a vital role in the growth and stability of the economy. Despite three decades of planned development effort and attempts to industrialize the economy, Bangladesh has still mainly a rural economy. Agricultural performance has direct impact on macroeconomic objectives like poverty alleviation, employment generation, development of human resources and attainment of food self sufficiency. In the past; it has been observed that for any kind of loss of food and cash corps due to devastated natural calamities there has been a serious disruption in the overall economy of the country. As a result, the contribution of agriculture to the economy has declined considerably. Still then agriculture has remained as the driving force behind the rate of economic growth in Bangladesh despite a marked decline in its contribution to GDP. At present, it accounts for about 20.01 per cent of country's GDP, and 43.60 per cent of the country's labour forces are engaged in agriculture (Bangladesh Economic Review, 2012). Agriculture has been considered as the single largest contributor to income and employment generation of the rural people. The country earned 989.56 million dollar in 2007-08 by exporting agricultural products such as, raw jute, jute products, frozen foods, tea and vegetables that is 7 per cent of total export earnings. In 2008-09 the export earnings from agricultural products stood at 870.11 million dollar, which is 5.59 per cent (BBS, 2010) of total export earnings. Contribution of export earnings by agricultural products are slightly decreasing day by day. This is one of the largest export sectors after knitwear and readymade garments. Because of its direct link with economy; it can be said that agricultural production is synonymous with economic development. By and large, a technological change and efficiency performance of the rice producers seemingly took place in the economy from the mid 1980s to 1990s and the ripples of that improvements touched food crop sectors. There has been a widespread adoption of new varieties and modern inputs. The government of Bangladesh has liberalized the markets of agriculture inputs and outputs through agricultural reform policy. This policy greatly increases the use of purchased inputs by reducing their prices. Rice is dominant agricultural activity accounting for 69 per cent of value added from crop production in 1973-74, the share rises to 73 per cent by 1989-90, and further to about 80 per cent by 1998-99. Bangladesh is a small country in South Asia with a population of almost 160.80 million, increasing at a rate of 1.37 per cent, adding about 2 million labour forces with the existing 72 million every year. Over the last 40 years, Bangladesh has greatly increased its food grains production from 110.81 lakh metric tonnes in 1973-74 to 240.10 lakh metric tonnes in 1999-2000, and 264.89 lakh metric tonnes in 2004-05. The total food grains production in 2006-07 is 289.54 lakh metric tonnes. The contribution of rice in total food grains was 94.97 per cent in 2004-05, and almost same in recent years. Actually it is 94.56 per cent in 2009-10 (Bangladesh Economic Review, 2012). The average overall food grains deficit over years is about 22.68 lakh metric tonnes per annum.

Bangladesh is mainly an agrarian country in which 70 per cent of total population and 65.41 per cent of total labour forces are located in rural areas (Bangladesh Economic Review March, 2012). Thus, agriculture sector is considered as the life blood of the country’s economy. The rice crops accounts for 74 per cent of the cultivated area, 83 per cent of the irrigated area, 88 per cent of fertilizer consumption. The rice is one of the main sources of caloric intake of people in Bangladesh it accounts 68 per cent. The growth rate of GDP is 6.50 per cent in 2009-10 and at the same period growth rate of agriculture is 5.44 per cent. That is why, rice production may affect seriously in the promotion of economic growth. The land of Bangladesh is fertile but its cultivation performance is not only poor but depends on climate, drought, erratic rainfall, lack of irrigation facilities, river erosion, salinity of soils and traditional methods of farming. It has often been argued that agricultural development, which promotes the producers efficiency does not have sufficient incentive to adopt modern practices and farms performance.

1.2. The Statement of the Problem

Bangladesh is predominantly an agricultural country. Agriculture being the engine of growth of the economy, we have no other alternative but to develop agriculture sector for alleviation of poverty. Since provision of food security, improvement of the living standard and generation of employment opportunities of the huge population of the country are directly linked to the development of agriculture, there have been continued efforts by the government for the overall development of agriculture sector during the 1990s. An important point is that the agriculture sector of our country is more diversified than before. As we have achieved a huge growth in crop sector production. Total cultivated land area in our country is 253.60 lakh acres in 1980-81 and it has increased 264.60 lakh acres in 2004-05. The cultivated land area for rice production is almost the same or slightly increased than before. But at that period rice production is almost doubled, it was 149.70 lakh metric tonnes in 1980-81, and was 264.89 lakh metric tonnes in 2004-05 respectively (Agricultural Statistics Book of Bangladesh, 2009). Our country has a little scope to increase rice production through expansion of land area, because the cultivated land area are constant at around 250 to 270 lakh acres. But it can be said that this growth in food grains production is not sufficient for the increasing population of Bangladesh. To fulfill the food and nutritional demand of the growing population of the country and to ensure sustainable food security, special emphasis has been laid on building up a modern agriculture system based on appropriate technology. So, in the meantime an improvement is made in agriculture sector, specially, food grain sector. We have achieved growth in food grains sector, perhaps because of technological change which is supported by a rapid development of irrigation infrastructure, ensuring the availability of agricultural inputs including fertilizer at the door steps of the farmers.

The economy of Bangladesh primarily depends on agriculture. The scope of modern agricultural practices has been widened significantly. Not only production of food grains but also any sorts of applied activities using natural resources related to production activities. Therefore, apart from production, animal husbandry, fisheries, forestry etc. are integral components of broad agriculture sector. For this reason, government has introduced a new National Agricultural Policy (NAP) in 1999. In the light of national agriculture policy, the Government has been staring a range of development projects or programmes for agriculture sector to ensure sustainable and profitable production in agriculture through more efficient and balanced use of land, water and other resources and thus creating purchasing power of the farmers by increasing real income. An action plan is in place for proper implementation of national agriculture policy. Along with poverty reduction, this action plan will assist in building a sustainable food system by achieving optimum growth in agriculture.

Some of the main objectives of the policy are:

i. To protect and develop the land productivity;
ii. To protect food security in the country by increasing food and other nutritional food grains production;
iii. To introduce biotechnological methods in agriculture effectively;
iv. To establish export oriented agro-based and agro-processing industries in the country;
v. To protect interest of the small, marginal and tenant farmers and
vi. To reduce environmental degradation
(National Agricultural Policy of Bangladesh, 1999).

All of these objectives are clearly good and helpful for the rice producers of Bangladesh if implemented. But to observe deeply about the objectives of new national agricultural policy, it can be said that it is very hard to implement, and it takes long time to get full benefits from it. So, the policy makers should take immediate measures to enhance rice production of the country. They may consider two measures of rice production gains: (1) technological improvement and (2) efficiency improvement.

Consistent with this, various reform measures are taken in agriculture sector since the late 1980s, that include ensuring the availability of agricultural inputs at the door steps of the farmers, implementation of the agricultural extension policy, simplification of the disbursement procedures of agricultural credit, creating opportunities for investment in agriculture, modernization of research system for quality improvement of agro-products, the utilization and extension of the integrated technologies derived from research. In order to alleviate hard-core poverty and food security in Monga-striven areas of the greater Rangpur region, Government has taken a lot of comprehensive measures in this region, such as strengthening research activities to produce HYVs. On the other hand, Bangladesh Rice Research Institute (BRRI) invented a rice called BR-33 which can be harvested by 110-115 days. In the meantime, BR-33 is known as Monga variety. The work plan for increasing the production at 8.55 per cent to 25 per cent of the main food grains of the country by 2012-13 is being implemented.

1.3. Contribution to GDP

During the birth of the country, 75 per cent of its GDP is acquired from agriculture. Since then the contribution of the sector has been declining gradually. This gradual erosion from the dominant position of agriculture in the national economy is in conformity with the general pattern of economic development in most countries. As the demand for agricultural products tends to be income inelastic, rising income of the people reduces the share of agriculture in national output. The contribution of broad agriculture to GDP is around 20.01 per cent in 2010-11. Though the contribution of agriculture to GDP is decreasing comparatively to other sectors as it is 50.48 per cent in 1985 and is around 65 per cent in 1975, the growth rate of agriculture sector is 5.5 per cent in 2000-01. Over the last couple of years after 2000-01, the growth rate of agriculture is decreasing sharply. Even it is negative (-2.39 per cent) in 2001-02. This is because of excess or less rainfall, frequent load-shedding, fuel price hike and sometimes heavy fogging causes destruction of initial seed ground all over the country. But the growth rate is improving one next years. It is 4.27 per cent in 2003-04 and 5.44 per cent in 2009-10 respectively (Bangladesh Economic Review, 2011). Given the socio-economic trend of the past 3 decades, it seems that the share of agriculture to GDP and growth rate has been declining relatively to other sectors. Yet it is likely that agriculture may remain the single most important sector of the economy in the foreseeable future. The economy of Bangladesh will likely to be highly dependent on agriculture in terms of its exports and its value addition and employment of labour force. So agriculture has a great impact on national economy.

1.4. Crops

Crops form the largest sub-sector of broad-based agriculture in Bangladesh. Sometimes, agriculture is believed to be crop agriculture. Crop agriculture represents a share of about 23 per cent in total GDP and about 73 per cent in agricultural GDP in 1972-73. The sub-sector is mainly responsible for the production of food grains. The rice crop dominates the country's agricultural scenario with respect to both cropped area and the production. Rice alone covers about 75 per cent of the total cropped area and accounts for about 70 per cent of the value crop output (FFYP), p-225, 1997-02). The crop sub-sector alone accounts for about 75 per cent employment of Bangladesh having more than 80 per cent of total population engaged in agriculture with approximately 150 lakh households (NAFP-1996). Among others, rice is the dominant crop and mostly determines the rate of progress in the agriculture sector to a greater extent. But recently, there has been shift in composition of agriculture with gradual decline in fisheries, livestock and forestry products. Annual growth rate of crop sub-sector is 57 per cent of total production. This is the single largest producing sector of the economy. Fisheries, livestock and forestry sub-sector are 22 per cent, 8 per cent and 13 per cent respectively (BBS, 2011). Cropping intensity is about 232 and this can be increased to 262 but needs much heavier investment levels complex water management and will generate further resource conflicts (Ibrahim, 1996).

"Food for all" is the prime commitment of the present Government. As such the government has given top priority to agriculture sector to achieve self-sufficiency in food again by 2013 through increased production. Total domestic supply of food grains was 311.21 lakh metric tonnes in the year 2007-08 and 328.96 and 360.65 lakh metric tonnes in 2008-09 and 2010-11 respectively. In this period we have imported 34.57 lakh metric tonnes food grains of which 20.47 lakh metric tonnes were rice and 14.10 lakh metric tonnes wheat in the year 2007-08. About 30.13 lakh metric tonnes food grains were imported in 2008-09 and 51.50 lakh metric tonnes food grains were imported of which 15.54 lakh metric tonnes were rice and 35.96 lakh metric tonnes wheat in the year 2010-11 (Bangladesh Economic Review, 2012). From this, it is evident that Bangladesh is not self-sufficient in food grain production to fulfillment the demands of growing population. To feed the growing number of population is one of the big challenges this country is facing now. For attaining food self-sufficiency through increased crop production chemical fertilizers, modern varieties of inputs, irrigation facilities and pesticides have been introduced in agriculture since the late 1980s. The introduction of modern varieties of rice, wheat, potato, oil seeds and other crops has increased cropping intensities and yields (Farouk and Hossain, 1996). Among others; rice is the dominant crop and mostly determines the rate of progress in the agriculture sector to a greater extent. In 1980-81 cropping intensity was 159.69, and it was increased to 232 in 2003-04 (Bangladesh Economic Survey, 2009). This can be increased up to 285. This needs much heavier investment for technological improvement, but this advancement has provided little benefit to the resource poor and small farmers because most of them are unable to purchase the required inputs. In addition, they can hardly apply inputs timely and as a result, receive low yield and production. For whatever reason, development of new technologies sometime make small farmers worse off than before (Shaner, 1982). Technological change in agricultural sector is time-consuming and needs huge amount of investment. On the contrary, efficiency improvement takes small time and requires small amount of investment. So, the policy makers could give more emphasis to the improvement of efficiency rather than technological change in order to obtain productivity gain within a short period of time.

Efficiency of farm depends on rice farmer's experience, level of education, plot size, credit facilities, extension services, use of modern technology, use of improved seed, fertilizers, pesticides and others inputs. This study enquires to assess the status of efficiency of farms in Northern Bangladesh and identify factors which could affect the efficiency level of farms.

1.5. Aims and Objectives of the Study

The general aim of this research is to assess productive efficiency of rice farms in Northern Bangladesh and to suggest ways for improving rice farm performance. The specific objectives are as follows:

i. to assess the technical efficiency performance of rice farms in Northern Bangladesh;
ii. to identify factors which affect technical efficiency of farms;
iii. to make a comparison of efficiency of rice farms during aman and boro rice season;
iv. to make a comparison of results obtained from the stochastic frontier analysis (SFA) and DEA model and
v. to suggest some policies to policy makers on how to improve efficiency of farms and reduce the adverse effect of factors on farm efficiency performance.

1.6. Contribution of the Study

Productive efficiency may be very useful tools of rice producers in Bangladesh for expansion and sustainability of rice production. Unfortunately, there is little information on productive efficiency in agriculture sector in Bangladesh. Few works have been done in this sector previously. This study enquires to estimate the farm-level technical efficiency of rice farms. We also enquire to identify sources of rice farm inefficiency where its improvement can be made. Therefore, this study could provide some vital information to the farm-level rice producers to assist themselves in becoming more competitive and to maintain long-term sustainability in the agriculture sector.

A rice farm may be inefficient by failing to achieve maximum output from using given level of inputs or using the inputs in a wrong proportion, given the input prices. Undoubtedly, inefficiency increases cost of production and decreases profit. So, identification of inefficient rice producers and factors affecting efficiency of the rice producers are the key to promoting efficient utilization of resources.

Determination of stochastic frontier technology and Data Envelopment Analysis (DEA) methods and the knowledge of various kinds of efficiency may provide important insights for the rice producers of the country.

Competition and production costs are increasing in agriculture sector. So, efficiency improvements will be all important factor in order to get financial success for producers, and profit gain.

Research works have been done all over the world related to efficiency using stochastic frontier approach (SFA) and data envelopment analysis (DEA). In Bangladesh, few works are done using these two methods.

Data envelopment analysis (DEA) method is generally used to assess the performance of non-agricultural sector, such as banks, hospital, educational institutions, nursing homes, public utilities. Bravo-Ureta (1986), Bravo-Ureta and Rieger (1990 and 1991), Bailey et al., (1989), Kumbhakar et al., (1989 and 1991), Cloutier and Rowley (1993) looked at dairy industry using DEA method. A small number of research is done in agriculture using DEA approach (Thompson, et. al., 1990; Haag et. al., 1992, Serrao, 2001; Suksamai, 2000, Wadud and White, 2000; Wadud, 2003).

Majority of the study have focused on estimating technical efficiency; few study has looked at economic efficiency (Bravo-Ureta, and Evenson, 1994). Few studies (Wadud and White 2000; and Wadud, 2000, 2003) have used stochastic frontier and DEA frontier estimating technical, allocative, and economic efficiency in Bangladesh agricultural sector. To our knowledge, no research work has been done on comparison of one season rice producers' efficiency to another season's for the same number of rice producers and the same area using both these two methods. This study enquires to fill this gap by doing a comparison between aman and boro seasons using both SFA and DEA model at the same area and same size of rice producers.

1.7. Organization of the Thesis

The main aim of this thesis is to estimate technical efficiency and identify factors associated with inefficiency of rice farms in Northern Bangladesh. The thesis is organized as follows:

Chapter 2 provides the review of the literature related to stochastic frontier approach (SFA) and data envelopment analysis (DEA) methods. In this chapter we have tried to see some of the related literature in critical ways and make understand that there is an opportunity to do such research in Bangladesh.

Chapter 3 provides a short history about the study area. It starts with describing overall physiographic, demographic, locative, climatic conditions, agricultural practices and total cultivable and total cultivated aman and boro land ownership and farm size of the farmers in our study area. Our study area lies in the High Barind Tract, so all concerned socioeconomic characteristics are the same. We describe here also ground water condition and use of chemical fertilizers and its impact on the environment of this area as well.

Chapter 4 gives a survey methodology and results. It explains the survey methodology and results of the survey. It gives the age, schooling and experience of the farmers. It also explains per acre and total cost of rice production, per acre and total output, per acre and total revenue, it gives per acre and total profit of the farmers. It also briefly describe the setting of the study villages and examines the characteristics of the sample households which are associated with inefficiency.

Chapter 5 explains some basic theoretical issues about production function and efficiencies. In this chapter, section 2 gives the simple concepts of total, average and marginal product and elasticity. We then analyze the concepts of technical efficiency.

Chapter 6 presents a detailed description about the stochastic frontier approach (SFA) to estimating efficiency. First we express the stochastic frontier model of efficiency measurement theoretically. Then we finally discuss the parametric approach to decompose efficiency into technical efficiency using the self-dual Cobb-Douglas stochastic frontier model.

Chapter 7 delivers the empirical results from the stochastic frontier production model. The results from the stochastic frontier model, technical efficiency estimates and technical inefficiency effects are considered. We then discuss the estimates of technical efficiency computed from the self-dual Cobb-Douglas stochastic frontier model based on maximum likelihood estimates separately for aman season (S_1) boro season (S_2) and both aman and boro seasons (S_1+S_2) together and quantify the effects of factors associated with inefficiency.

Chapter 8 presents a detailed theoretical description of data envelopment analysis (DEA). First, we discuss the input-oriented and output-oriented constant returns to scale (CRS) and variable returns to scale (VRS) methods of measuring technical efficiency. Then we describe the process of calculating the scale efficiency. The final section gives a Tobit model to quantify the source of rice producer's specific factors affecting inefficiency.

Chapter 9 gives the empirical DEA frontier results. First, the results of technical efficiency estimates and estimates of the effects of farm-specific characteristics on technical inefficiency derived from input-oriented and output-oriented CRS and VRS models are described. It also gives a comparison between stochastic frontier analysis and data envelopment analysis results for aman season (S_1) boro seasons (S_2) and both aman and boro seasons (S_1+S_2) together are presented in this chapter. First, we have given a comparison of efficiency scores. Then we discuss the effects of factors associated with inefficiency by Tobit model.

Chapter 10 presents the summary and main results. It provides some conclusions and policy implications and finally we identify some issues, where further research is needed.

Finally, this thesis contains appendix and bibliography.

Chapter 2

Review of Literature

2.1. Introduction

Efficiency of rice crop sub-sector in agriculture has been discussed for years. Recently, because of the rapid increase of rice productions and agricultural innovations, it has become more important to measure the efficiency of rice producers. The dynamic changes in the agricultural sector for the last two decades have attracted research attention throughout the country. Review of literature in this arena shows that the performance of the rice producers of agricultural sector receives extensive scrutiny from the scholars.

In an article, Farrell's (1957) proposes two ways to estimate efficiency of a farm in production frontiers. His article leads to the foundation for development of several approaches to efficiency analysis. Among several approaches, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are the two most popular and presently being used to measure efficiency of production units.

This study is expected to furnish room for efficiency measurement opportunity. There are some related research papers on the topic of rice production and efficiency measurement all over the world. But to my knowledge there are few empirical papers on efficiency measurement of rice producers in Bangladesh applying the tools of stochastic frontier approach (SFA) and data envelopment analysis (DEA) model. However, numbers of books and articles on producer's efficiency of the agriculture and other farms related literature have been reviewed in this connection. The reviews are categorized into three sections. Section 2.2 describes reviews about Stochastic Frontier Analysis (SFA) and Section 2.3 presents review of Data Envelopment Analysis (DEA) Frontier and Section 2.4 gives summary and conclusions.

2.2. Stochastic Frontier Analysis (SFA) Model

Kumbhakar and Efthymios (2003) discuss the Baysian estimation of input-oriented (IO) technical efficiency using stochastic production frontier approach. They provide inferences for parameter and efficiency using Baysian method based on Markov Chain Monte Carlo techniques, especially the Gibbs sample with data augmentation. Both cross-section and panel data models are developed. To emphasize the point estimate of efficiency, returns to scale, etc., might differ depending on whether one specifies an input-oriented (IO) or output-oriented (OO) technical efficiency within context of the model.

Abdulai and Huffman (1998) employ a stochastic frontier model to examine profit inefficiency of rice producers in the Northern Region of Ghana using the farm level survey data. The data used for this empirical application are a sub-sample of a random sample of 256 producers in four districts in Northern Ghana conducted in 1992-1993. The efficiency index, based on a half-normal distribution of the stochastic error is related to farm and household characteristics. The average measure of efficiency is 27.4 per cent, which suggests that on average, about 27 per cent of potential maximum profit is lost due to inefficiency. The estimates of the translog profit frontier indicate that inputs are still important to profitability of rice farming in Ghana. Efficiency measures indicate that rice farms are not applying their inputs in an absolutely efficient way and investigation suggests that a considerable amount of profit is lost due to inefficiency. The economic condition of Ghana and Bangladesh is more or less same. So, it is logical to investigate rice farms and to estimate efficiency measures of rice producers in Bangladesh in order to identify the inefficiency factors.

Suzanne, Matthews and Leavy (1999) use a methodology for estimating technical efficiency levels for individual farms using both a fixed effects panel model and a stochastic production frontier approach. It tests whether the estimated technical efficiency levels are associated with measures of contact with the advisory service. The results show evidences that extension contact has had a positive impact on agricultural output.

Tadesse and Krishnamoorthy (1997) examine the level of stochastic efficiency across ecological zones and farm size groups in paddy farms of the Southern Indian state of Tamil Nadu. The study shows that 90 per cent of the variations in output among paddy farms in the state are due to differences in technical efficiency. Land, animal power and fertilizers have significant influence on the level of paddy production. They have used the data pertaining to crop cultivation in all agro climate zones of the state, collected from 60 clusters taken on an appropriate random sampling basis. Data for this study refer to 129 high yielding varieties rice (IR-20) producers distributed over the four zones during the major production season of October-December for the year 1992-1993. The overall mean technical efficiency of 83 per cent is achieved by paddy farms in the state which means that there is a scope for increasing paddy production by 17 per cent with the present state of technology. A significant variation is observed in the mean level of technical efficiency among the four major rice production zones of the state and producers operating on small and medium size farms achieved a high level of technical efficiency than those with large farm holdings. This study suggests that special attention should be given to improve the efficiency of paddy farms with large farm holdings through the adoption of practices of small and medium sized farms.

So, with this information the model can be reviewed in the context of paddy cultivation in Bangladesh, because the climate condition and farm condition in southern state of Tamil Nadu in India and Bangladesh is almost similar.

Kumbhaker and Hesmati (1995) conduct a study on efficiency measurement in Swedish dairy farms. In this paper the researcher consider a specification in modeling technical inefficiency in a panel data setup by decomposing it into a persistent farm-specific component, a residual farm and time component. Output and several inputs used in this study are measured in value term. They do not use a single-stage maximum likelihood method, but consider a multi-stage procedure, which minimizes distributional assumption on the error components. They make distributional assumptions only to the estimate of the residual component of technical inefficiency. This paper shows that, they persistent component of inefficiency was much larger than the residual components for all farms. The implication of a higher level of persistent inefficiency is that a decline or withdrawal of support payments is likely to change the structure of the dairy industry. Finally they find the competitiveness of the Swedish dairy industry with other members of the European community. They also comment that Swedish dairy farm inefficiency results of this study might be comparable with other country dairy farms where output and inputs conditions and system of production are similar.

Kumbhakar (1994) uses a flexible (translog) production function to estimate efficiency of 227 farms from West Bengal, India. The maximum likelihood method of estimation applied in this paper. Farm-specific technical and allocative efficiencies are estimated. Empirical results show that the mean level of technical efficiency is 75.46 per cent while the best farm is 85.87 per cent efficient. The author points out that the research can be extended in several ways. First, factors like, land size, land tenure, credit availability, education, extension services, etc. may be introduced to explain differences in technical and allocative efficiencies. Second, if the product market and factor market are not competitive due to government regulations, social and cultural barriers, by relax government regulations and socio-cultural barriers. Finally, availability of panel data may be helpful to control for farm-specific effects, which can be separated from technical inefficiency using cross sectional data.

Wang, Wailes, and Cramer (1996) have developed a shadow price profit frontier model to examine production efficiency of Chinese households. In this study they have chosen the observations from the national sample randomly. For the analysis in this study, they have used 1889 observations. Two output prices of crops and livestock, two variable input prices of technical fertilizer and other purchased materials, and three fixed inputs of labour, land and capital are constructive from the survey data set. The survey contains no price variable. All price variables for individual commodities and input factors imputed using quantity, revenue and expenditure variables. This study examines the Chinese farm household production efficiency. Given a mixed government-control and free market economy, the observed prices used in the analysis are an average of government-controlled prices, semi controlled prices, and free marked prices. This study uses a profit function approach that combines technical and allocative efficiency in the profit relationship. They also develop the concept of a shadow-price profit frontier. Study shows that a considerable potential productivity can be gained by continuously improving efficiencies. Both technical and allocative efficiencies can be improved by reducing market distortions, allowing land to transfer more freely, enhancing the producer's accessibility to education, and providing a social-economic environmental factor that help producers to increase their net income.

So, there is a lot of scope to use the shadow-price model for the individual level producers to improve their technical and allocative efficiency by using the mechanism of reducing market distortions, allowing land using rights more freely and more accessibility to education, and social-economic and environmental activities.

Bravo-Ureta and Evenson (1994) use a stochastic efficiency decomposition methodology to estimate technical, allocative, and economic efficiency of Paraguay's agricultural producers. The results of this study suggest that the sample of peasant producers could increase output and thereby, household income through better use of available resources given the state of technology. These find that the rate of population growth is more than the rate of output growth. This is important finding of this study. An examination of the relationship between efficiency and various socio-economic variables do not reveal a clear strategy that could be recommended to improve performance. The research results imply that the sample of Paraguayan producer is yet to reach threshold. Consequently, they suggest policy to improve education and extension services.

Reinhard, Lovell, and Thijssen (1999) estimate the technical and environmental efficiency of a panel of Dutch dairy farms. A stochastic translog production frontier is specified to estimate the output-oriented technical efficiency. Environmental efficiency is estimated as the input-oriented technical efficiency of a single input, the nitrogen surplus of each farm. In this study, they use the data of production activities of 613 strongly specialized dairy farms that were in the Dutch Farm Accountancy Data Network (FADN) for 1991-1994 periods. They have developed an analytical framework within which to calculate environmental efficiency as a single factor measure of input-oriented technical efficiency. They show how this environmental efficiency measure can be estimated within a stochastic translog production frontier context. They also show that there is a positive relationship between technical and environmental efficiency. They estimate the "shadow price" of the nitrogen surplus. This estimate gives the guideline to the government to charge some levy on nitrogen surpluses.

So, there is a scope to use this model to estimate the environmental efficiency and to correlate this efficiency with technical efficiency of farm-specific agricultural sector, so that the government can realize how much natural distortion is happening in agricultural sector.

Bravo-Ureta and Rieger (1991) present a paper on New England Dairy Farms. They apply a stochastic efficiency decomposition model based on Kopp and Diewert's deterministic methodology. The stochastic model is used to analyze technical, allocative, and economic efficiency. The methodology developed here yields efficiency measures that are not distorted by statistical noise. Their results suggest small difference between technical and allocative inefficiency. However, the research paper exhibits that focusing only on technical efficiency understands the benefits that could be derived by individual producers as well as society from an improvement in overall performance. Here the researchers discuss the relationship between efficiency and four socio-economic variables- farm size, education, extension and experience. Results reveal that, despite some statistically significant variations, efficiency levels are not vastly affected by these variables.

Coelli and Battese (1996) analyze the agricultural production of Indian farmers using a stochastic frontier production function, which incorporates a model for the technical inefficiency effects. The stochastic frontier production functions are estimated for each of three villages from diverse agro-climate regions of the semi-arid tropics of India. The production frontiers involve inputs of land, labour, and cost of other inputs. The model of the inefficiency effects in the production frontier includes age and years of formal schooling of the farmer, size of the land and the year of observation as explanatory variables. But this empirical study does not include some variables which might be important in modeling output and inefficiency effects, such as rainfall data, use of agricultural extension services and access to credit etc. So, there is a further scope to investigate and estimate inefficiency of farms if the data and information of these omitted variables are available.

Schmidt, Lovell and Knox (1978) discuss the relationship between stochastic production, factor demand and cost frontiers. They demonstrate how technically and allocativelly inefficient production processes could be modeled in an empirical way. They develop several types of techniques, which were appropriate for the estimation of such stochastic frontiers under three different assumptions concerning the magnitude and the nature of allocative inefficiency. Their technique provides only sample mean estimates of the extent and cost of technical inefficiency, but they are unable to conduct a search for its sources. But they obtain estimates of allocative inefficiency by plant. They hope to consider alternative to the cost minimizing hypothesis. Finally, they desire to obtain estimates of the extent and cost of technical inefficiency by plant. In this paper the researchers do not see how to solve the problem.

Battese and Corra (1977) have applied a statistical model for output observation that is consistent with the traditional definition of a production function. The empirical results obtained in the estimation of the sheep production function for the pastoral zone of Eastern Australia indicate that the variance of asymmetric error in the model is a highly significant component. Data from 149 sample farms were used in the empirical analysis, 57 being from New South Wales, 60 from Queensland and 32 from South Australia. The coefficient of determination for the ordinary least-squares regression for the N.S.W., Queensland, S.A. and the whole zone were 0.59, 0.31 and 0.86 and 0.44 respectively. In this paper, they estimate a production frontier model, but do not estimate the efficiency.

Schmidt and Lovell (1979) have investigated the relationship among stochastic production factor demand and cost frontiers. They demonstrate how technically inefficient production process can be modeled in an empirically useful way using these frontiers. They also have developed various techniques appropriate for the estimation of such stochastic frontier under three different assumptions concerning the magnitude and the nature of technical inefficiency. They have used the empirical data from a previous collected sample of 150 new privately-owned steam-electricity generating plants constructed in the US between 1947 and 1963. The mean of the one-sided disturbance in the production function is -0.09889, indicating that output on average 9.9 per cent below the frontier. The mean of the one-sided disturbance in the cost function is -0.08059, which indicates that technical inefficiency raises cost on average of 8.5 per cent above the cost frontier.

The technique provides only sample mean estimates of the extent and cost of technical inefficiency. But they do not able to conduct a search for its sources. The authors suggest that the model can estimate allocative inefficiency by plant and so a search for its sources is feasible. The authors point out that much works can be done with this topic. For example, they assume that the two types of inefficiency are uncorrected. The assumption can be relaxed. Secondly, homogeneous Cobb-Douglas assumption can also be relaxed. Thirdly, one can consider alternatives to the cost minimizing hypothesis. Finally, it will be desirable to obtain the extent and cost of technical inefficiency by plant. So, there is a scope to extend the model by relaxing the assumptions discussed.

Thiele and Brodersen (1999) produce a comparison of the efficiency of East German and West German farms for the year of 1995-1997. Non-parametric frontier analysis is used to decompose efficiency differences into technical and scale effects. They used data from a sample of about 600 farm groups of the National Agricultural Data Net (8773 farms per year) under the German Federal Ministry of Agriculture. They show that after half a decade of transition in East German, eastern farms still have lower overall efficiencies than those of the West Germany. On an average, scale inefficiencies are slightly lower than technical inefficiencies. They also find that the economic environment has greater influence on efficiency than the organization of a farm. Their results show that scale inefficiencies are as prevalent in West as in East German agriculture and that more structural adjustment is essential to force scale inefficient farms to an efficient and viable scale.

At the same time, they show that distribution of efficiencies within ownership types of farm suggests that there is not simple solution to improve the efficiency on the basis of particular farm ownership type. They suggest that the only way to achieve an efficient and competitive agricultural industry in transition countries requires more free allocation of resources between different types of farms. So, at this particular point of free allocation of resources between different types of farms, there are good opportunities to do further research.

2.3. Data Envelopment Analysis (DEA) Model

Latruffe, Balcombe and Davidova (2003) analyze the technical efficiency and scale efficiency of polish farms using data envelopment analysis. They estimate efficiency according to farm specialization. The statistical variability of efficiency estimates is investigated. The efficiency results are reviewed in the light of confidence interval provided by boostrapping, and of a summary measure introduced in this study "the coefficient of separation." The inference analysis suggests that farms might be less efficient than revealed by the point estimates alone and that they might be clearly different from each other.

Henderson and Kingwell (2005) examine rain-fed broad-acre agriculture farm. Researchers apply data envelopment analysis (DEA) to measure technical efficiency for a sample of broad-acre farms. They use specially rainfall as a non-discretionary production input in an input-oriented DEA model. They have gathered data from Western Australia region mixed enterprises of crop and livestock. The numbers of farms are 100 and data are collected up to 5 consecutive years. They compare un-confounded technical efficiency measures with the conventional DEA model results that do not explicitly include rainfall. They show that the conventional DEA model gives lower levels of technical efficiency. Results suggest that the conventional DEA model gives 35 per cent efficient farms in 1997 where rainfall adjusted DEA model gives 45 per cent efficient farms in the same year. So, in our country, researcher may find out the results of rainfall adjusted DEA model and compare these results with conventional DEA model where environmental effects such as rainfall are not included.

Yu (1998) conducts a Monte Carlo Study to compare frontier method and the data envelopment analysis (DEA) method in measuring efficiency in situation where farms are subject to the effects of factors which are beyond managerial control. This study compares the stochastic frontier model and three DEA models in terms of their abilities to distinguish the effects of exogenous variables from the effects of efficiency in measuring farm-specific efficiency. He reports, that in general, the stochastic frontier method has a dominant advantage over the other methods in dealing with the exogenous variables if the exogenous variables can be correctly identified and incorporated in estimating the production function. Therefore, in our country, there is a scope for estimating efficiency of farms by using the stochastic frontier method.

Coelli (1995) examines recent development in the estimation of the frontier function and DEA frontier. The measurements of efficiency from both frontiers are surveyed and the potential applicability of these models in agricultural economics is discussed. Frontier production cost and profit functions are discussed, along with the construction of technical, allocative, scale and overall efficiency measures relative to these estimated frontiers. The two primary methods of frontier estimation econometric and linear programming are also compared. The main focus of this paper is that none of the proposed methods of measuring efficiency relative to an estimated frontier is perfect. However, they all provide substantially better measures, such as output per unit of labour or land. In his paper Coelli points out that as with all farms of empirical modeling, a frontier study can suffer from a variety of possible pitfalls, such as the possibility that omitted or poorly measured inputs may influence technical efficiency measures; the possibility that unaccounted environmental factors, such as soil quality or topography, may influence technical efficiency measures; the possibility that poorly measured price variables may influence allocative inefficiency measures; and the use of data from a single season to measure efficiency may result in same farmers being labeled as inefficiency. So, with this last point one interested researcher can go for further investment.

Wadud and White (2000) compare estimates of technical efficiency obtained from stochastic frontier and DEA approaches using farm-specific survey data for rice farmers in Bangladesh. Technical inefficiency effects are modeled as a function of farm specific socioeconomic factors, environmental factors and irrigation infrastructure. Results from both economic and programming frontier indicate that the inefficiency effects in agricultural production are positively influenced by the irrigation infrastructure. Results also show that soil degradation increases technical inefficiency. This study compares only results of technical efficiency estimates. So, there is a scope of further investigation to compare results of technical, allocative and economic efficiency of farmers obtained from both methodologies in this region.

Wadud (2003) estimate technical, allocative and economic efficiencies of farmers using farm-specific survey data for rice farmers in Bangladesh. In this paper, the researcher applies the stochastic frontier decomposition techniques and data envelopment analysis for estimating efficiencies. Stochastic frontier model shows results for technical, allocative, and economic efficiency scores of 86, 91 and 78 percent respectively. On the other hand, data envelopment analysis model shows that the corresponding efficiency scores are 86, 91 and 78 percent respectively for CRS DEA and 91, 87 and 79 percent respectively for VRS DEA method. This study compares results from SF and DEA model.

The research examines the inefficiency effects as a function of various farm-specific socioeconomic factors, environmental factors and irrigation infrastructure. This paper points out that there is further scope for research. Because, many other socioeconomic and farm-specific factors that could affect efficiency which are not included in this study.

2.4. Summary and Conclusions

We have reviewed both stochastic frontier and data envelopment analysis frontier in this chapter. The main strength of the econometric approach is that it can be deal with stochastic noise. But the distributional assumption for the inefficiency term and its inability to deal with multiple outputs are considered as the weakness of the econometric approach.

Kumbhakar (1994) points that inefficiency effects could be assessed by introducing factors like, land size, land tenure, credit availability, education of farmers, extension services etc. Coelli and Battese (1996) analyze the agricultural production of Indian farmers by using stochastic frontier. This study does not include some variables such as, rainfall data, extension services, access to credit etc. which might be important for modeling output and inefficiency effects.

Bravo-Ureta and Rieger (1991) study show that efficiency level is not markedly affected by the socioeconomic variables like, farm size, education of the farmer, extension services and experience of cultivation. So, this statement can be reexamined by doing further study. Kalirajan (1981) does not examine allocative efficiency of sample farmers in his study directly. So, there is a scope for extending the approach to estimate both technical and allocative efficiency in paddy production. Kopp and Diewert (1982) use a frontier cost function in place of production frontier function to measure the technical and allocative efficiencies. Bravo-Ureta and Evenson (1994) use a stochastic efficiency decomposition methodology to derive technical, allocative and economic efficiency measures separately for cotton and cassava. The relationship between efficiency and various socioeconomic variables does not reveal a clear strategy in this study that may be recommendation to improve performance of the farmers. So, this model can be extended by establishing a consistent relationship between efficiency and socioeconomic variables in developing countries. Tadesse and Krishnamoorthy (1997) examine the level of technical efficiency in different size of paddy farms of the southern India State of Tamil Nadu. This study shows that a special attention should be given to improve the efficiency of paddy farms with holding through the adoption of practices of small and medium sized farms.

On the other hand, DEA is deterministic nonparametric and non-statistical approach to efficiency measurement. It is deterministic as it attributes all the deviations from the frontier to inefficiency, nonparametric as it does not assume any parametric structure on data, and non-statistical as it makes no distributional assumption on the residuals.

The main advantage of mathematical programming or the DEA approach is that no explicit functional form needs to be imposed on data. DEA can easily accommodate multiple output which is not possible in econometric approach. The main limitation of DEA relative to SF method is that it is deterministic. DEA attributes all deviations from the frontier is inefficiency, whereas SF permits the decomposition of deviations into random component and inefficiency component.

Coelli (1995) discusses recent development in the estimation of frontier functions and DEA frontier. Sharma, Leung and Zeleski (1990) use both parametric and nonparametric frontiers approaches for estimating the efficiencies and make a comparison between two approaches. It is expected that DEA approach is more sensitive to outliners and other noise in the data, but this study shows that the DEA results to be more robust than those obtained from the parametric approach. Henderson and Kingwell (2005) specify as a non-discretionary production input in an input-oriented DEA model. So, any researcher may find out results of rainfall-adjusted DEA model and compare these results with conventional DEA model where environmental effects, such as, rainfall are not considered.

From the above review of literature it is clear to us that these kinds of research, such as, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are not much familiar in Bangladesh. Few researchers have done the efficiency measure using these two modern and sophisticated techniques of mathematical and econometrical methods particularly in agriculture sector. So far as we know that simultaneous estimation of technical and economic efficiency and comparison of results of these efficiencies using data from two different seasons, aman and boro seasons, particularly in northern Bangladesh is not done. We do not find any research, applying the stochastic frontier analysis (SFA) and data envelopment analysis (DEA), which explains efficiency performance of rice farms in northern part of our country. To our knowledge this is first of its kind in Bangladesh. Thus it definite fills this gap.

Chapter 3

Socioeconomic and Environmental Conditions of the Study Area

3.1. Introduction

This research is basically an empirical research about efficiency of rice production in Bangladesh, based on primary data. The researcher selects study area in greater Rajshahi division situated under the Northern part of Bangladesh where rice is the main crop, that could be representative for country as a whole. The High Barind Tract is also in this division. The surface water is not sufficient in this region, so the Barind Multipurpose Development Authority (BMDA) has given a great assistance for developing the use of ground water in this region. Therefore, we have seen some spring crops cultivated here other than main crop rice recently. Despite the fact described in next chapters in details, two kinds of rice, aman and boro are the main crops in this region. To have a clear idea about this region, first of all, we discussed overall physiographic, demographic, locative, climatic conditions and agricultural practices in our study area of northern Bangladesh. Our study area lies in the High Barind Tract where concerned socio-economic characteristics are the same.

The plan of this Chapter is as follows; Section 2 and 3 explain the physiographic and demographic characteristics of the study area; Section 4 describes location and extent of the selected study area; Section 5 gives map showing the study districts with study areas; Section 6 describes climate of the study region; Section 7 and 8 explain agricultural practices and soil types of the different study areas; Section 9 and 10 give agricultural implements used and socio-economic features of respondents in the study area; Section 11 and 12 explain environmental and water conditions and constraints for using the soil in the study area; Section 13 and 14 give cropping pattern and role of BMDA for developing the region and Section 15 gives summary and conclusions.

3.2. Physiographic Structure of our Study Area

Bangladesh is a delta, periodically ravaged by devastating floods and other natural disasters. Bangladesh can be divided into 3 major physiographic units; the hill, terrace and floodplain areas. These three categories can further be classified into 8 units; the hill areas, terrace areas, haor areas, river char land, coastal char land, river floodplains, peat areas and the sundarbans (Hossain, 1991). The northern and eastern hills occupy about 12 per cent of the country, the so-called terrace areas (the Madhupur and Barind Tracts) about 8 per cent and flood plains the remaining 80 per cent (Brammer,1991). In our study area the Barind Tract covers most part of the greater Dinajpur, Rangpur, Pabna, Rajshahi, Joypurhat, Naogaon and Chapai Nawabganj districts in Rajshahi division of Bangladesh (Banglapedia, 2008).

The Barind unit has comparatively a higher elevation than the adjoining floodplains. The contours of the tract suggest that there are two terrace levels, one is at 40 meters and the other between 19.8 meters and 22.9 meters. Therefore, when the floodplains go under water during the monsoon, The Barind Tract remains free from the flooding and is drained by few small streams. About 47 per cent of the Barind region is classified as highland; about 41 per cent as medium highland and the rest are lowland. Agricultural land commonly occupies about 93.35 per cent of the hill slopes of the Barind unit during the year. As this region is generally free from the floodwater, rainwater is the only major source of groundwater recharge. Once there were many isolated small depressions but those have since been covered into agricultural land. This landscape modification has affected the groundwater recharge and has increased dependence on rainwater. Again the channel migration, mainly the shifting of the Tista and the Atrai River and their distributions cover the last couple of centuries, has greatly influenced the climatic conditions of the area. Geographic modifications gradually turned this area into a hot region.

3.3. Demographic Characteristics of the Study Area

According to ministry of finance, the total population of Bangladesh is 160.80 million of which 72.21 million are male and 68.59 million are female. Annual growth rate over 2010-2011 is 1.3 per cent and population density is 941 person per sq. km. The life expectancy at birth of the total population is 65 years. The distributions of population between urban and rural areas are 30 per cent and 70 per cent respectively (Bangladesh Economic Review, 2012). In our study area during 2011 the population of Tanore upazilla is 193495 of which 97975 are male and are 95520 female. The population of Manda and Nachole upazilas in the same period is 470790 and 193196, of which 240492 and 98816 are male and 230298 and 94380 are female respectively. The total number of households of the study area is 163648, in Tanore 38282, 86543 and 38823 are Manda and Nachole upazilas. The average family size is 4.41 in Tanore upazila in Rajshahi district, 5.37 and 4.51 are in Manda and Nachole upazilas under Naogaon and Chapai Nawabganj district. Majority of the population in all villages are Muslims. Some of Hindus families also live in all villages. However the number of such families is higher in Manda than in Tanore and Nachole upazilas. All households are mostly local.

3.4. Location and Extent of the Selected Study Area

The Barind Tract is the largest Pleistocene Physiographic unit of the Bengal Basin covering an area of about 7,770 square kilometers. It has been recognized as a unit of old alluvium which differs from surrounding floodplains. Geographically this unit lies between $24^{0}20^{/}$ and $25^{0}35^{/}$ North latitudes and between $88^{0}20^{/}$ and $89^{0}30^{/}$ East longitudes. This physiographic unit is bounded by the Karatoya River on the East, Mahananda River on the West, and Northern bank of the Ganges on the South (Banglapedia, 2007). For in-depth analysis it is required to have a clear idea about the study area. Three upazillas are taken from three districts as study area. The upazilas are Tanore from Rajshahi district, Manda from Naogaon district and Nachole from Chapai Nawabganj district. The fundamental objectives of this section are to discuss the salient features of study villages for having geographical, social and economic activities especially agricultural practices that have much impact on agrarian relations in rural areas of Bangladesh. Location of the study area can be seen from the map of three upazilas from three different districts. Basic information of the study area total number of households, total land tenure, irrigation facilities system, type of farm households and land used in both aman and boro seasons during survey period 2009-2010 are explored in Table 3.1.

Table 3.1 shows that total farm households in our study area are 251, which are chosen from three districts. About 28.29 per cent rice farmers are selected from Tanore upazila of Rajshahi district, 47.81 per cent and 23.90 per cent rice farmers are sampled from Manda and Nachole upazilas of Naogaon and Chapai Nawabganj districts respectively. Average

age, education and experience of farmers in our study area are 47 years, 5 years and 25 years respectively. List of farmers are collected from upazila agricultural offices.

The total amount of land under the ownership of a household does not necessarily indicate the total amount of land which has been utilized for cultivation. Consideration, therefore, to the operational arrangement of land-holdings becomes relevant. Table 3.1 shows the operational arrangement of land holdings in our study area. Total operational area under a upazila is the land owned by that area plus land taken on rented-in and sharecropping-in land minus rented-out and sharecropping-out land to others. Defining operational area in this way a close look into this Table 3.1 makes it clear that farmers in Manda upazila are more involve (around 16.39 acres of total cultivable land) in the rented-in and sharecropping-in market. The farmers of Tanore and Nachole upazilas are less involved (around 7.65 and 5.76 acres of total cultivable land) in the rented-in and sharecropping-in market respectively. On the other hand, The farmers of Tanore and Nachole upazilas are less involved (around 11.52 and 10.7 acres of total cultivable land) in the rented-out and sharecropping-out market, but farmers in Manda upazila are more involved. In total, net cultivable land in the study area are accounted for 170.08 acres in Tanore upazila, 327.56 acres and 160.48 acres in Manda and Nachole upazilas respectively.

Total net cultivated land of all area is not same under irrigation system. About 5.14 acres of land in Tanore area, 16.83 and 6.35 acres of land in Manda and Nachole area lack of irrigation facilities turne seasonal fallow land. Irrigation is life blood for rice cultivation. Ground and surface water are the main sources of irrigation during dry seasons (November-April). But surface water is in short supply during the winter. On the other hand, ground water irrigation needs heavy capital investment. So rice farmers of the study area could not afford this opportunity. It is evident from the survey findings that irrigation cost is much higher in boro season than for aman season.

Table 3.1 also shows that number of farm households in our study area. In Tanore upazila 64.79 per cent farmers are marginal and small, whereas, 68.33 per cent and 71.67 per cent farmers in Manda and Nachole upazilas are in this category. About 26.76 per cent, 21.67 per cent and 20 per cent farmers are medium in Tanore, Manda and Nachole upazilas respectively. Only 8.45 per cent, 10 per cent and 8.33 per cent large farmers' exists in Tanore, Manda and Nachole upazilas respectively.

Table 3.1: Basic Information of the Study Area

Features		Tanore upazila	Manda upazila	Nachole upazila	Total study area
Information about farm households	Total households	71	120	60	251
	Percentage (%)	28.29	47.81	23.90	100.00
	Average age	47.27	46.86	47.38	47.17
	Average education	5.37	5.20	5.55	5.37
	Average experience	24.82	25.83	25.23	25.29
Land tenure (in acres)	Total cultivable land	173.95	331.20	165.42	670.57
	Total ranted-in-land	4.18	8.53	3.76	16.47
	Sharecropping-in-land	3.47	7.86	2.0	13.33
	Total rented-out-land	5.77	11.58	4.95	22.30
	Sharecropping-out-land	5.75	8.45	5.75	19.95
	Total net cultivable land	170.08	327.56	160.48	658.12
	Average plot size	0.26	0.29	0.30	0.28
Seasonal fallow land	Seasonal fallow land	5.14	16.83	6.35	28.32
	Total net cultivated land	164.94	310.73	154.13	629.80
Classification of farm households	Marginal farm households	11	18	10	39
	Small farm households	24	34	18	76
	Medium farm households	34	64	30	128
	Large farm households	2	4	2	8
	Total	71	120	60	251
Land utilization during survey period (in acres)	Totat aman cultivated land	164.94	293.90	154.13	612.97
	Total boro cultivated land	159.80	310.73	147.78	618.31
	Fallow land in aman season	‘ - `	16.83	‘ - `	16.83
	Fallow land in boro season	5.14	‘ - `	6.35	11.49
	One cropped (only boro) land	‘ - `	16.83	‘ - `	16.83

Source: Field survey data, (2009-2010).
Notes: ‘ - ` indicates that figures are not available.

Land utilized under different rice seasons during the survey period 2009-2010 are also shown in Table 3.1. In aman season total land utilized in different areas are 164.94 acres in Tanore upazila, 293.90 acres in Manda upazila and 154.13 acres in Nachole upazila. On the contrary, in boro season total land utilized in survey areas are 159.80 acres in Tanore upazila, 310.73 acres and 147.78 acres in Manda and Nachole upazilas. In boro season total 5.14 and 6.35 acres of land are unused for seasonal variations in Tanore and Nachole upazilas. In our study area 16.83 acres of cultivable low land seem to become one cropped land in Manda upazila. This amount of land used only in boro rice season. The main problems in our study area are excess or less rainfall, frequently load-shedding, fuel price hike may reduce the efficiency of agricultural production by reducing the availability of water during critical periods in the growing season. Sometimes heavy fogging causes destruction of initial seed ground and rising crops. As a result, farmers always remain under uncertainty in getting their crops.

3.4.1. Selected Upazila Tanore

Tanore upazila stands by north-west side and is situated about 29 kilometers away from the district head quarter of Rajshahi. The upazila is bounded on the north by Manda and Niamatpur upazila of Naogaon district, on the east by Paba and Mohanpur upazila of Rajshahi district, on the south and west by Godagari and Nachole upazila of Chapai Nawabganj district. The total area of the upazila is 295.39 sq. km. The upazila lies between $24^0 06^/$ and $25^0 13^/$ north latitudes and between $88^0 02^/$ and $89^0 21^/$ east longitudes. The upazila consists of seven union parishad and two Pourosoba. Tanore upazila has 207 mauzas and 211 villages.

The upazila is specially a tropical monsoon climatic area. The average annual rainfall is about 1640 millimeter and the maximum temperatures are 38.8^0 and 10.9^0 Celsius respectively. According to Ministry of Finance, Bangladesh Economic Review 2012 the total population and literacy rate of this upazila are 193495 and 45.35 per cent. Per head average cultivable land is 0.32 acre. The upazila is adjacent to the metalled road and well communicated with the district head quarter of Rajshahi, Chapai Nawabganj and Naogaon district. Almost all rain comes down between July to October. Rainfall is comparatively little in this upazila and it varies from place to place over years. Weather remains hot by the day time but becomes cooler at late night. This upazila has already been designated as drought prone. So, this region experiences extremes that are clearly in contrast to the climate condition of the rest of the country. Under rainfed conditions, transplanted aman is the principal crop, generally preceded by aus in the centre and west. Deep tube-well irrigation has spreaded widely in the past two and half decades, making HYVs boro rice the principal crop in most area of this upazila. Without irrigation, most of the land lies fallow during the dry season. Most irrigated lands also remain fallow between the aman and boro crops, potatoes and spring vegetables are grown in some areas of the upazila. About 97 per cent of this upazila is classified as high and medium land and the rest are lowland. Almost all of the land are double and triple cropped land. The cropping intensity of this upazila is 262 per cent. There are 643.85 acres Khash lands in Tanore upazila, which are also used for rice and fish cultivation. Tanore is known as agricultural upazila. Almost all people are engaged with agricultural activities. A large number of capable people became unemployed in this upazila. Poverty is their daily companion. Low-income poor people of these areas are becoming more solved by involving themselves mainly in rice and various agricultural related activities. At the same time, middle and large rice farmers are now well established. Hence they have changed their life style. We have tired to collect primary data related additional information from agricultural personnel like sub-assistant agriculture officer (SAAO), who is the field level government employee in agricultural department. Basic information of this upazila is also given in Table 3.1.

3.4.2. Selected Upazila Manda

Manda is one of the largest upazila of Naogaon district. It is said that this area had strategic and commercial importance due to its location at the junction of the rivers Atrai. The upazila stands on the southern bank of the river Atrai and is situated at western side around 35 kilometers away from the Naogaon district head quarter. The total area of this upazila is 414 sq. km. The upazila is bounded on the north by Mohadebpur upazila, on the east by Naogaon sadar and Raninagar upazila, on the south and west by Bagmara, Atrai and Niamatpur, Tanore upazila. The upazila lies between $23^0 74^/$ and $24^0 51^/$ north latitudes and between $87^0 88^/$ and $90^0 11^/$ east longitudes. The upazila consists of fourteen union parishad. Manda upazila has 285 mauzas and 289 villages.

According to ministry of finance, Bangladesh Economic Review (BSS 2011), the total population and literacy rate of this upazila is 470790 and 40.72 per cent. Per head average cultivable land is 0.38 acres. A metalled road crosses the upazila and have well communicated with the district head quarter and other districts of Bangladesh. About 10.71 per cent of this area is classified as very high land, 60.53 per cent medium high land, 19.74 per cent medium low land and the rest of 9.02 per cent low land. Almost all of this land is double and triple cropped, only 5.58 per cent alone one cropped lands. The cropping intensity of this upazila is 224 per cent. Low laying land is flood-prone which go under water for around 4 months in every year. So, in this season only boro rice is grown. Bhita and Mathan or the flat lands are very fertile and flood free area. So, varieties of crops such as, wheat, potato, maize, sugarcane, banana and vegetables are grown. But rice is pre-dominant. Varieties of crops are grown throughout the year in this upazila. Almost all of the high lands are triple cropped lands. During the rainy season from July to October the major problem in agriculture in this upazila are excessive or less rainfall, devastating and untimely flood and they cause heavy destruction to rising crops. As a result farmers always remain under uncertainty in getting their harvest.

3.4.3. Selected Upazila Nachole

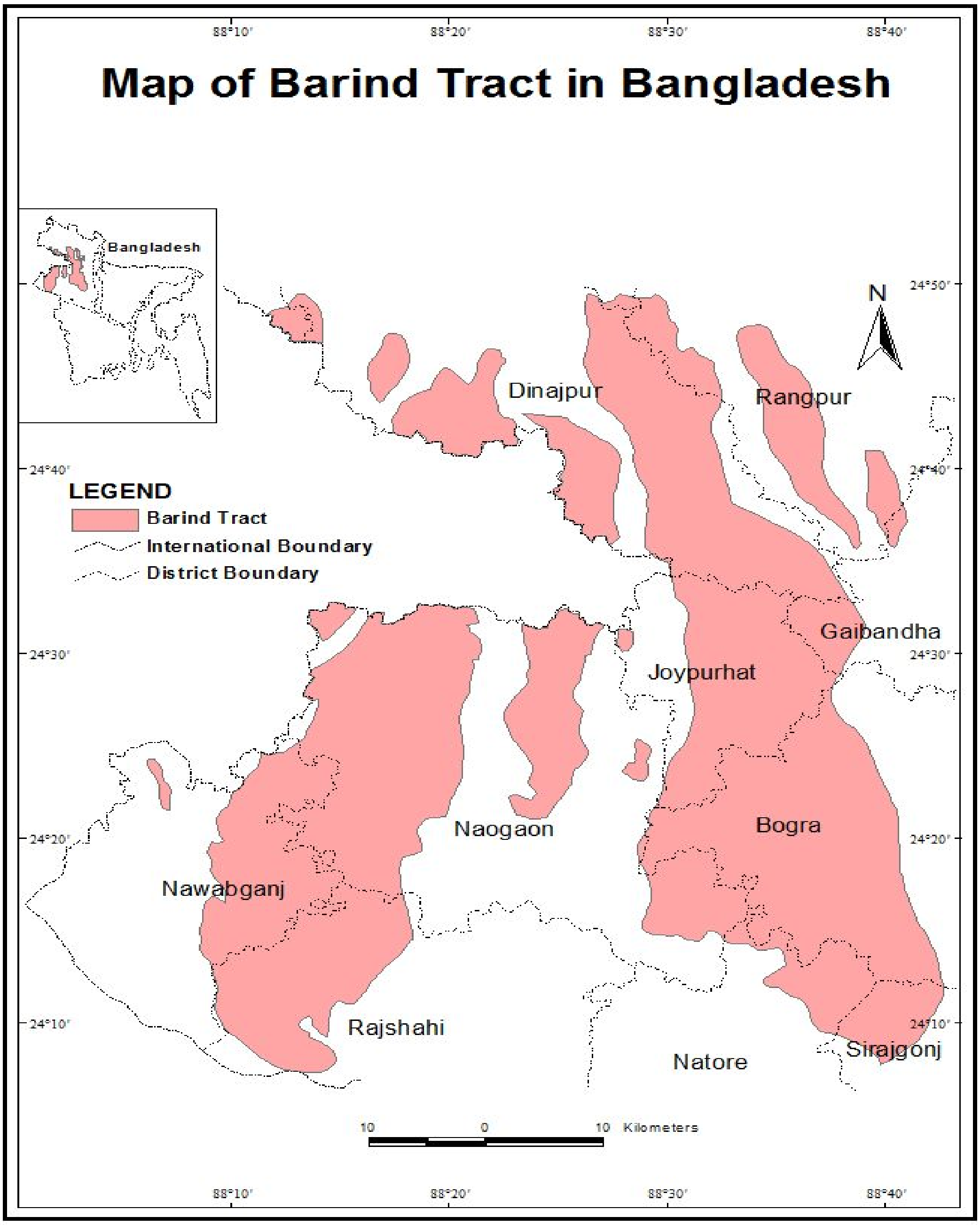
Nachole upazila stands by north-east side and is situated around 30 kilometers away from the district head quarters of Chapai Nawabganj. The upazila is bounded on the north by Gomastapur upazila and Niamatpur upazila of Naogaon district, on the east by Tanore upazila of Rajshahi district and Niamatpur upazila, on the south and west by Tanore upazila and Chapai Nawabganj sadar upazila and Chapai Nawabganj sadar, Shibgonj and Gomastapur upazila.

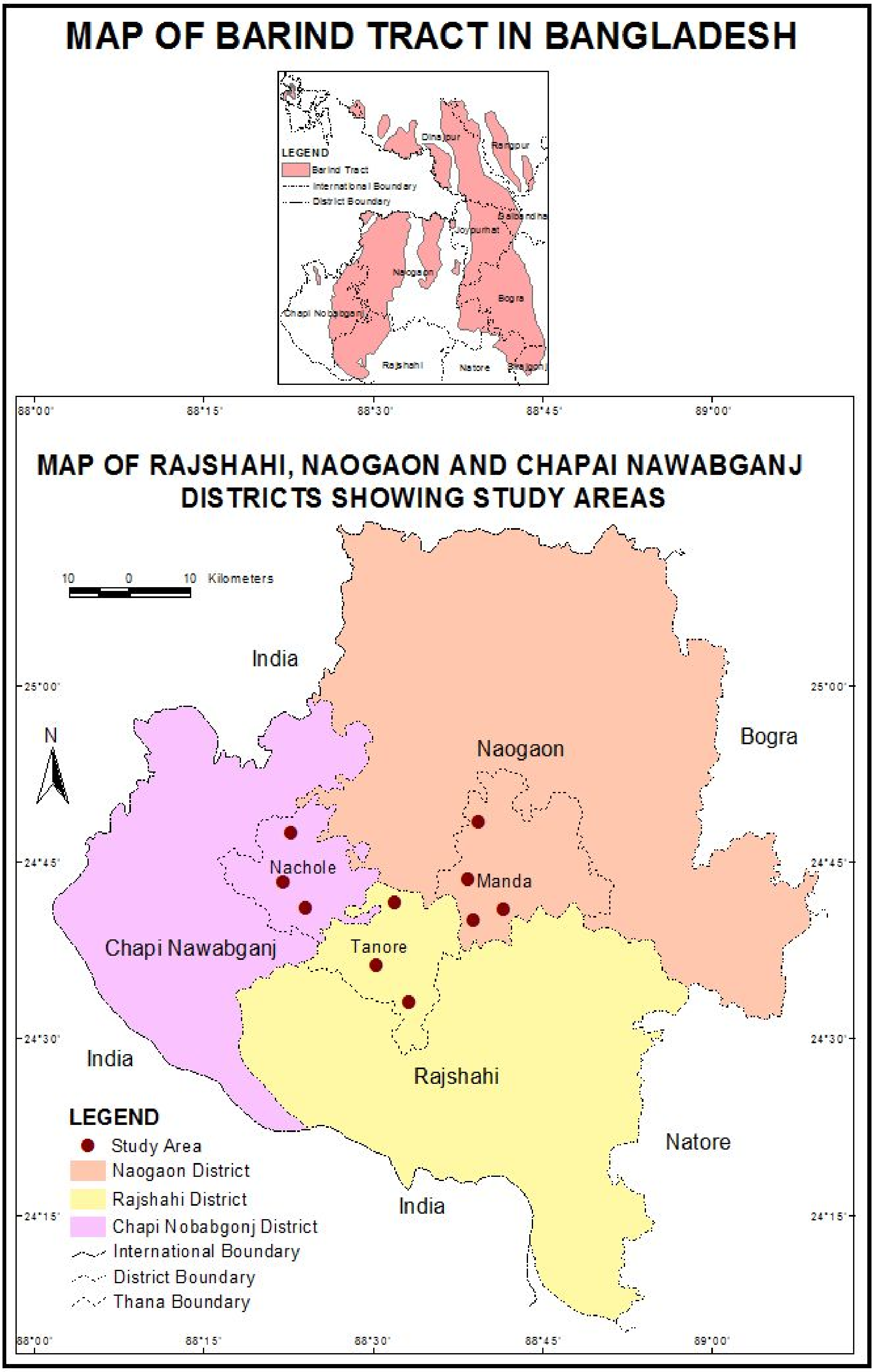
The total area of the upazila is 286.24 sq. km. The upazila lies between $24^{0}38^{/}$ and $24^{0}50^{/}$ north latitudes and between $88^{0}16^{/}$ and $88^{0}31^{/}$ east longitudes. This physiographic unit is bounded by the Karatoya river to the east, Mahananda river to the west, and northern of the Ganges to the south (Banglapedia, 2008). Physiographically the upazila area is divided into two units. These are older alluvial fan and Barind Pleistocene. According to ministry of finance, Bangladesh Economic Review 2011 the total population 193196 and literacy rate of this upazila 42.22 per cent. Per head average cultivable land is 0.49 acres. The upazila consists of four union parishad and one Pourosoba. Nachole upazila has 201 mauzas and 220 villages.

The upazila is adjacent to the metalled road and well communicated with the district head quarter. The uapzila is specially a tropical monsoon climate area. The average annual rainfall is about 1348.70 millimeter, and the maximum temperatures are 30.4^0 and 17.9^0 Celsius respectively. Almost maximum rain comes down between July to September. Transplanted aman and aus rice cultivation is quitely depends on rainwater but boro rice cultivations goes on irrigation. Groundwater is the only major sources of irrigation. Five hundred and thirty deep tube-wells have been set-up in this upazila, which facilitate dry season irrigation for cultivations. About 90 per cent of this upazila is classified as high and medium land and the rest are lowland. Main agricultural product of this upazila is rice. Except this, varieties crops such as; wheat, maize, mustard, sugarcane, onion, potato and vegetables are grown enormously in this upazila throughout the year. Almost all of this land is double and triple cropped land. The cropping intensity of this upazila is 213 per cent. The farmers who are engaged in agricultural work have not gathered any skill out side of agricultural work.

3.5. Map of Barind Tract Showing Study Areas in Bangladesh

The Barind Tract is situated in Northern Bangladesh and our study area is also in this area. So a geographical diagram is depicted here to show the map of the Barind Tract. On the other hand, the second map shows three selected upazilas showing study areas from three different districts of the Barind Tract.




MAP OF BARIND TRACT IN BANGLADESH
LEGEND
Barind Tract
International Boundary
District Boundary
Dinajpur
Rangpur
Joypurhat
Naogaon
Bogra
Rajshahi
Natore
88°00'
88°15'
88°30'
88°45'
89°00'
MAP OF RAJSHAHI, NAOGAON AND CHAPAI NAWABGANJ DISTRICTS SHOWING STUDY AREAS
10 0 10 Kilometers
India
25°00'
N
Bogra
Naogaon
24°45'
Nachole
Manda
Chapai Nawabganj
Tanore
24°30'
India
Rajshahi
LEGEND
Study Area
Naogaon District
Rajshahi District
Chapi Nobabgonj District
International Boundary
District Boundary
Thana Boundary
Natore
India
24°15'

3.6. Climate of the Study Region

The climate of the Barind Tract is, as a tropical monsoon climate having four main seasons, recognized as (Brammer, 1991):

a) Pre-monsoon period (March-May): This is hot or "summer" season with highest temperature and occasional north-western thunderstorm rainfall and strong wind. Tropical cyclone seriously affects coastal areas.

b) Monsoon (June-September): This is a period of highest rainfall, humidity and cloudy. Heavy rainfall may cause flood in different areas of Bangladesh.

c) Post-Monsoon (October-November): This is a hot and humid period with decreasing rainfall but sunny and with heavy dew at night.

d) Dry season or winter (December-February): This season is the coolest, driest and sunniest period of the year. The maximum average temperature in winter season is 29^0c and the minimum is 11^0c. While in summer season, average maximum temperature is 34^0c and the average minimum is 21^0c (Brammer, 1991). With a humid subtropical monsoon climate, Bangladesh is suitable for the growth and cultivation of a wide variety of tropical and sub-tropical crop such as rice.

Rainfall is comparatively little in this region, the average being about 1971 mm. It mainly occurs during the monsoon. Rainfall varies from place to place as well as years to years. For instance, the rainfall recorded in 1981 was about 1738 mm, but in 1992 it was about 1798 mm and in 2009 it was recorded 1628.23 mm only. This region has already been designated as drought prone. Its average temperatures ranges from 25^0c to 35^0c in the hottest season and 9^0c to 15^0c in the coolest season. Generally this region is hot and is considered as semi-arid. In summer, some of the hottest days experience a temperature of about 45^0c or even more in Rajshahi area. In winter it falls to about 5^0c in some places of Dinajpur, Rangpur and Rajshahi districts. So, this older alluvium region experiences extremes that are clearly in contrast to the climate condition of the rest of the country.

3.7. Agricultural Practices

The monsoon and the seasonal flooding determine agricultural practices in Bangladesh. Moreover, agricultural practices and potential productivity of the crops are highly influenced by a number of factors such as, climate (rainfall, evaporation, temperature and hours of light), topography of the soil, soil structure, social values and customs, land tenure, fragmentation and sub-division of land. Since Bangladesh is a humid tropical monsoon oriented region, agricultural practices or cropping pattern covers a wide variety of tropical and sub-tropical crops. Climate of Bangladesh makes conditions suitable for growing tropical crops such as rice and jute in the warm rainy season, temperate crops such as, wheat, potatoes, mustard, groundnuts, pulses spices, and vegetables etc. in the winter season, and sub-tropical crops such as sugarcane and banana throughout the year. High rainfall and seasonal flooding make condition particularly suitable for rice cultivation. The cropping pattern and the intensity are more specially influenced by the time of onset of the monsoon rains, the amount and distribution of rainfall, the occurrence of natural calamities such as, storms and cyclones and the length of flooding period.

The crops in Bangladesh are grown throughout 3 distinct cropping seasons. The1st kharif season starts in the end of March and continues up to the end of May. This is pre-monsoon season characterized by high soil moisture with moderate humidity or flooding and therefore, aus rice, broad cast aman and jute becomes the dominating crop of this season. The 2nd Kharif seasons or hot monsoon season is characterized by high humidity, low solar radiation or flooding, and therefore, transplanted aman rice becomes the dominating crops covering the period from May to September. And the Rabi season ranges from November to early March is a cool, winter dry season. In this season, there is negligible amount of rainfall, low humidity and high solar radiation. Rabi crops included local boro and HYVs boro rice, wheat, mustard, potatoes, pulses, spices, groundnuts, and vegetables etc. We have shown a crop calendar of Bangladesh in Table 3.2. The table shows that harvesting period of the major crops of rice depends critically on their sowing period which in turn depends on the timeliness, adequacy, regularity and consistency of the monsoonal rainfall. High seasonality and irregularity in rainfall have led Bangladesh to suffer from excesses and shortage of water. Late arrival of rainfall leads to a late starting of the sowing season and hence a late harvest. This adversely affects cultivation of crops which have shown after the harvest of one crops. A calendar of rice cultivation seasons is shown in Table 3.2.

Table 3.2: Calendar of Rice Cultivation Seasons in Bangladesh

Name of seasons	Sowing period	Harvesting period	Activities
Kharif-1 season (Aus)	March-May	June-August	Seedbed preparation Swing/ Plantation Weeding Harvesting Threshing Preservation/ Sale
Kharif-2 season (Broad cast Aman)	March-April	June-July	Seedbed preparation Swing/ Plantation Weeding Harvesting Threshing Preservation/ Sale
(Transplanted Aman)	May-September	August-December	
Rabi season (Local Boro)	November-March	February-June	Seedbed preparation Swing/ Plantation Weeding Harvesting Threshing Preservation/ Sale
(HYV Boro)	February-March	May-June	

Source: Bangladesh Bureau of Statistics, (2011).

3.8. Soil Types of the Different Study Areas

Northern Bangladesh is our study area. More specially, we have selected three upazilas from three different districts situated in the northern Bangladesh. The upazilas are Tanore from Rajshahi district, Manda from Naogaon district and Nachole from Chapai Nawabganj district. A geographical location are depicted on maps, here it shows the study area and also the selected three upazilas from three different districts. In the first map total study area is shown with the country map of Bangladesh. Total geographical area is 72994 acres in Tanore upazila, 101260.12 acres and 70698.81 acres are in Manda and Nachole upazilas respectively. All of the upazilas fall in the same soil region. Rice farmers in our study area distinguish three categories of land on the texture which can be classified as:

a) The Bhita land or the elevated land above the flood level;

b) Mathan or the flat field of intermediate level partially inundated during the rainy seasons and

c) The Beels or the low lying lands which go under flood water during the rains. The soil of the elevated land is known as “Bali mati”, (Sandy soil), because of higher proportion of sand in its composition. The “Doash Mati”, (loamy soil), is the most important variety of the alluvial soil comprising the flat field of intermediate level. The usual soil of low lying land is called the “Entel Mati”, (the clay loam). Of the various categories of land the Bhita land is utilized for settlement, Betel leaves chamber, Tree crops, Bamboo bushes, Fruit gardens, orchards etc. It’s very demandable land for growing vegetables. Both Mathan and Beel land are used for the cultivation of various crops. Ten villages have been selected from three different upazilas of the three districts in Northern Bangladesh as sample area for having different agricultural practices. The location of the study area can be seen from the above second map of three upazilas of the different three districts Rajshahi, Naogaon and Chapai Nawabganj.

3.9. Agricultural Implements Utilized in the Study Areas

The following traditional and modern agricultural implements are utilized together in the study area.

a) Power tiller which is made by shallow machine,
b) Tractor,
c) Deep tube-well, Power-Pump, Shallow machine, Vhutvhuti (Local name),
d) Dram seeder,
e) Thresher which is locally made by shallow machine,
f) Sprayer,
g) Wooden plough (Langale),
h) Mai (Beam),
i) Nirani (Harrow),
j) Kodal (Spade) and
k) Kachi (Sickle).

Besides these, farners of the study areas are now well acquainted with some improved implements which are needed for agricultural operations related to the cultivation of HYVs and modern rice crops.

3.10. Socioeconomic Features of Respondents in the Study Areas

The main objectives of this section are to discuss the socio-economic conditions of farmers in the study area that may affect farming practices. To analyze the socio-economic situation of households, at the outset, the researcher would like to present the family structure, farm size and land ownership.

3.10.1. Structure of Farm Households

It is surprising that all the households interviewed in the study area are found to be male headed. But the findings of agriculture census 1996 are that the male-headed and female-headed farm family was 96.52 per cent and 3.48 per cent (BBS, December 2008) respectively. Table 3.3 shows that 96 per cent, and 4 per cent of the farm households are male and female-headed.

Table 3.3: Head of Households Family in the Study Area

Study area	Gender				Single family		Joint family	
	Male headed		Female headed		No. of house-holds	Percen -tage	No. of house-holds	Percen-tage
	No. of house-holds	Percen-tage	No. of house-holds	Percen -tage				
Tanore	68	95.77	03	4.23	64	90.00	07	10.00
Manda	115	95.83	05	4.17	110	91.67	10	8.33
Nachole	58	96.67	02	3.33	53	88.33	07	11.67
Total	241	96.00	10	4.00	227	90.44	24	9.56

Source: Field survey data, (2009-2010).

From the Table 3.3 it is observed that 90.44 per cent household families are single family and 9.56 per cent are joint family. The conclusion can be drawn from the survey results that the family structure has been drastically changed over the years. The values behind joint family concept have been saken up. It may be the result of population pressure and poverty of the household family. This may lead to unwillingness to bear the burden of parents and other nearest relatives.

3.10.2. Farm Size and Land Ownership of the Study Area

Command over economic resources which farmers achieved or inherited is a significant role in the dynamic of the socioeconomic framework of the rural economy in Bangladesh. In a densely populated agricultural country like ours where land is considered as most scarce and where private property in land exist command over labour power access to other resources are likely to emanate mostly from command over land. In what follows we have attempted to examine command over land of the sample. Table 3.4 shows the distribution of sample farmers of our study area in seven categories ranging from 1.5 acres to 9 acres of land. It also provides the total area owned in each size group as well as average size of holdings and average per capita land. So far as the distribution of farmers in different size groups is concerned, it is seen that in our study area 71.71 per cent farmer's land is below 3.01 acres. Again 23.51 per cent farmer's land ranges 3.01 to 6 acres and 3.58 per cent farmer's land is above 6 acres but less than 9.01 acres. Only 1.20 per cent farmers have land in the size group, more than 9 acres and above. It is also seen that both average size of land holdings and average per capita land in our study area are 2.67 acres and 0.49 acres respectively.

Table 3.4 : Land Ownership According to Size of Farms

Farm size (in acre)	Farmers		Aggregated area (in acre)	Average size of holdings (in acre)	Area per capita (in acre)
	No. of farmers	Percentage of farmers			
0.1-1.5	56	22.31	62.65	1.12	0.28
1.5-3.0	124	49.40	272.52	2.20	0.43
3.0-4.50	53	21.12	206.15	3.89	0.62
4.5-6.0	6	2.39	32.45	5.41	0.62
6.0-7.50	4	1.59	26.30	6.57	1.31
7.50-9.0	5	1.99	43.35	8.67	0.96
9.0-10.5	3	1.20	27.15	9.05	1.51
Total	251	100.00	670.57	2.67	0.49

Source: Field survey data, (2009-2010).

The cumulative distribution of the ownership of cultivable land is shown in Table 3.5. In order to show the extent of inequality is in the distribution of farmers' cultivable land. In our study area 71.71 per cent of the marginal and small farmers possess 39.51 per cent of the total cultivable land area. About 25.1 per cent medium sized farmers belong to 36.18 per cent of total cultivable land. Only 3.19 per cent large farmers possess 10.51 per cent of total cultivable land.

Table 3.5: Cumulative Distribution of Land Ownership

Farm size (in acre)	Percentage of farmers	Cumulative % of farmers	Amount of land	Percentage of land	Cumulative % of land
0.1-1.5	22.31	22.31	62.65	9.34	9.34
1.5-3.0	49.40	71.71	272.52	40.64	49.98
3.0-4.50	21.12	92.83	206.15	30.74	80.72
4.5-6.0	2.39	95.22	32.45	4.84	85.56
6.0-7.50	1.59	96.81	26.30	3.93	89.49
7.50-9.0	1.99	98.80	43.35	6.46	95.95
9.0-10.5	1.20	100	27.15	4.05	100
Total	100.00		670.57	100.00	

Source: Field survey data, (2009-2010).

Table 3.6 and 3.7 provide the operational arrangement of total net aman cultivated area and cumulative distribution of operational aman land in each size group as well as average size of holdings and average per capita land. It shows the average size of farm households' net cultivated aman land and average per capita land in our study area of 2.44 and 0.45 acres respectively.

Table 3.6 : Operational Arrangement of Aman Land Holdings

Farm size (in acre)	Farmers		Aggregated area (in acre)	Average size of holdings (in acre)	Area per capita (in acre)
	No. of farmers	Percentage of farmers			
0.1-1.5	56	22.31	59.96	1.07	0.27
1.5-3.0	122	48.61	217.40	1.78	0.34
3.0-4.50	41	16.33	130.60	3.18	0.39
4.5-6.0	16	6.37	80.68	5.04	1.55
6.0-7.50	8	3.19	56.65	7.08	2.83
7.50-9.0	5	1.99	40.28	8.06	0.89
9.0-10.5	3	1.20	27.40	9.13	1.52
Total	251	100.00	612.97	2.44	0.45

Source: Field survey data, (2009-2010).

Table 3.7: Cumulative Distribution of Operational Aman Land

Farm size (in acre)	Percentage of farmers	Cumulative % of farmers	Amount of land	Percentage of land	Cumulative % of land
0.1-1.5	22.31	22.31	59.96	9.78	9.78
1.5-3.0	48.61	70.92	217.40	35.47	45.25
3.0-4.50	16.33	87.23	130.60	21.31	66.56
4.5-6.0	6.37	93.62	80.68	13.16	79.72
6.0-7.50	3.19	96.81	56.65	9.24	88.96
7.50-9.0	1.99	98.80	40.28	6.57	95.53
9.0-10.5	1.20	100	27.40	4.47	100
Total	100.00		612.97	100.00	

Source: Field survey data, (2009-2010).

In our study area, 70.92 per cent marginal and small farmers possess 45.25 per cent of the total net aman cultivated land. About 25.89 per cent medium size farmers belong to 43.71 per cent of total net aman cultivated land and only 3.19 per cent large farmers possess 11.04 per cent of total net aman cultivated land.

Table 3.8 and 3.9 provide the operational arrangement of total net boro cultivated area and cumulative distribution of operational boro land in each size group as well as average size of holdings and average per capita land. It shows the average size of farm households' net cultivated boro land and average per capita land in our study area of 2.46 and 0.45 acres respectively.

Table 3.8 : Operational Arrangement of Boro Land Holdings in the Study Area

Farm size (in acre)	Farmers		Aggregated area (in acre)	Average size of holding (in acre)	Area per capita (in acre)
	No. of farmers	Percentage of farmers			
0.1-1.5	51	20.31	50.96	0.99	0.23
1.5-3.0	115	45.82	198.40	1.72	0.31
3.0-4.50	46	18.34	140.60	3.18	0.43
4.5-6.0	19	7.57	87.68	4.61	1.69
6.0-7.50	12	4.78	73.65	6.14	3.68
7.50-9.0	5	1.99	39.28	7.86	0.87
9.0-10.5	3	1.20	27.74	9.25	1.54
Total	251	100.00	618.31	2.46	0.45

Source: Field survey data, (2009-2010).

Table 3.9: Cumulative Distribution of Operational Boro Land in the Study Area

Farm size (in acre)	Percentage of farmers	Cumulative % of farmers	Amount of land	Percentage of land	Cumulative % of land
0.1-1.5	20.31	20.31	50.96	8.24	8.24
1.5-3.0	45.82	66.13	198.40	32.09	40.33
3.0-4.50	18.34	84.47	140.60	22.74	63.07
4.5-6.0	7.57	92.04	87.68	14.18	77.25
6.0-7.50	4.78	96.82	73.65	11.91	89.16
7.50-9.0	1.99	98.80	39.28	6.35	95.51
9.0-10.5	1.20	100	27.74	4.49	100
Total	100.00		618.31	100.00	

Source: Field survey data, (2009-2010).

3.10.3. Land Plot Size of the Farms

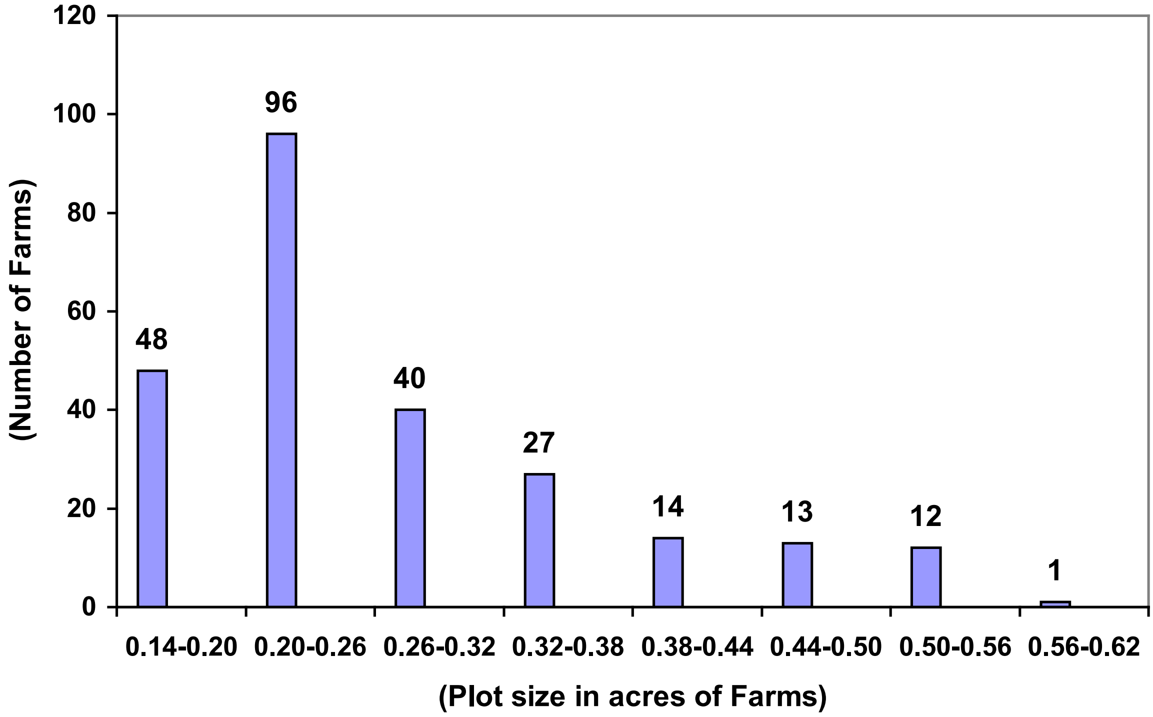
Table 3.10 and Figure 3.1 describe the average plot size in the study area. Farms in Bangladesh are typically small and highly fragmented and farmers in our study area are no exception. The average plot size in a farm is 0.28 acres (Hossain, 1991, p.378). The high degree of land fragmentation does not allow the application of modern equipments, especially tractors and irrigation equipments, and reduce labour efficiency in farming activities causing low efficiency and productivity.

Table 3.10: Plot Size of the Farms in the Study Area

Plot size (acre)	Number of farms	Percentage of farms	Plot size (acre)	Number of farms	Percentage of farms
0.14-0.20	48	19.12	0.38-0.44	14	5.58
0.20-0.26	96	38.25	0.44-0.50	13	5.18
0.26-0.32	40	15.94	0.50-0.56	12	4.78
0.32-0.38	27	10.76	0.56-0.62	1	0.40
Total				251	100.00

Source: Field survey data, (2009-2010).

Figure 3.10: Plot Size of the Farms during 2009-10



About 57.37 per cent farms' average plot size is less than 0.27 acres and 37.45 per cent farms have plot size group of 0.27-0.44 acres. Only 10.36 per cent farms have a plot size of 0.45 acres and more. In both seasons we have investigated same number of rice farms and similar amount of land, no difference is found as far as land plot size is concerned.

3.11. Environmental and Water Conditions of the Study Area

Rapid population growth along with modifications of the land in the study area has degrading the biophysical environment of the Northern Bangladesh. The climate condition in this region has changed. There is very little rainfall and the weather remains hot by the day time but becomes cooler at late night. Since rainwater is the main sources of the groundwater recharge in this region, the climate change disfavours abundant precipitation has adversely affected the groundwater recharge system. The withdrawal of more groundwater than its recharge causes successive lowering of the groundwater table of the study area. This phenomena have eventually been greatly affected the environment parameters and if it persists the environment of the area will become rather unfavourable for habitation in the near future.

Besides lowering the water table another noticeable change is the decrease in forest area. According to some reports from the British colonial times, about 42 per cent of this area was covered by forests in early 19^{th} century. Statistical reports of the land survey since 1849 showed that forest covered about 55 per cent of the study area land. But by 1974, about 70 per cent land of the study area had been changed into cultivable land (Banglapedia, 2008).

Our study area almost became an arid area due to massive deforestation. Also due to its extreme dry nature and relatively low rainfall the vegetation cover decreased remarkably and the area could be picked up by a satellite images as a hot and dry land. As the area was considered a low potential area for groundwater development, agriculture used to depend on monsoon rainwater. As a consequence, there used to be grown only one crop and this area was a food deficit area. With the initiatives from the local engineers, there have been new investigations for groundwater resources and it was found that there were good aquifers to be developed for the large scale irrigation.

3.12. Constraints for Using the Soil in the Study Area

The main constraints on agricultural use and potential are:

i. Low moisture-holding capacity;
ii. Uncertain depth and duration of seasonal flooding on the brown-mottled and grey soil and
iii. Low natural soil fertility.

On the other hand, deep and shallow gray soils occupy the greater part of the study area. The deep soils occupy over half of the area and the shallow soils about one quarter. The two types of soils often occur closely intermixed in the landscape, but the deep soil is relatively more extensive in the west, specially in the Rajshahi region.

In our study area more than 90 per cent of the land lies about normal flood levels, but rainwater is held on arable fields within high field bunds in order to grow transplanted rice. On the level of this area occupies 30 per cent, highland 55 per cent and the rest are lowland. These land types are mainly flooded by rainwater pounded within field bunds or by the raised groundwater table in the monsoon season, but a belt adjoining the lower Atrai Basin is more deeply flooded when high flood levels impede the drainage of local rain-off from the Rajshahi region (Brammer, 1996).

Under rainfed condition, transplanted aman is the principal crop, generally preceded by aus rice in the centre and east. Tube-well irrigation has extended widely in the past two and half decades, making HYVs boro the principal crop in most central and western area, generally followed by HYVs aman. Without irrigation, most of the lands lie fallow through the dry season. Most irrigation land also remain fallow between the aman and boro crops, potatoes and spring vegetables are produced in some areas in this region.

The major constraints to agriculture especially to the cultivation of dry land crops are provided by the unstable silty top soils and strongly developed plough pans which make the soils quickly wet and dry. Variable pre-monsoon and monsoon rainfall, especially uncertain in the west, aggravate the poor moisture relations. Natural soil fertility is low, and zinc and sulphur deficiency occur. Areas near to rivers and the lower Atrai Basin are subject to flash floods and occasional deep floods. Depression sites within the level area are subject to moderately deep flooding in years with exceptionally high rainfall.

3.13. Cropping Pattern

Agriculture in Bangladesh consists predominantly of crop production. Prosperity of agriculture and for the matter, the prosperity of an agricultural household depends a great extent upon the crop output, yield rate and intensity of cropping. Though cropping pattern is mostly determined by natural constraints, it gives an idea of the farmers' involvement in the output as well as input market thereby reflecting farm-income on the one hand, and the extent to which purchased inputs enter his production activities on the other. From this point of view, it would be necessary to know the cropping pattern prevailing on sample farms.

Cultivation of various croped land by the sample farms in our study area is set forth in Table 3.1 before. Table 3.11 shows the farmers of Tanore upazila with its various improved varieties and the major crop covering in aman season 97.02 per cent, and boro season 93.96 per cent of the total net rice cultivable land are utilized respectively. In Manda and Nachole, farmers are covering to 89.72 per cent and 96.04 per cent in aman season and 94.86 per cent and 92.09 per cent in boro seasons in both upazilas of total net rice cultivable land are utilized respectively during the survey period 2009-10. It is also seen that the farmers of Tanore and Manda upazila are more advanced to utilize their cultivable land in aman and boro season than other upazila respectively.

Table 3.11: Cropping Pattern on Sample Farms in the Study Area

Crops	Tanore upazila		Manda upazila		Nachole upazila	
	Land allocated (in acre)	Land as % of gross cropped area	Land allocated (in acre)	Land as % of gross cropped area	Land allocated (in acre)	Land as % of gross cropped area
Aman season	164.94	97.02	293.90	89.72	154.13	96.04
Boro season	159.80	93.96	310.73	94.86	147.78	92.09
Total	170.08	97.75	327.56	98.90	160.48	97.01

Source: Field survey data, (2009-2010).

3.14. Role of BMDA for Developing the Study Region

A project named the Barind Integrated Area Development Project (BIADP) was initiated in mid-1980s to develop groundwater irrigation in the area. Under this project thousands of irrigation deep tube wells have been installed, which facilitated dry season irrigation for cultivation. As a result, agricultural production has increased and the area has become a food surplus area. Apart from providing irrigation, there have been other programmes such as tree planting and excavation of ponds and khals (canals) to arrest the degradation of the environment. Other concerned development schemes such as road development, have had a positive impact on the socio-economic conditions of the Barind Multipurpose Development Authority (BMDA) since the early 1990s. It now covers a large part of the Barind area. The Barind area is located in northern part of Bangladesh.

3.15. Summary and Conclusions

In this chapter, we have described various features of the study area which comprises three upazilas from different three districts. All the selected areas are situated under the Northern part of Bangladesh and same agricultural region where rice is the main crop. But there are some little difference as far as educational, socio-economic, climatic and soil conditions are concerned. Our study area lies in the High Barind Tract. All concerned socio-economic characteristics are similar.

The Barind unit has comparatively a higher elevation than the adjoining flood plains. The contours of the tract suggest that there are two terrace levels, one is 40 meters and the other between 19.8 meters to 22.9 meters high. Therefore, when the floodplains go under water during the monsoon, The Barind Tract remains free from the flooding and is drained by few small streams. About 47 per cent of the Barind region is classified as highland, about 41 per cent as medium highland and the rest are lowland. Agricultural land commonly occupies about 93.35 per cent of the hill slopes of the Barind unit.

The Barind Tract is the largest pleistocene physiographic unit of the Bengal basin covering an area of about 7,770 sq. kilometers. It has been recognized as a unit of old alluvium which differs from surrounding flood plains. Geographically this unit lies between $24^0 20^/$ and $25^0 35^/$ North latitudes and between $88^0 20^/$ and $89^0 30^/$ East longitudes. Three upazilas have taken from different three districts as study area. The upazilas are Tanore from Rajshahi district, Manda from Naogaon district Nachole from Chapai Nawabganj district.

In our study area total population of Tanore upazilla is 193495 in which 97975 male and 95520 female. Total population of Manda and Nachole upazilas are 470790 and 193196, in which 240492 and 98816 male and 230298 and 94380 female respectively. The total number of households of the study areas is 163648. It is 38282, 86543 and 38823 in Tanore Manda and Nachole upazila respectively. Thus the average family size are 4.41 in Tanore upazila of Rajshahi district, 5.37 and 4.51 in Manda and Nachole upazilas of Naogaon and Chapai Nawabganj districts.

The climate of the study area is generally warm and humid. Rainfall is comparatively little in this region, the average being about 1628 mm. The region has already been designated as draught-prone. The average temperature ranges from 25^0 c to 35^0 c in the hottest season and 9^0 c to 15^0 c in the coolest season.

In our study area, about 70.92 per cent marginal and small farmers possess 45.25 per cent of the total net aman cultivated land. About 25.89 per cent medium size farmers belong 43.71 per cent of total net aman cultivated land and only 3.19 per cent large farmers possess 11.04 per cent of total net aman cultivated land. The operational arrangement of total net boro cultivated area and cumulative distribution of operational boro land in each size groups as well as the average size of holdings and average per capita of aman land. It shows that average size of farm household net cultivated and per capita of boro land of our study area are 2.46 acres and 0.45 acres respectively.

Aman rice is widely cultivated all over the study area. About 97.02 per cent, 89.72 per cent and 96.04 per cent of net cultivated land in Tanore, Manda and Nachole upazilas utilized under aman seasons during our survey period 2009-10. In boro season, it accounts for 93.96 per cent, 94.86 per cent and 92.09 per cent land utilized in Tanore, Manda and Nachole upazilas in the same season respectively. The average cropping intensity of the study area is 233.

In our study area more than 90 per cent of the land lies at about normal flood levels, but rainwater is held on arable fields within high field bunds in order to grow transplanted rice. On the level of this area occupies 30 per cent high, medium highland 55 per cent and the rest are lowland. These land types are mainly flooded by rainwater pounded within field bunds or by the raised groundwater table in the monsoon season, but a belt adjoining the lower Atrai Basin is more deeply flooded when high flood levels impede the drainage of local rain-off from the Rajshahi region (Brammer, 1996).

The climate condition of this region is changed rapidly. There is very little rainfall and weather remains hot during the day time but becomes cooler at the late night. Rainwater is the main source of the groundwater recharge in this area. So, withdrawal of more groundwater than its recharge causes the successive lowering of the groundwater level in our study area.

The main constraints to agricultural use are (1) low moisture-holding capacity (2) uncertain depth and duration of seasonal flooding on the brown-mottled and gray soil and (3) low natural soil fertility. So, the main constraints to agriculture especially to the cultivation of dry land crops are the unstable silty top soils and strongly developed plough pans which make the soils quickly wet and dry.

Barind Multipurpose Development Authority (BMDA) has done a remarkable change in our study region. BMDA has taken initiative to develop groundwater irrigation in this region since mid-1980s. Under this project thousands of irrigation deep tube-wells have been installed, which facilitated dry season irrigation for boro rice cultivation. As a result, agricultural production has increased and production intensity has improved than before.

All of these factors may affect the efficiency performance of rice farmers and hence contribute to decrease in farm production and low income of the household.

Chapter 4

Survey Methodology and its Results

4.1. Introduction

In this chapter, we discuss various steps which are adopted in conducting the research survey along with logic behind them. This study is done based on primary data. We conduct a field work for collection of rice cultivation data and information. Three upazilas are chosen from three different districts, one from Rajshahi district, one from Naogaon district and one from Chapai Nawabganj district in Northern Bangladesh, where aman and boro, two kinds of rice, are widely cultivated. We apply purposive sampling techniques for selecting three to four villages from each upazila. These villages are considered as strata. In the second stage we have used the technique of stratified random sampling. At first, we complete a pilot survey which was helpful for designing the main survey. Then a final survey is conducted.

When the population is divided into strata, then the samples are selected from each stratum by simple random sampling procedure. We have selected three villages from Tanore upazila of Rajshahi district under the procedure of purposive sampling. Name of the villages are Kalma, Saranjai and Chanduria. Then we have categorized the rice farmers into four groups, such as large farmers, medium farmers, small and marginal farmers. Finally we have sampled seventy one rice farmers from the selected three villages under the procedure of simple random sampling technique. List of farmers are collected from upazila agricultural offices.

Similarly, we have selected four villages from Manda upazila of Naogaon district under the procedure of purposive sampling. Name of the villages are Bharso, Tentulia, Kalikapur and Paranpur. With the same procedure the simple random sampling technique, one hundred and twenty rice farmers are selected.

Finally, we have selected three villages from Nachole upazila of Chapai Nawabganj district under the procedure of purposive sampling. Name of the villages are Nizampur, Nachole and Kasba. We have categorized the rice farmers into four groups, such as large farmers, medium farmers, small and marginal farmers. Then we have sampled sixty rice farmers by the procedure of simple random sampling for collecting data. The numbers of the farms in sample are based on the size of the population.

The plan of this chapter is as follows: Section 2 and 3 explain survey methodology and results, It begins with explaining the methodology of the survey and it then describes the results; Section 4 gives summary and conclusions.

4.2. Methodology of the Survey

It is required to describe and analyze how research work is done scientifically and systematically. We discussed various steps which are adopted in conducting a survey along with logic behind them. This study is quantitative and qualitative in nature and it is based on field survey data. So, a survey is designed to fulfill the objectives of the study.

4.2.1. Some Concepts of Used Structural Variables

The data used in this research are collected from ten villages of three different upazilas of three different districts in Northern Bangladesh. The survey data are collected for consecutive rice seasons. One is aman season (S_1) which ranges from December to February 2009-2010 and another is boro season (S_1) ranges from June to August in 2010 year.

We have discussed our theoretical and empirical models in chapter 5. But here we give some definition and description of variables. We have used one output and seven inputs in this study. We have also used seven socioeconomic and infrastructural variables which affect cultivation, production and inefficiency of the farmers.

Owner Farm

An owner farm is one who owns the land and operates and bears all the cost of production including management and supervision. That is, owner farm is one who cultivates his land by himself or by hired labour and bears all costs and takes all production. (BBS, June 2009).

Small Farm

A farm holding having an operated area between 0.050 to 2.49 acres of land, with a minimum of 0.050 acres is cultivated area (BBS, June 2009).

Medium Farm

A farm having an operated area of 2.5 to 7.49 acres of land is considered as medium farm. (BBS, June 2009).

Large Farm

A farm having an operated area of 7.5 acres and above land is called large farm. (BBS, June 2009)

Output

Output is defined as the observed rice produced and is measured in mound (1 mound = 37.32 Kg).

Land

Land is the basic factor of rice cultivation. Land represents as the total amount of area which is used for rice production.

Labour

Labour is a valuable input for rice cultivation. Rice cultivation requires skilled, trained and experienced labour. Labour cost of rice cultivation of all seasons is not the same. Generally labour cost of per acre boro rice is more than per acre aman rice. Hired labour costs are calculated by summing up the amount of man-day employed for cultivating land during the crop season. It is also estimated by adding up total labour employed times the prevailing local wage rate. On the contrary, family labour costs are estimated by adding up 90 per cent of local wage rate.

Plough

It is surprising that agricultural mechanization, in case of plough system, has been taken place across Bangladesh for both landlord and tenant farmers. About hundred per cent farmer said that they have used power-tiller for plough of land. The costs of plough are estimated as the money paid to the power-tiller holder per acre and per times of land plough.

Seed

Seed plays a vital role in production. Good, healthy and improved seed for more production is a popular saying. HYVs and hybride seeds bear more cost so maximum farmers of our study area can not bear the excess costs of seed. Generally, farmers used their produced crop as seed. Sometimes they buy seed from government agencies and other NGOs. Moreover, some farmers used high yielding varieties (HYV) as the direction of their respective sub-assistant agriculture officer (SAAO), Whether buying seeds from market or from different NGOs, costs of seed has been calculated at the current market price. Total costs of seeds are calculated as the total amount of seed multiplied by its price.

Irrigation

Irrigation is vital or life blood for rice cultivation. Ground and surface water are the main sources of irrigation during the dry season (November–April). But surface water supply is in short during the winter. On the other hand, ground water irrigation needs heavy capital investment. So rice farmers of the study area can not afford. It is evident from the survey findings that irrigation cost is much higher in boro season than that in aman season. Cost of irrigation is paid either in cash or in terms of rice product. It is paid in terms of rice as a specific portion of total output. It ranges from one fifth to one seventh of total output in the surveyed area. The total irrigation costs are estimated in terms of taka ($ 1 = about 80 Bangladeshi taka). Irrigation costs, which is paid in terms of crops, is also measured in taka multiplying by prevailing local market price of rice for irrigation.

Fertilizer

Among aman and boro rice, specially HYVs, are heavily fertilized. Land productivity and crop yield can be raised with balanced dose of fertilizer along with manure of various kinds. In Bangladesh per acre use of fertilizer is one of the lowest. Fertilizer used at farm level in our surveyed area is dominated by Urea of 68 per cent followed by TSP and of SSP 16 per cent and MP of 16 per cent. Survey results reveal that hundred per cent farmers use fertilizers and all of them are used chemical fertilizers. Some farmer used non–chemical fertilizers, such as, cow-dung and ashes in their land. Owing to increases in price of cow feed and the tremendous decrease in pasture land, cattle rearing are prevalent only for commercial purposes. This made non–chemical fertilizer scarce. Total cost of fertilizer has been calculated as the total amount of fertilizer multiplied by its price.

Pesticides

Annual loss of crops caused by various pest attack and diseases is about 10–15 per cent. Bangladesh is situated in a tropical climate zone that is known as a pest prone area. Pest control measure to protect crops is an integral part of modern farm practice. Almost, all farmers use pesticides in their cropped land. Total costs of pesticides are calculated as the total amount of pesticides multiplied by its price.

We now discuss socio-economic and infrastructural variables which affect production and efficiency of the farmers. The variables are denoted the age of the farmers, the year of education of the farmers, experience of the farmers, land fragmentation, credit facilities dummy which assumes the value one if the farmers do not take any kind of credit from any institutional sources and zero otherwise, extension services dummy which assume the value one if the farmers do not get any extension services from the related officials and zero otherwise, land degradation dummy which takes the value one if the land is undegraded and zero otherwise.

4.2.2. Factors Associated with Inefficiency

Factors associated with inefficiency have played an important role. Therefore, we should carefully identify and isolate the factors as far as efficiency is concerned. From the review of literature we have seen some socio-economic and demographic factors associated with inefficiency. These factors include land tenure, households' and labours' education, land use and credit facilities (Seyoum et.al., 1998; Coelli and Battese, 1996; Wilson et.al., 1998; kumbhakar, 1994). Techniques of rice cultivation, sharecropping tendency, farm holding size influence the efficiency of farmers (Ali and Choudhury, 1990; Coelli and Battese, 1996; Kumbhakar, 1994). Apart from this related information, cultivation experience, supervision could affect the capability of the farmer to use the existing technology efficiently (Parikh and Shah, 1995; Kumbhakar, 1994). Now we discuss what about this situation in context of Bangladesh particularly in our study area.

In our study area the variables, viz., age, year of education, experience of cultivation of the farmers, land fragmentation, credit facilities, extension services and land degradation may be considered as relevant. The age of the farmers could have a positive or negative effect on efficiency. A *priori*, more years of education (schooling), that is, more formal education will generally increase efficiency. Because, educated farmers can learn about new technologies quickly and so they can apply improve techniques on cultivation accordingly. Extension services and education prompt the adjustment process in the application of fertilizer and pesticides in response to a decrease in its price in the U.S. corn output (Huffman, 1977). Years of cultivation experience may reduce the inefficiency of the farmers but sometimes the farmers are less receptive and more conservative in nature to adopt new technologies of production.

Land fragmentation, that is, plot size may have a negative effect on efficiency. Because, the greater the plot size of a farm the greater could be the opportunity to apply new technologies, such as, tractors, modern irrigation system and other modern equipments and hence farmers with less land fragmentation could be expected to have more efficiency.

As we know, the cultivation system is changed. Farmers turns their cropping pattern from old natural less costly to new modern mechanical more expensive system. So, credit is now an essential part of modern cultivation. Generally, more and easy availability of credit could have positive effect on efficiency of the farmers.

Extension services may have a positive impact on efficiency of the farmers. Because quality extension services could improve the ability of the farmers to allocate inputs more successfully.

Environmental factors are given more attention to economist recently in the case of verifying the efficiency of the farmers. Therefore, land degradation is likely to have a negative effect upon the efficiency measures. Land degradation is increasing because of more mechanization and unplanned use of chemical in cultivation. Land degradation is enhanced because of dependency for household fuel on crop residuals and animal dung along with wood, leaves and twigs which, if recycled back to the soils, would reduce the rate of soil erosion, and soil structure degradation (Idris, 1990).

The demand for irrigation is increasing day by day, because of changing the pattern of cropping in Bangladesh. During the last decades, there has been a comprehensive change in irrigation system in our study area. Barind Multipurpose Development Authority (BMDA) has done this job by setting a large number of deep tube-wells (DTWs). A posteriori, this improved irrigation infrastructural could have a positive impact upon the production as well as the efficiency of the farmers.

4.2.3. Framework of the Field Work Survey

Ten villages from three different districts are selected, where two types of rice, aman and boro are widely cultivated. The data are obtained using a structured questionnaire administered personally with the help of sub-assistant agriculture officer (SAAO). Data are collected from respondent's houses, Union parishad, tea stall, seed, fertilizer and pesticide selling centers, where cultivators are available. The questionnaire is structured in English and translated into Bengali verbally when administered. In total 251 rice farmers were interviewed. The field work survey was held during the period of December to February for aman season (S_1) 2009-2010 and June to August for boro season (S_2) in 2010 year.

4.2.4. Questionnaire Design

We aim to achieve two goals. First, to obtain data relative to the objectives of the survey and second, gather data, which are reliable and valid. At first, the researcher operates a pilot survey on 60 rice producers. This pilot survey collects information about output, cost of production, revenue, profit, management of fund, some personal information and socio-economic problems, which are related to rice cultivation. The pilot survey is required to check the questionnaire, the effectiveness of the framework of field work, the quality of the interviews, the justification and satisfaction of the sample instruction, the frequency of the different reasons for refusals and the overall correctness of the survey methods. After this pilot survey, an integrated questionnaire is prepared. Total questionnaire is shown in Appendix 4.1.

The questionnaire consists of five major sections. The first section contains area based information, address and a number of personal details discussing name, age, experience, sex, marital status, member of households, educational status and social status of the respondents. The second section includes land ownership, production costs and other related questions, like, total owned cultivable land, homestead area, garden area, rented-in land, rented-out land, sharecropping-in land, sharecropping-out land, total rice cultivated land, number of plots, average plot size, average plot distance from residence, land and utilized labour pattern (own and hired labour, male, female and child labour), plough costs, seed utilization, application of fertilizers, use of pesticides, irrigation costs, output, revenue and information about credit. Third section contains the non-farm activities income, like, business, services, fishing, poultry, labourer and others. The fourth section explains about utilized capital assets, information about livestock, lastly, some participatory rural appraisal (PRA) questions like, extension services, about training of rice farmers, information from newspaper, magazine and television for gathering knowledge about rice cultivation and market availability and the last section includes socio-economic factors which affect rice cultivation.

4.2.5. Sampling Strategy and Sample Size

We have collected a list of farmers with total amount of rice cultivated land from upazila agricultural offices of Tanore, Manda and Nachole upazilas from Rajshahi, Naogaon and Chapai Nawabganj districts. In the study area, categories of rice producers and the land distribution of the farm households is skewed. Therefore if the sample random sampling procedure is applied to such a distribution of farm households in each upazilas, there is a chance that either or too many large farmers may be included in the sample. As a result, the sample may not adequately represent this group in the population. Simple random sampling by stratification may improve the representativeness of the sample drawn from a population when we know something about make up of the population relevant to our research. Stratification can reduce the sampling error, a measure of the variability of the population estimates from repeated samples around the population value (Warwick and Lininger, 1975), which depends not only on the sample size but also on the sample design (Casley and Kumar, 1988). So it is advantageous to specify strata of rice farmers like, large, medium, small and marginal farmers.

4.2.6. Period of Data Collection

In the study area due to the existence of mainly two category of rice named aman and boro rice, data are collected during two harvesting seasons. The researcher conducts a field work survey during the period of December to February 2009-10 for aman season (S_1) and June to August 2010 for boro seasons (S_2) in the selected areas taking a larger time period for data collection covering the harvesting seasons of main two rice cultivation aman and boro. Collected data enable the researcher to assess different components of costs and their variations with respect to rice cultivation. It also enables the researcher to examine the revenue accruing from selling rice in different seasons. That is why selection of time period for collecting data covering 6 months may be considered significant for research.

4.2.7. Policy to Ensure Correctness in the Accumulation of Data

Before preparing the final questionnaire we conducted a survey to 60 rice cultivators to check the appropriateness and relevance of the questions being asked and to ensure data accuracy. This pilot survey identified the possible problem which might be encountered during the main field work survey. In the study area most of rice producers are not well educated. For that, when the researcher at first tried to collect data, then the respondent did not understand many questions. For this reason the researcher designed the questionnaire as easy and simple as possible. In fact, the researcher tried to gather the confidence of some rice producers and their family members to get accurate information. Stephen (1964) noted, "The greater part of the research rests on kindness in the willingness of respondents to give time to the interview and to do what is requested, confidence of the interviewer that he will not take advantage of the respondents and that the survey will in no way harm his interest."

4.2.8. Primary Data Collection

The primary data collected from the survey for the year 2009-10 can be categorized in Table 4.1 and the sub-headings set forth bellow:

(i) Non-farm income data: include non-farm work hours, days, costs and income in each season for various non-farm activities.

(ii) Livestock data: include livestock numbers, hours spent on livestock husbandry, livestock costs and income from livestock.

(iii) Miscellaneous data: These data include household's name, social status, household sharecropping information and some information about peak period of farming.

Table 4.1: Some Information of Primary Collected Data

Output and inputs	Variables recorded	Units
Output	Output per acre	Mound (1 mound = 37.32 kg)
	Output price per mound	Taka ($ 1 = 80 Taka)
	Revenue and profit from output	Taka.
Land	Total cultivated land	Acre
	Price of land per acre (1%)	Taka.
	Homestead area	Acre
	Aman rice area	Acre
	Boro rice area	Acre
	Distance from residence	Km.
Labour	Labour used per acre	Per man-day
	Owned labour	Per man-day
	Hire labour	Per man-day
	Wage per man-day	Taka.
	Per acre labour cost (weighted average)	Taka
Plough	Plough times per acre	Number
	Per acre plough cost	Taka.
Seed	Seed used per acre	Kg.
	Seed price per Kg.	Taka.
	Per acre seed cost	Taka.
Irrigation	Irrigated land	Per acre
	Per acre irrigation cost	Taka.
Fertilizer	Fertilizer used per acre	Kg.
	Fertilizer price per Kg.	Taka.
	Per acre fertilizer cost (weighted average)	Taka.
Pesticides	Pesticides used per acre	Kg/ milliliter.
	Per acre pesticides cost (weighted average)	Taka.
Factors associated with inefficiency	Age	Year
	Education	Year
	Experience	Year
	Land fragmentation, i.e., plot size	Acre
	Credit facilities	Dummy
	Extension services	Dummy
	Land degradation	Dummy

Source: Field survey data, (2009-2010).

Some educated and clever rice producers at first try to refuse to supply the accurate information, especially the cultivated land area, productivity, revenue and profit. Because they thought that if they deliver the accurate figures about this information, the government may impose taxes or some registration fees. When we told them like a friend it would not be used otherwise except research work and higher degree, then they feel assured and supplied accurate information about rice cultivation.

About 15.6 per cent rice producers are absolutely illiterate, but some family of each stratum is literate. For rice cultivation, input ratio is a most significant factor. Rice producers do not keep written documents about rice cultivation, For this reason, when we interview them, they depend upon their memory to recall or call their family members to supply perfect information about rice cultivation. Most of them have had enough experience of rice cultivation. Therefore it is possible for them to store information and knowledge about rice cultivation.

During survey period we have chosen seven structural or ordinary variables and some inefficiency variables with some socio-economic and infrastructural variables. There are three dummy variables used in our study. All structural and inefficiency variables are indicated in Table 4.1.

Our study area is a well communicated area in northern Bangladesh. For this reason, it was easy to collect data from the rice producers. The researcher has to stay few days in that selected area to collect data.

4.3. Results of Survey

In this section, we show results what we get from the primary survey of our study area. We are interested to know what the primary conditions of the farmers are. For example, what are the age, experience of rice cultivation, and educational status of the farmer? We also try to know about the area of total cultivable land and area of the total cultivated aman and boro land, average plot size, per acre production cost, per acre output, per acre revenue and profit of the farmers. Now we give the survey results in details. In this chapter we describe the cost of production, output, revenue and profit in aman season (S_1), boro season (S_2) and total both aman and boro seasons (S_1+S_2) together and total aman and total boro indicate entire aman season and boro season.

4.3.1. Age Classification of the Farmers

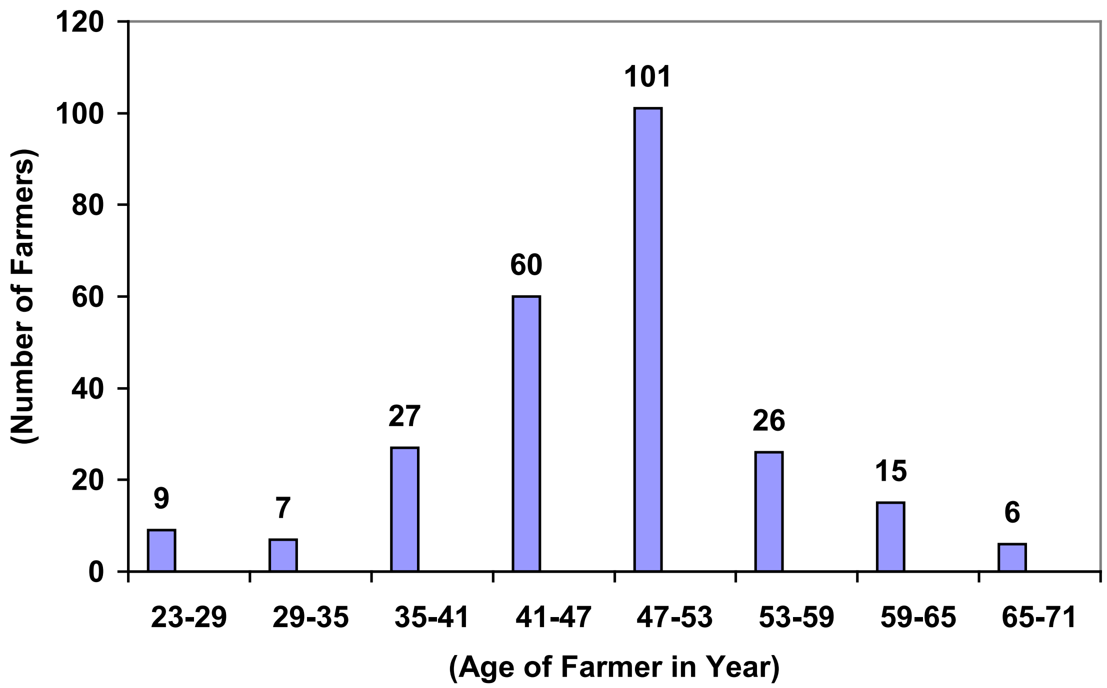
We have taken different types of rice farmers in our study area as far as age is concerned. The age limit of the farmers is from 23 years to 66 years. The survey result shows that most of the farmers are young and energetic. About 74.50 per cent farmers have the age ranging between 42-49 years. About 40.24 per cent farmers fall in the age group of 47-53 years and 6.37 per cent farmers are fall in the age group of 23-35 years. On the other hand, a significant number of farmer's 8.37 per cent have the age of 60 years and above We have indicated this result in Table 4.2 and Figure 4.1.

Table 4.2: Age Classification of the Farmers

Age (years)	Number of farmers	Percentage of farmers	Age (years)	Number of farmers	Percentage of farmers
23-29	9	3.59	47-53	101	40.24
29-35	7	2.79	53-59	26	10.36
35-41	27	10.76	59-65	15	5.98
41-47	60	23.90	65-71	6	2.39
Total				251	100.00

Source: Field survey data, (2009-2010).

Figure 4.1: Age Classification of the Farmers



4.3.2. Duration of Schooling of the Farmers

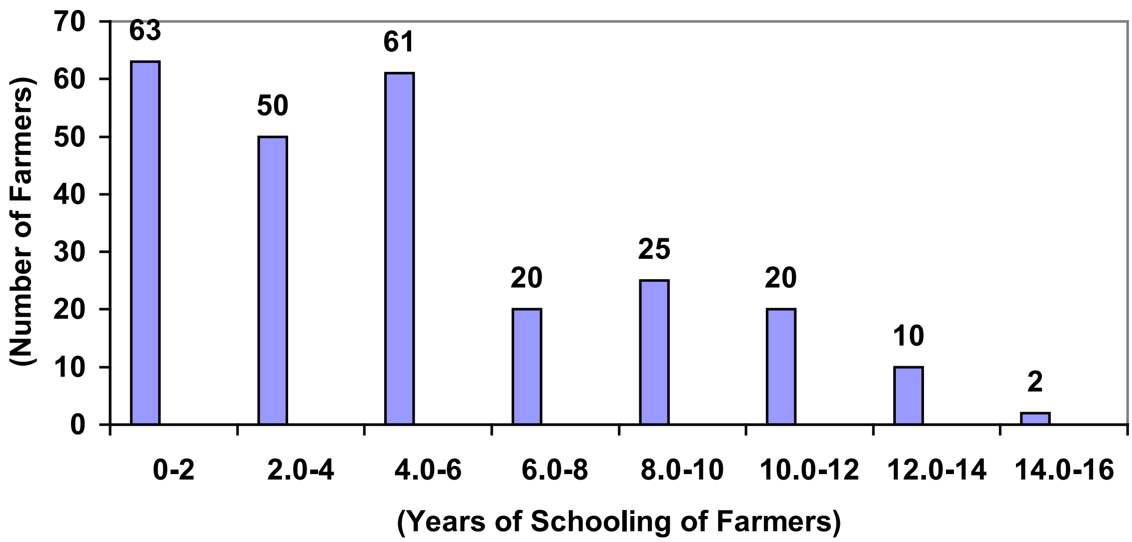
Education plays an important role in making decisions concerning selection of seeds, adoption of fertilizers, pesticides, supplying quality inputs, timely contact with agricultural officials and banking activities for taking suggestions and advice regarding rice cultivation and credit management system (Tetlay, 1991). In the survey area, of 17.13 per cent farmers have never attended the school and others have no professional training about rice cultivation. About 27.89 per cent rice farmers in the study area include in the education group of 1-4 years. Table 4.3 and Figure 4.2 show that in our study area 42.23 per cent farmers fall in the education group of 5-10 years. This group mainly operates the rice cultivation in our study area on an average. Only 12.75 per cent farmers fall in the education group of 11 years and above.

Table 4.3: Duration of Schooling of the Farmers

Years of schooling	Number of farmers	Percentage of farmers	Years of schooling	Number of farmers	Percentage of farmers
0-2	63	25.10	8-10	25	9.96
2-4	50	19.92	10-12	20	7.97
4-6	61	24.30	12-14	10	3.98
6-8	20	7.97	14-16	2	0.80
Total				251	100.00

Source: Field survey data, (2009-2010).

Figure 4.2: Duration of Schooling of the Farmers



4.3.3. Years of Farming Experience of the Farmers

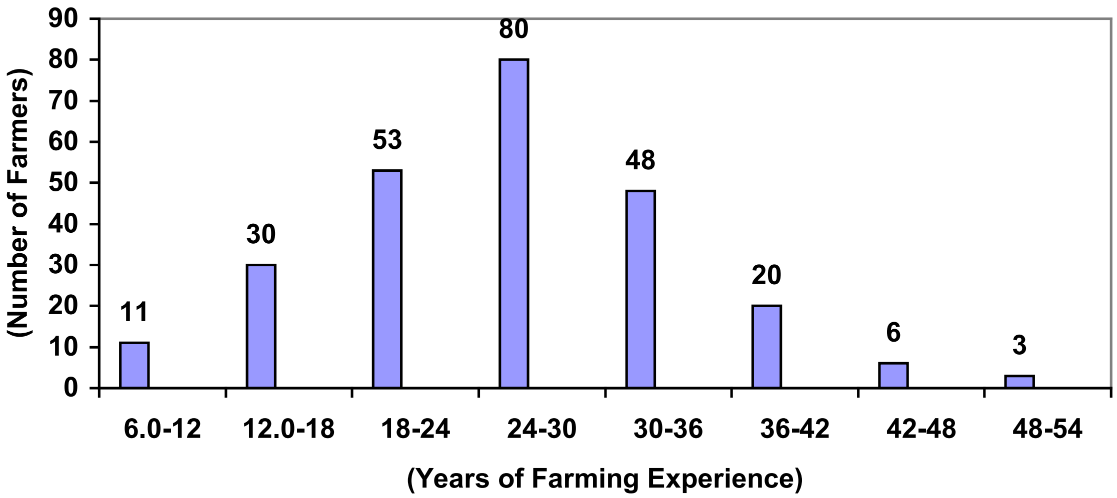
Experience of rice producers is a considerable factor for rice cultivation. In our study area experience of the rice producers ranges between 6–49 years with an average of 26 years. In our study area, most of the rice producers have been found experienced in rice production. They have no academic training or experience in this regards. They have no training on modern cultivation system. They do not use proper proportion of fertilizer and pesticides. They use traditional system of cultivation to produce rice for long time. For an example, 37.45 per cent farmers have an experience between 6-24 years in rice cultivation. About 58.96 per cent farmers have an experience in group of 25-42 years and only 3.59 per cent farmers have an experience of 43 years and more. In both aman and boro seasons, farmers have almost similar length of experience. So, there are no difference of both seasons as far as length of experience in rice cultivation. We have depicted this result in Table 4.4 and Figure 4.3.

Table 4.4: Years of Farming Experience of the Farmers

Experience (years)	Number of farmers	Percentage of farmers	Experience (years)	Number of farmers	Percentage of farmers
6-12	11	4.38	30-36	48	19.12
12-18	30	11.95	36-42	20	7.97
18-24	53	21.12	42-48	6	2.39
24-30	80	31.87	48-54	3	1.20
Total				251	100.00

Source: Field survey data, (2009-2010).

Figure 4.3: Years of Farming Experience of the Farmers



4.3.4. Average Cost of Aman Season (S_1) of the Farmers

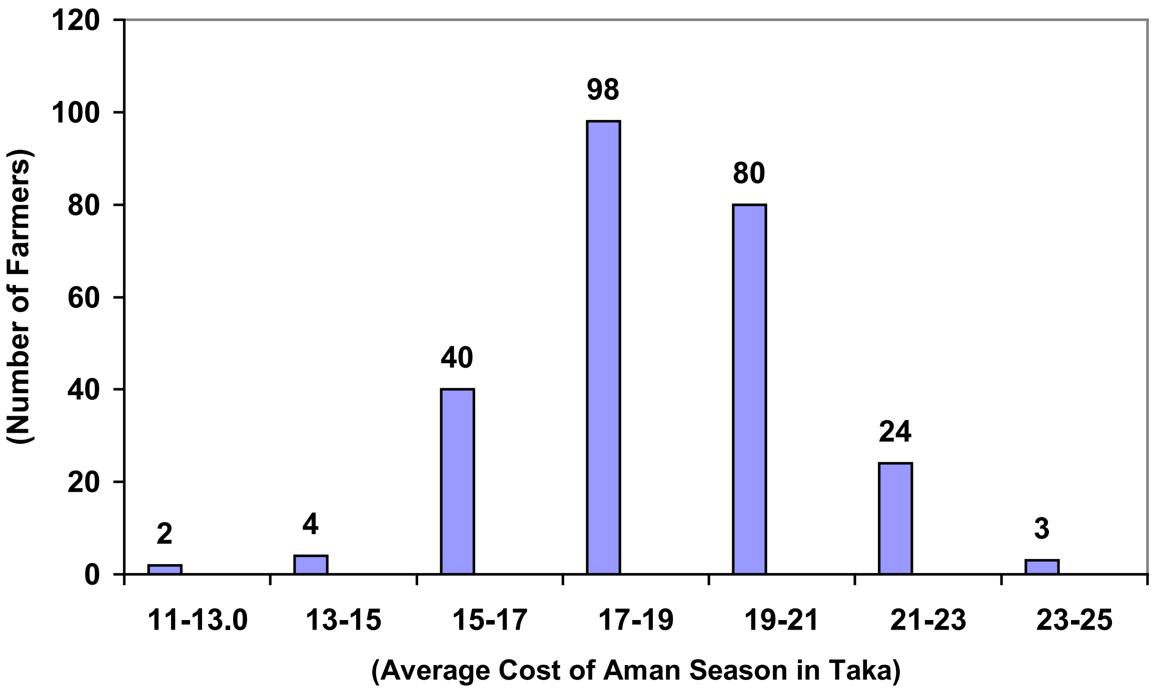
Costs of different inputs are added and the average total variable cost (ATVC) of aman season (S_1) is calculated in terms of money. In our study area, average cost of aman season (S_1) exists in the ranges of 11-25 thousand taka during survey period in December-February 2009-10. Average total cost of aman season (S_1) is shown in Table 4.5 and Figure 4.4.

Table 4.5: Average Cost of Aman Season (S_1) of the Farmers

Aamn cost (Thousand Tk.)	No. of farmers	Percentage of farmers	Aman cost (Thousand Tk.)	No. of farmers	Percentage of farmers
11-13	2	0.80	19-21	80	31.87
13-15	4	1.59	21-23	24	9.56
15-17	40	15.94	23-25	3	1.20
17-19	98	39.04	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.4: Average Cost of Aman Season (S_1) of the Farmers



In our study area, only 2.39 per cent farmers average total variable cost (ATVC) of aman season (S_1) is less than 16 thousand taka. About 15.94 per cent farmers' average total variable cost lie between 15-17 thousand taka. About 39.04 per cent farmers have average total variable cost in aman season (S_1) between 17-19 thousand taka and 32.27 per cent farmers have average cost of aman season (S_1) more than 19 thousand taka but less than 22 thousand taka. Only 10.36 per cent farmers' average total variable costs of aman season (S_1) are more than 21 thousand taka.

4.3.5. Average Cost of Boro Season (S_2) of the Farmers

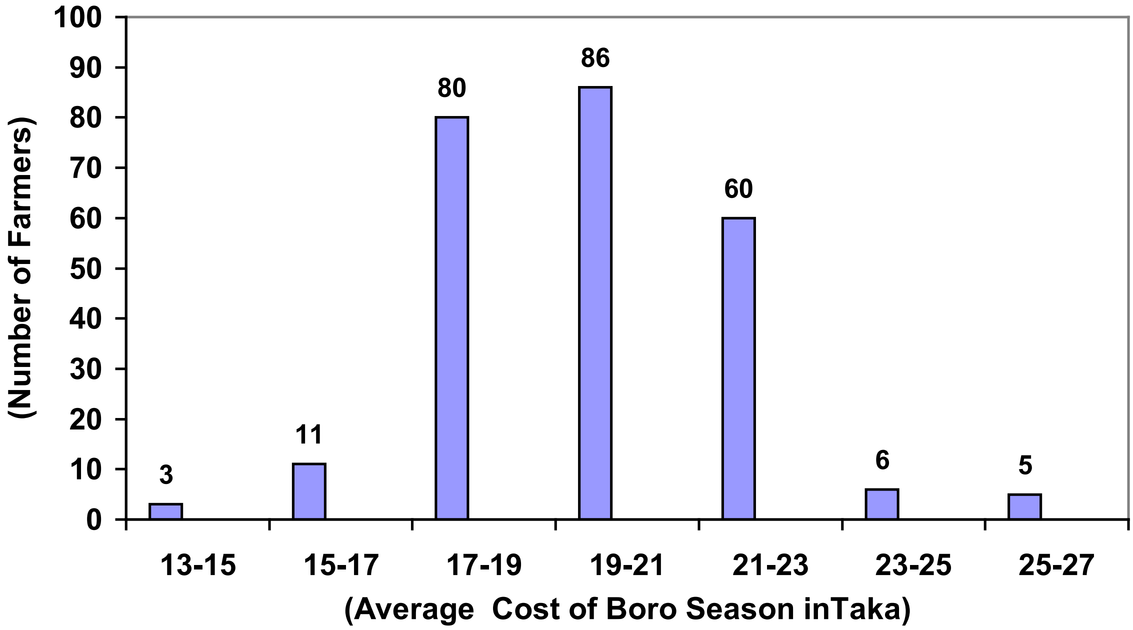
In our study area, average total variable cost of boro season (S_2) is higher than in aman season (S_1). In boro season (S_2) average total variable cost (ATVC) of production ranges from 13-27 thousand taka during survey period in June-August 2010. Average total variable cost of boro season (S_2) is shown in Table 4.6 and Figure 4.5.

Table 4.6: Average Cost of Boro Season (S_2) of the Farmers

Boro cost (Thousand Tk.)	No. of farmers	Percentage of farmers	Boro cost (Thousand Tk.)	No. of farmers	Percentage of farmers
13-15	3	1.20	21-23	60	23.91
15-17	11	4.38	23-25	6	2.39
17-19	80	31.87	25-27	5	1.99
19-21	86	34.26	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.5: Average Cost of Boro Season (S_2) of the Farmers



In our study area, 5.58 per cent of boro season (S_2) farmers average total variables cost is less than 17.1 thousand taka. About 31.87 per cent farmers have boro seasons (S_2) average cost is between 17-19 thousand taka. About 58.17 per cent farmers cost in boro season (S_2) ranges from 19-23 thousand taka. Only 4.38 per cent farmers have average total variable cost in boro season (S_2) more than 23 thousand taka.

4.3.6. Average Cost of both Aman and Boro Seasons (S_1+S_2) Together

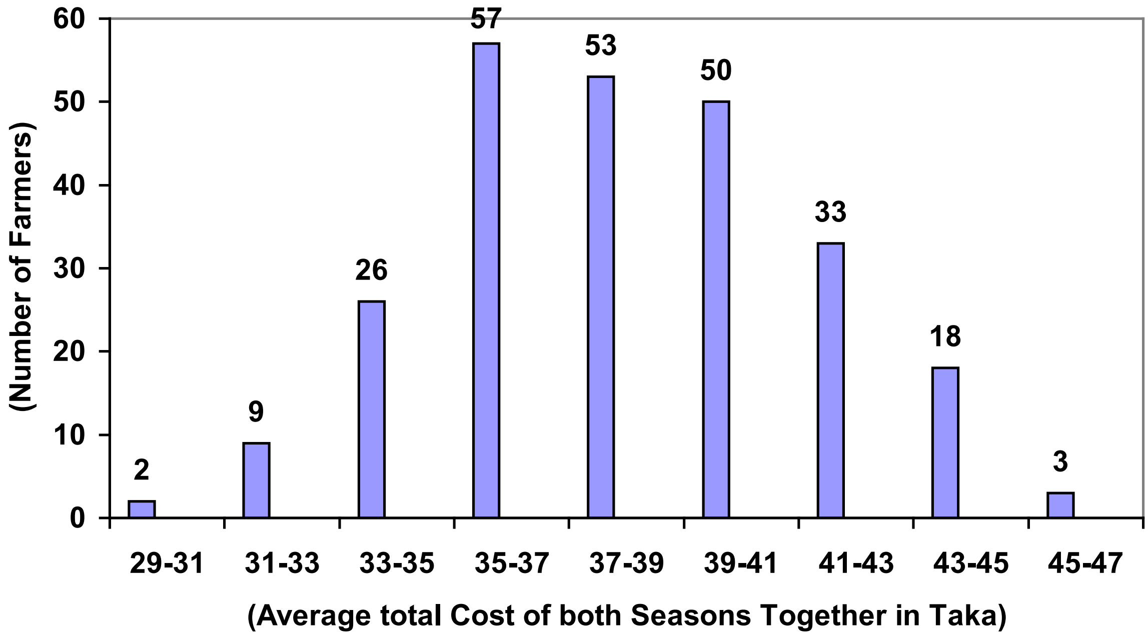
Table 4.7 and Figure 4.6 exhibit that 14.74 per cent farmers expenses average total variable cost of both aman and boro seasons (S_1+S_2) together are less than 36 thousand taka during survey period 2009-10. About 63.74 per cent farmers' average cost of both seasons together lies between 36-41 thousand taka. Only 21.51 per cent farmers have average total costs of both aman and boro seasons (S_1+S_2) together more than 41 thousand taka.

Table 4.7: Average Cost of both Aman and Boro Seasons (S_1+S_2) Together

Average cost (Thousand Tk.)	No. of farmers	Percentage of farmers	Average cost (Thousand Tk.)	No. of farmers	Percentage of farmers
29-31	2	0.80	39-41	50	19.92
31-33	9	3.58	41-43	33	13.15
33-35	26	10.36	43-45	18	7.17
35-37	57	22.71	45-47	3	1.20
37-39	53	21.11	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.6: Average Cost of both Aman and Boro Seasons (S_1+S_2) Together



4.3.7. Total Production Cost in Aman Season of the Farmers

Total cost of rice production depends on how many acres of land and how much amount of inputs have been used for rice cultivation. Cost of different inputs are added and calculated in terms of money. Though a large number of farmers' are marginal and small so they have less amount of cost for this purpose.

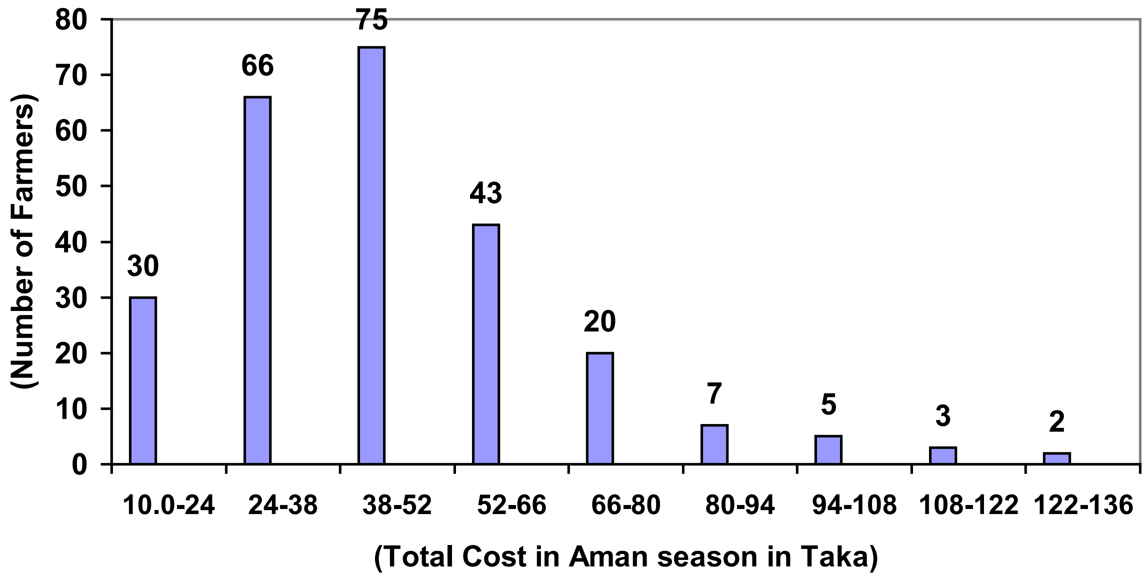
Table 4.8 and Figure 4.7 exhibit that 38.25 per cent farmer's total production costs are less than 39 thousand taka during aman rice cultivation in 2009-10. About 47.01 per cent farmer's total cost lies between 39-66 thousand taka. Only 14.74 per cent farmers have total cost in aman season is more than 66 thousand taka.

Table 4.8: Total Production Cost in Aman Season of the Farmers

Total aman cost (Thousand Tk.)	No. of farmers	Percentage of farmers	Total aman cost (Thousand Tk.)	No. of farmers	Percentage of farmers
10.0-24	30	11.95	80-94	7	2.79
24-38	66	26.29	94-108	5	1.99
38-52	75	29.88	108-122	3	1.19
52-66	43	17.13	122-136	2	0.80
66-80	20	7.97	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.7: Total Production Cost in Aman Season of the Farmers



4.3.8. Total Production Cost in Boro Season of the Farmers

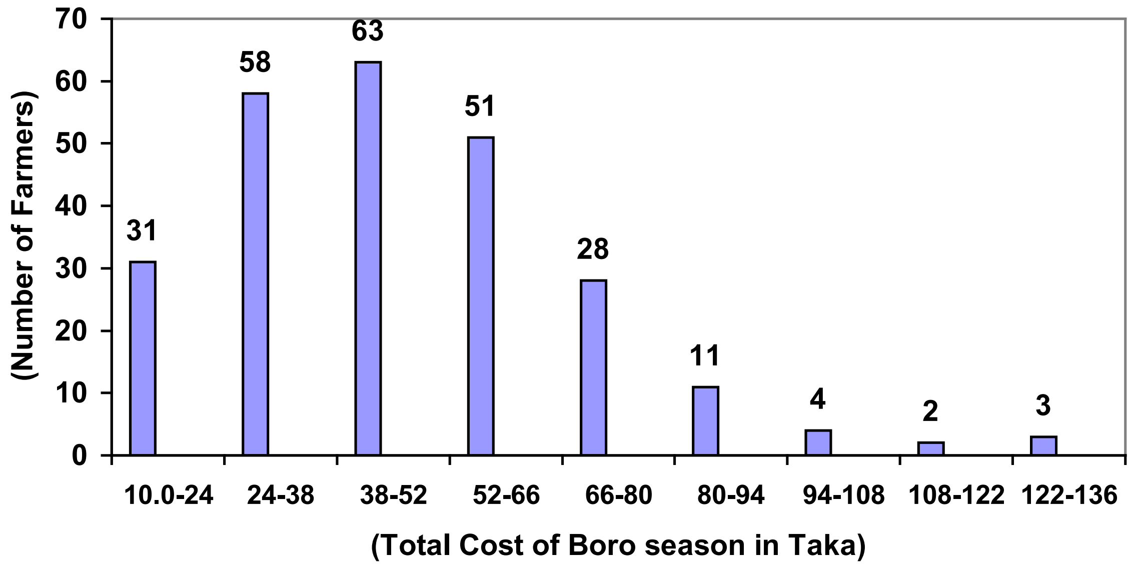
Total rice cultivation costs in each seasons are not the same amount. Generally total production cost in boro season is more than aman season. Specially, labour, irrigation, fertilizer and pesticides of all costs in boro season is much high than in aman season. For an example, of 35.46 per cent farmers' total cost of boro season is less than 37 thousand taka and 45.42 per cent farmers' total cost in boro season cultivation is more than 38 thousand taka but less than 67 thousand taka. About 11.15 per cent farmers' total boro production costs is between 66-80 thousand taka. Only 7.37 per cent farmers' total boro cost is more than 80 thousand taka. Survey results are exhibited in Table 4.9 and Figure 4.8. Total cost, output, revenue and profit of both aman and boro seasons (S_1+S_2) together are shown in Appendix 4.2.

Table 4.9: Total Production Cost of Boro Season of the Farmers

Total boro cost (Thousand Tk.)	No. of farmers	Percentage of farmers	Total boro cost (Thousand Tk.)	No. of farmers	Percentage of farmers
10.0-24	31	12.35	80-94	11	4.38
24-38	58	23.11	94-108	4	1.59
38-52	63	25.10	108-122	2	0.80
52-66	51	20.32	122-136	3	1.20
66-80	28	11.15	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.8: Total Production Costs of Boro Season of the Farmers



4.3.9. Average Output of Aman Season (S_1) of the Farmers

Average output of all seasons in our study area is found to be low. From inquiry to the grassroots level of rice producers, some major reasons have seen found. Firstly, in the beginning stage of the rice cultivation, there is serious shortage of water. Secondly, at the last stage of the production, when the rice almost grew up, there occurs frequent load-shedding which affected rice production. Thirdly, fuel price gradually rose up and hampered all kinds of rice cultivation. Fourthly, sometimes heavy fogging causes destruction of initial seed ground and rising crops. As a result, farmers always remain under uncertainty in getting their crops.

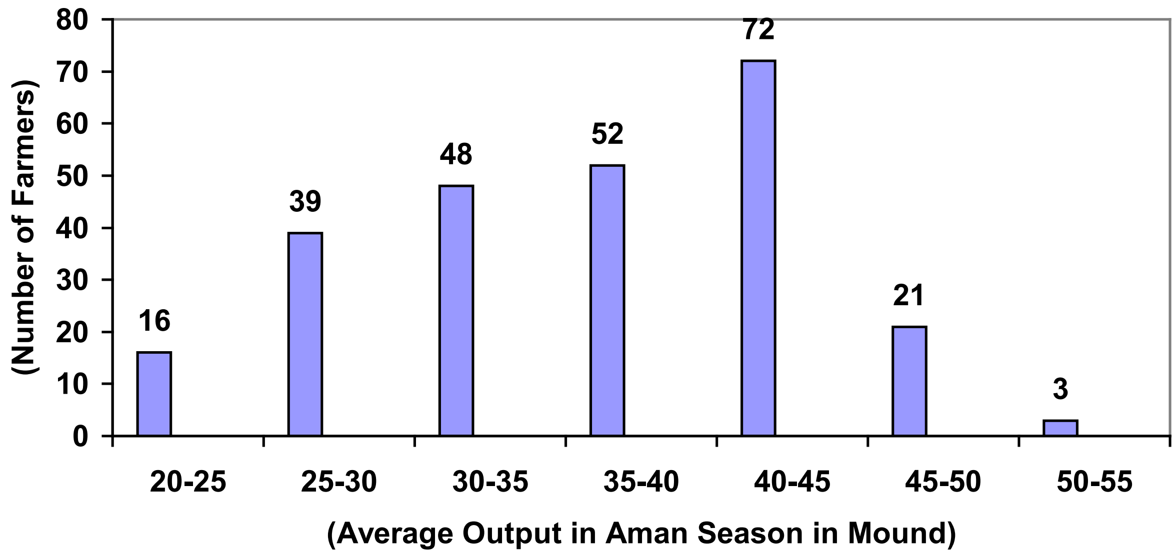
Average output in aman season (S_1) of our survey area during survey period ranges 20-55 mounds. This result is indicated in Table 4.10 and Figure 4.9. The survey result shows that 21.91 per cent farmers' average output in aman season (S_1) is less than 31 mounds.

Table 4.10: Average Output of Aman Season (S_1) of the Farmers

Aman output (In mound)	No. of farmers	Percentage of farmers	Aman output (In mound)	No. of farmers	Percentage of farmers
20-25	16	6.37	40-45	72	28.68
25-30	39	15.54	45-50	21	8.37
30-35	48	19.12	50-55	3	1.20
35-40	52	20.72	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.9: Average Output of Aman Season (S_1) of the Farmers



About 68.52 per cent farmers' average output in aman season (S_1) is more than 31 mounds but less than 46 mounds and only 9.57 per cent farmers output in aman season (S_1) is more than 45 mounds during survey period in 2009-10.

4.3.10. Average Output in Boro season (S_2) of the Farmers

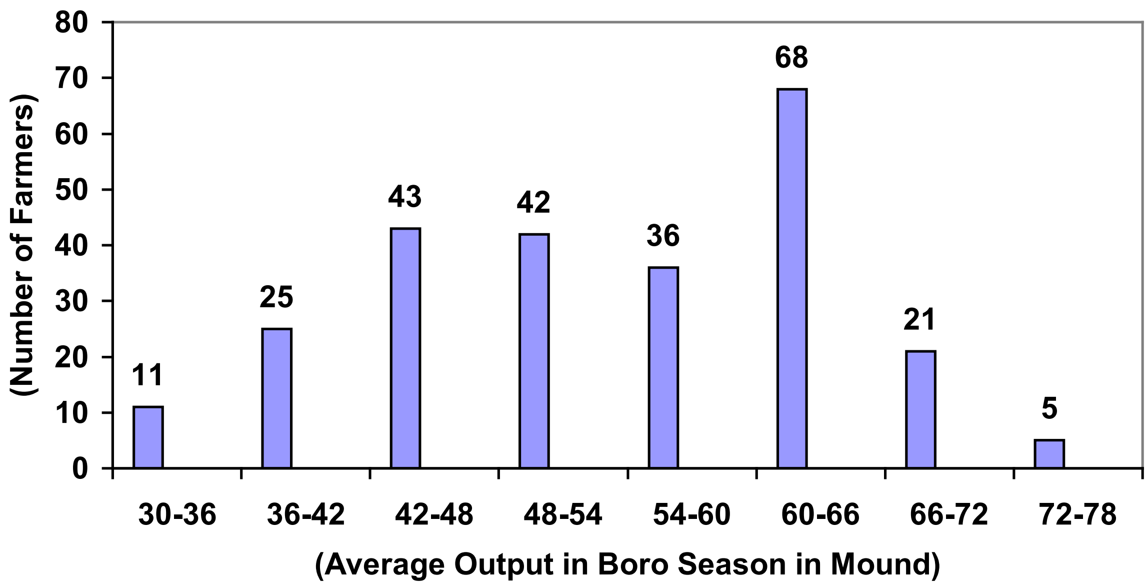
Average output in boro season (S_2) in our survey area is not satisfactory in amount. There are some reasons for that which stated before. Average output in boro season (S_2) of our study area ranges from 31-75 mounds. The survey results show that 31.47 per cent farmers' average output in boro season (S_2) is 30-48 mounds. About 58.17 per cent farmers' average boro output is between 49-66 mounds and only 10.37 per cent farmers' average output in boro season (S_2) is more than 66 mounds during survey period in June-August 2010. These results exhibited in Table 4.11 and Figure 4.10.

Table 4.11: Average Output in Boro Season (S_2) of the Farmers

Boro output (In mound)	No. of farmers	Percentage of farmers	Boro output (In mound)	No. of farmers	Percentage of farmers
30-36	11	4.38	54-60	36	14.34
36-42	25	9.96	60-66	68	27.09
42-48	43	17.13	66-72	21	8.37
48-54	42	16.73	72-78	5	2.0
Total				251	100.00

Source: Field survey data, (2010).

Figure 4.10: Average Output in Boro Season (S_2) of the Farmers



4.3.11. Average Total Output of both Aman and Boro Seasons (S_1+S_2) Together

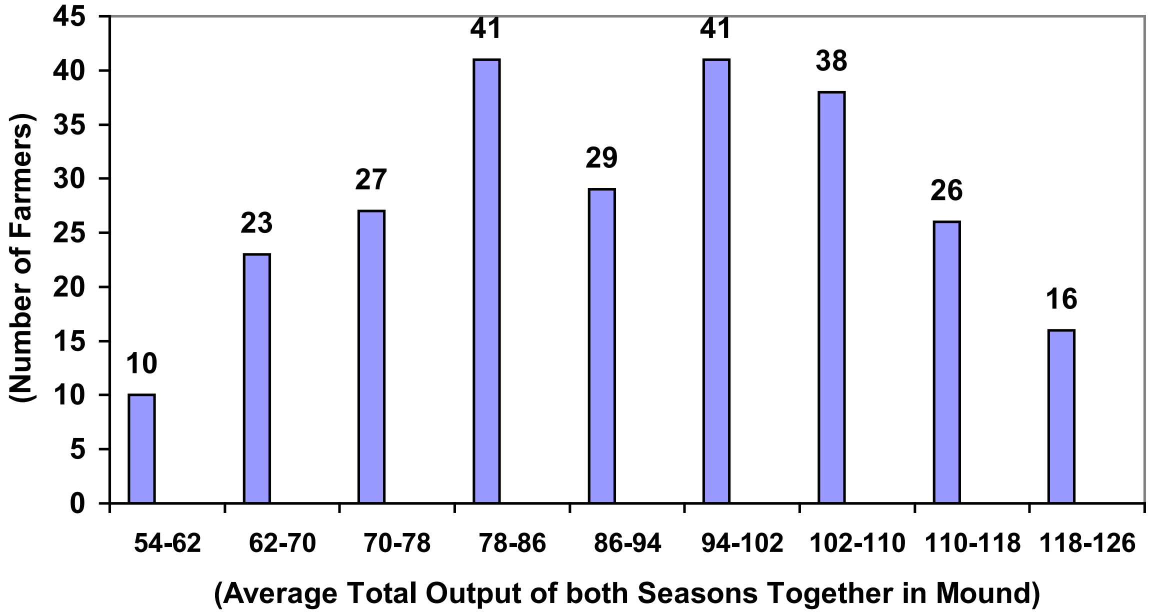
The survey results show that 23.90 per cent farmers average total output of both aman and boro (S_1+S_2) seasons together are less than 79 mounds. About 27.89 per cent farmers' average total output of both seasons (S_1+S_2) together is ranges from 78-94 mounds. About 41.47 per cent farmers' average total output of both seasons (S_1+S_2) together are more than 94 mounds but les than 111 mounds. Only 16.73 per cent farmers average total output of both seasons (S_1++S_2) is more than 111 mounds during both seasons together 2009-10. These results have shown in Table 4.12 and Figure 4.11.

Table 4.12: Average Total Output of both Aman and Boro Seasons (S_1+S_2) Together

Average output (In mound)	No. of farmers	Percentage of farmers	Average output (In mound)	No. of farmers	Percentage of farmers
54-62	10	3.98	94-102	41	16.33
62-70	23	9.16	102-110	38	15.14
70-78	27	10.76	110-118	26	10.36
78-86	41	16.34	118-126	16	6.37
86-94	29	11.56	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.11: Average Total Output of both Aman and Boro (S_1+S_2) Seasons Together



4.3.12. Total Output of Aman Season of the Farmers

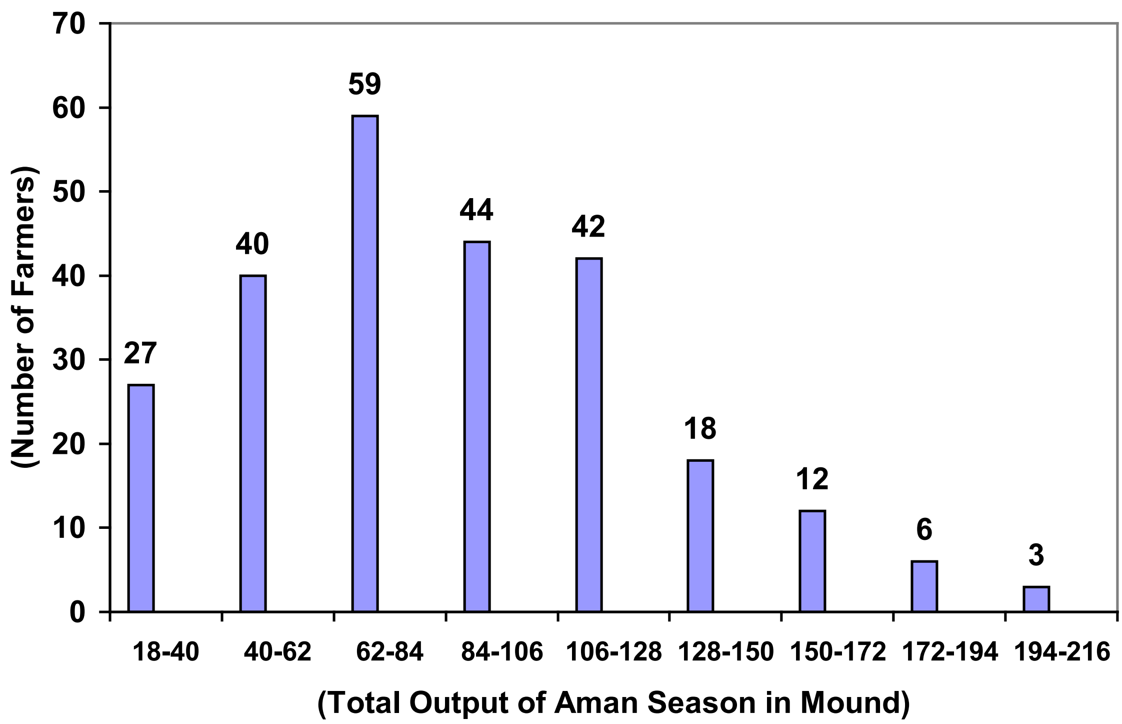
The survey result shows that only 26.69 per cent farmers' total output of aman season is less than 63 mounds. About 41.04 per cent farmers' total output of aman season is ranges from 63-106 mounds but less than 107 mounds. About 23.90 per cent farmers' total aman rice output is between 107-150 mounds, and only 8.37 per cent farmers' total aman rice output is more than 150 mounds during survey period in December-February 2009-10. These results have shown in Table 4.13 and Figure 4.12.

Table 4.13: Total Output of Aman Season of the Farmers

Aman output (In mound)	No. of farmers	Percentage of farmers	Aman output (In mound)	No. of farmers	Percentage of farmers
18-40	27	10.76	128-150	18	7.17
40-62	40	15.94	150-172	12	4.78
62-84	59	23.50	172-194	6	2.39
84-106	44	17.53	194-216	3	1.20
106-128	42	16.73	Total	251	100.00

Source: Field survey data, (2009-2010).

Fi6gure 4.12: Total Output of Aman Season of the Farmers



4.3.13. Total Output of Boro Season of the Farmers

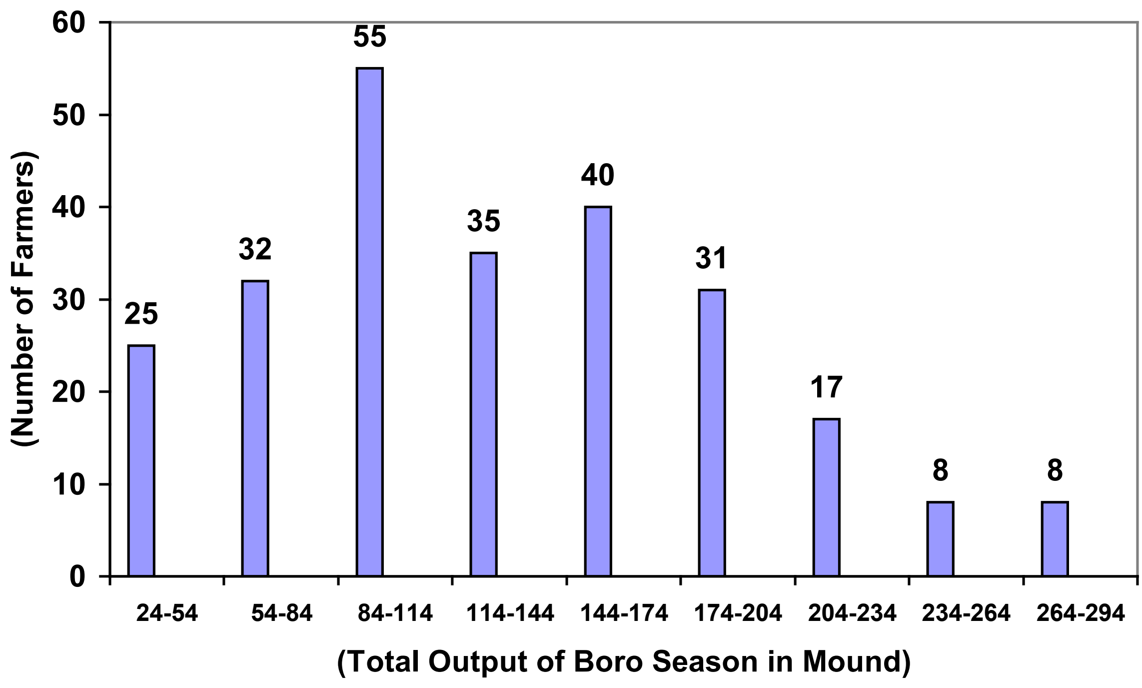
The survey result shows that only 39.04 per cent farmers' total output of boro season is less than 141 mounds. About 44.62 per cent farmers' total output of boro season are ranges from 141-290 mounds but less than 291 mounds. About 13.15 per cent farmers total boro rice output is between 291-440 mounds, and only 3.19 per cent farmers' total boro rice output is more than 440 mounds during survey period in June-August 2010. This result exhibited in Table 4.14 and Figure 4.13.

Table 4.14: Total Output of Boro Season of the Farmers

Total output (In mound)	No. of farmers	Percentage of farmers	Total output (In mound)	No. of farmers	Percentage of farmers
24-54	25	9.96	174-204	31	12.35
54-84	32	12.75	204-234	17	6.77
84-114	55	21.91	234-264	8	3.19
114-144	35	13.94	264-294	8	3.19
144-174	40	15.94	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.13: Total Output of Boro Season of the Farmers



4.3.14. Average Revenue in Aman season (S_1) of the Farmers

Revenue means quantity of output multiplied by price per mound, that is, R = (Q × P). In both aman and boro seasons rice production have been affected due to various reasons, which are stated before. Therefore, revenue of both aman and boro seasons during survey period 2009-10 are not satisfactory.

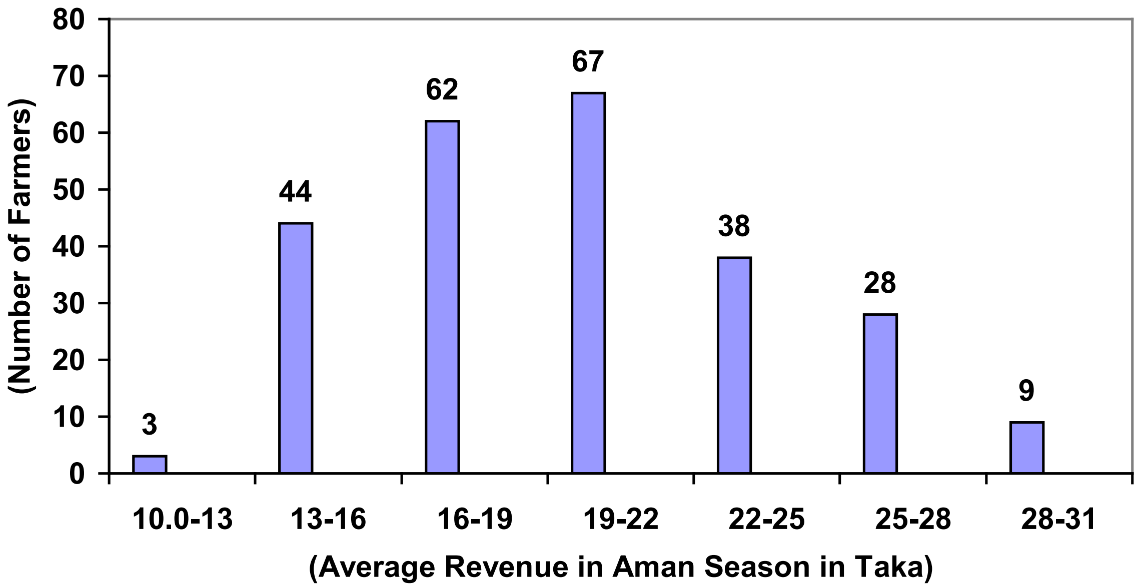
The survey result shows that 18.72 per cent farmers' average revenue in aman season (S_1) is less than 17 thousand taka. About 51.39 per cent rice producers' average revenue exists in ranges of 17-22 thousand taka and 26.29 per cent farmers' average revenue in aman season (S_1) lies between 23-28 thousand taka. Only 3.58 per cent farmers' average revenue in aman season (S_1) is more than 28 thousand taka. These results are depicted in Table 4.15 and Figure 4.14.

Table 4.15: Average Revenue in Aman Season (S_1) of the Farmers

Per acre revenue (Thousand Tk)	No. of farmers	Percentage of farmers	Per acre revenue (Thousand Tk)	No. of farmers	Percentage of farmers
10-13	3	1.20	22-25	38	15.14
13-16	44	17.53	25-28	28	11.16
16-19	62	24.70	28-31	9	3.59
19-22	67	26.69	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.14: Average Revenue in Aman Season (S_1) of the Farmers



4.3.15. Average Revenue in Boro Season (S_2) of the Farmers

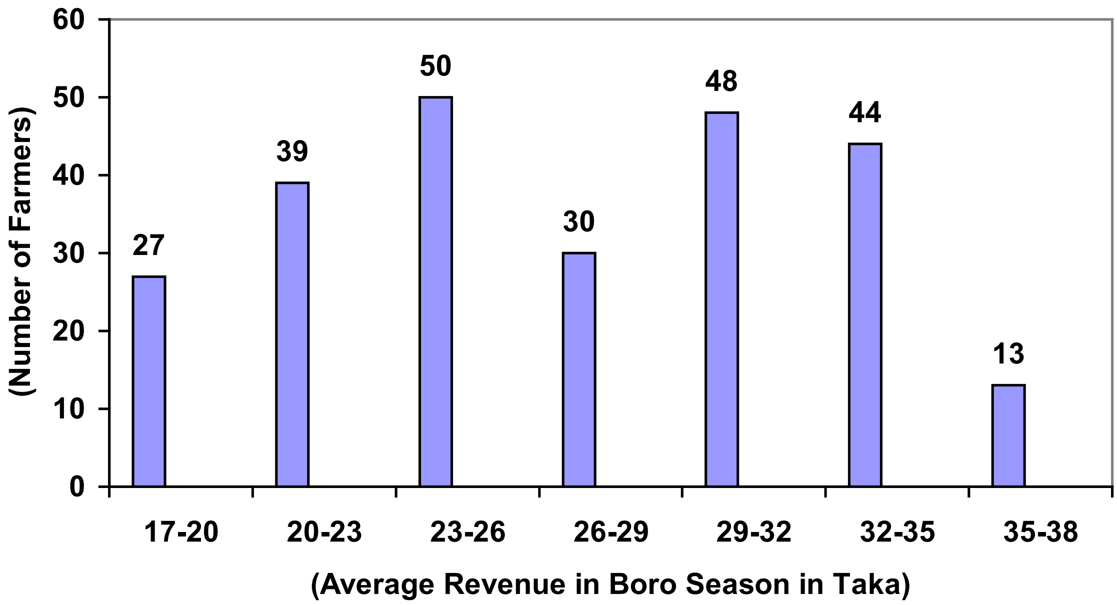
Average output in boro season (S_2) during 2010 has been affected due to shortage of irrigation and almost every farmer has lost their initial seed ground for bad weather. Therefore, average output in boro season (S_2) and revenue during survey period is not satisfactory. Our survey result shows that 26.30 per cent farmers' average revenue in boro season (S_2) is less than 24 thousand taka. About 32.27 per cent farmers' average revenue is more than 24 thousand taka but less than 30 thousand taka and 36.25 per cent farmers' revenue ranges 30-35 thousand taka. Only 5.18 per cent farmers' average revenue in boro season (S_2) is more than 35 thousand taka. These results have shown in Table 4.16 and Figure 4.15.

Table 4.16: Average Revenue in Boro Season (S_2) of the Farmers

Per acre revenue (Thousand Tk)	No. of farmers	Percentage of farmers	Per acre revenue (Thousand Tk)	No. of farmers	Percentage of farmers
17-20	27	10.76	29-32	47	18.72
20-23	39	15.54	32-35	44	17.53
23-26	51	20.32	35-38	13	5.18
26-29	30	11.95	Total	251	100.00

Source: Field survey data, (2010)

Figure 4.15: Average Revenue in Boro Season (S_2) of the Farmers



4.3.16. Average Total Revenue of both Aman and Boro Seasons (S_1+S_2) Together

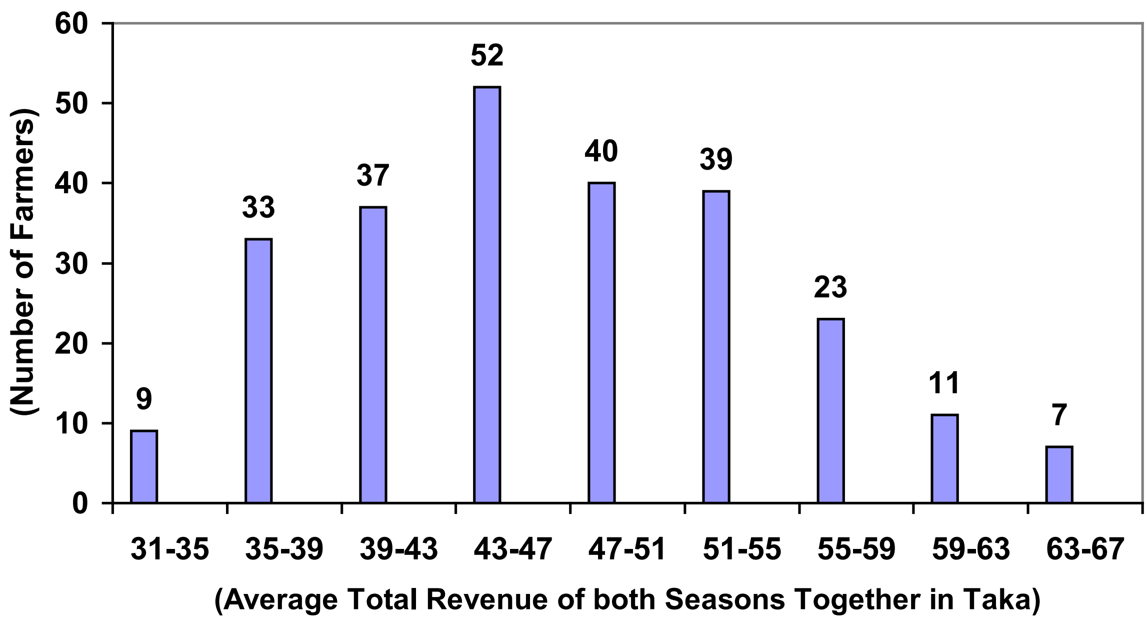
The survey result indicates that 16.73 per cent farmers' average total revenue of both aman and boro seasons (S_1+S_2) together are less than 40 thousand taka and 35.46 per cent farmers' average total average revenue of both seasons are accounted to 39-47 thousand taka. But 31.47 per cent farmers' average total revenue of both seasons (S_1+S_2) together are more than 47 thousand taka and less than 56 thousand taka. Only 16.33 per cent farmers' average total revenue of both seasons' are more than 55 thousand taka during the survey period 2009-10. This result is depicted the following Table 4.17 and Figure 4.16.

Table 4.17: Average Total Revenue of both Aman and Boro Seasons Together

Average revenue (Thousand Tk)	No. of farmers	Percentage of farmers	Average revenue (Thousand Tk)	No. of farmers	Percentage of farmers
31-35	9	3.58	51-55	39	15.54
35-39	33	13.14	55-59	23	9.16
39-43	37	14.74	59-63	11	4.38
43-47	52	20.74	63-67	7	2.78
47-51	40	15.94	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.16: Average Total Revenue of both Aman and Boro Seasons Together



4.3.17. Total Revenue of Aman Season of the Farmers

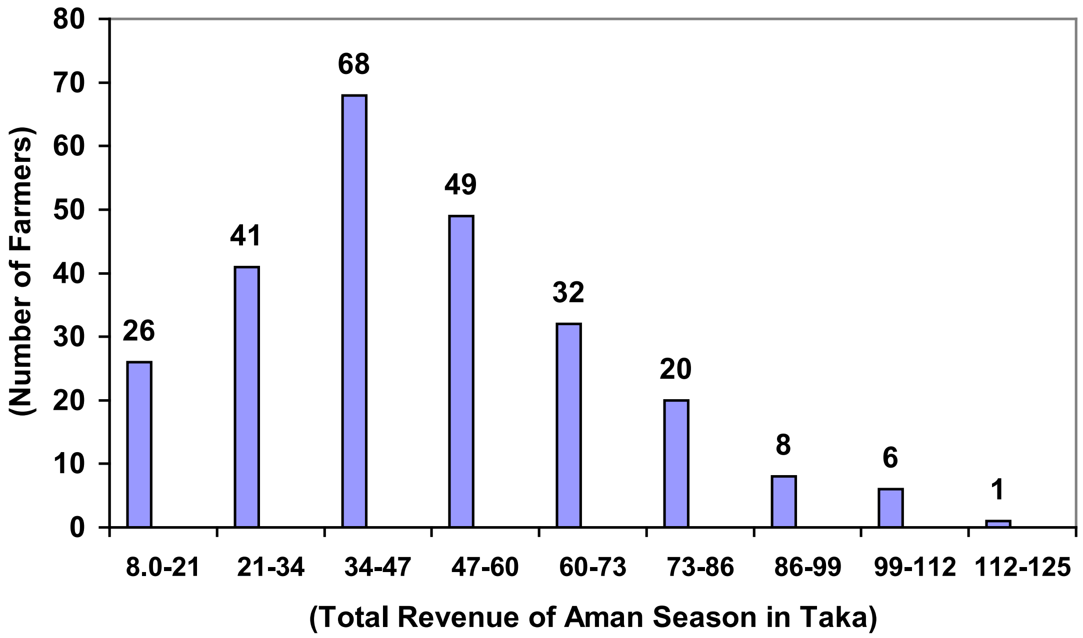
The survey results exhibite that 26.69 per cent farmers' total revenue of aman season is less than 35 thousand taka and 46.61 per cent farmers' total revenue is accounted to 34-60 thousand taka. But 20.72 per cent farmers' total revenue is more than 60 thousand taka and less than 87 thousand taka. Only 5.98 per cent rice producers total revenue of aman season during the survey period 2010 is more than 85 thousand taka. This result is indicated the following Table 4.18 and Figure 4.17.

Table 4.18: Total Revenue of Aman Season of the Farmers

Total revenue (Thousand Tk)	No. of farmers	Percentage of farmers	Total revenue (Thousand Tk)	No. of farmers	Percentage of farmers
8-21	26	10.36	73-86	20	7.97
21-34	41	16.33	86-99	8	3.19
34-47	68	27.09	99-112	6	2.39
47-60	49	19.52	112-125	1	0.40
60-73	32	12.75	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.17: Total Revenue of Aman Season of the Farmers



4.3.18. Total Revenue of Boro Season of the Farmers

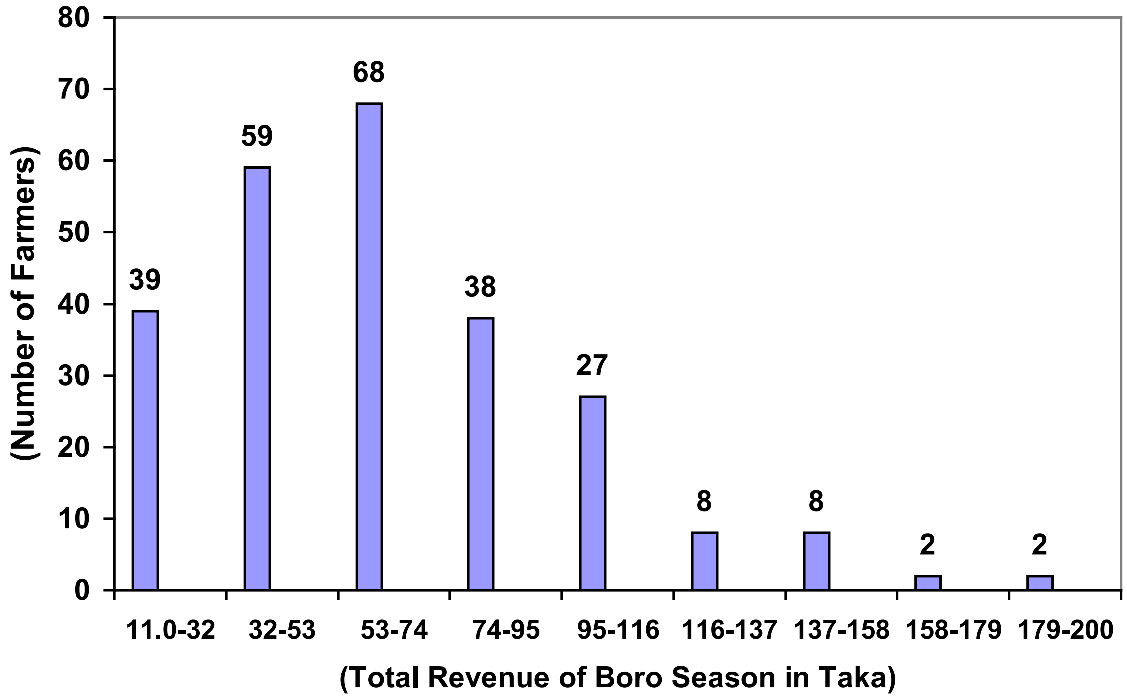
The survey result indicates that 39.04 per cent farmers' total revenue of boro season is less than 54 thousand taka and 42.23 per cent farmers' total revenue is accounted to 53-95 thousand taka. But 13.94 per cent farmers' total revenue is more than 95 thousand taka and less than 138 thousand taka. Only 4.79 per cent farmer's total revenue is more than 137 thousand taka during the survey period. This result is depicted in following Table 4.19 and Figure 4.18.

Table 4.19: Total Revenue of Boro Season of the Farmers

Total revenue (Thousand Tk)	No. of farmers	Percentage of farmers	Total revenue (Thousand Tk)	No. of farmers	Percentage of farmers
11-32	39	15.54	116-137	8	3.19
32-53	59	23.50	137-158	8	3.19
53-74	68	27.09	158-179	2	0.80
74-95	38	15.14	179-200	2	0.80
95-116	27	10.75	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.18: Total Revenue of Boro Season of the Farmers



4.3.19. Average Profit of Aman and Boro Seasons of the Farmers

The main objective of this section is to show the profitability ranges of rice producers. Profit depends on total output, total cost and price of the related product. As we have seen earlier that, in both aman and boro seasons output during survey period in 2009-10 are not satisfactory in our study area. Cost of production is comparatively high.

4.3.20. Average Profit in Aman season (S_1) of the Farmers

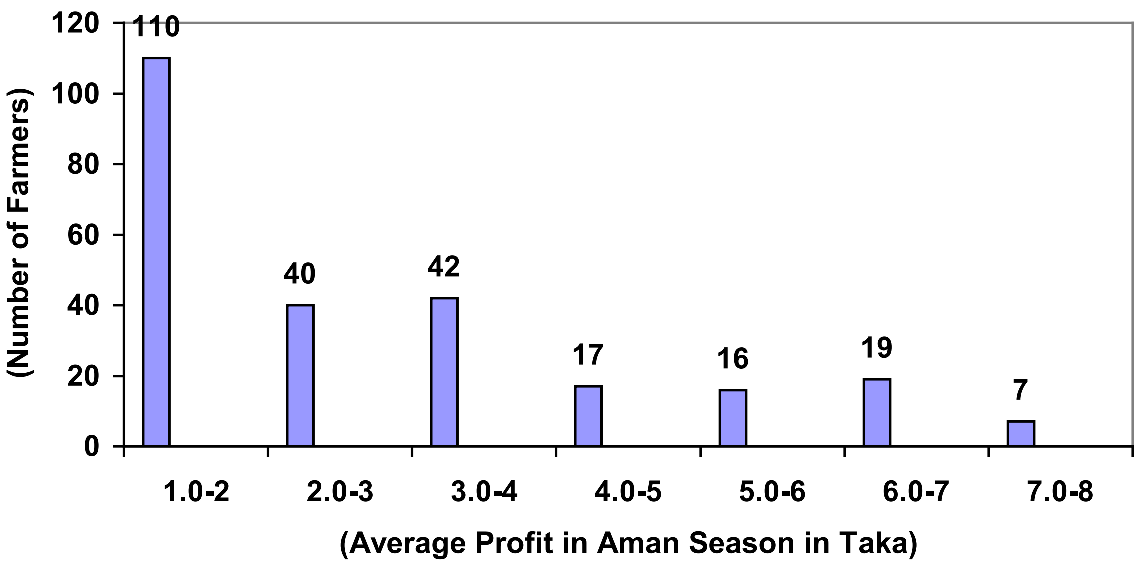
Survey result shows that 43.82 per cent farmers' average profit in aman season (S_1) is less than 3 thousand taka. Another 32.67 per cent farmers' average profit in aman season is between 2-3 thousand taka. About 13.15 per cent farmers' average profit is more than 3 thousand taka but less than 7 thousand taka during aman season (S_1). Only 10.36 per cent farmers' average profit in aman season (S_1) is more than 6 thousand taka. We have shown this result in Table 4.20 and Figure 4.19.

Table 4.20: Average Profit in Aman Season (S_1) of the Farmers

Per acre profit (Thousand Tk)	No. of farmers	Percentage of farmers	Per acre profit (Thousand Tk)	No. of farmers	Percentage of farmers
1-2	110	43.82	5-6	16	6.37
2-3	40	15.94	6-7	19	7.57
3-4	42	16.74	7-8	7	2.79
4-5	17	6.77	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.19: Average Profit in Aman Season (S_1) of the Farmers



4.3.21. Average Profit in Boro Season (S_2) of the Farmers

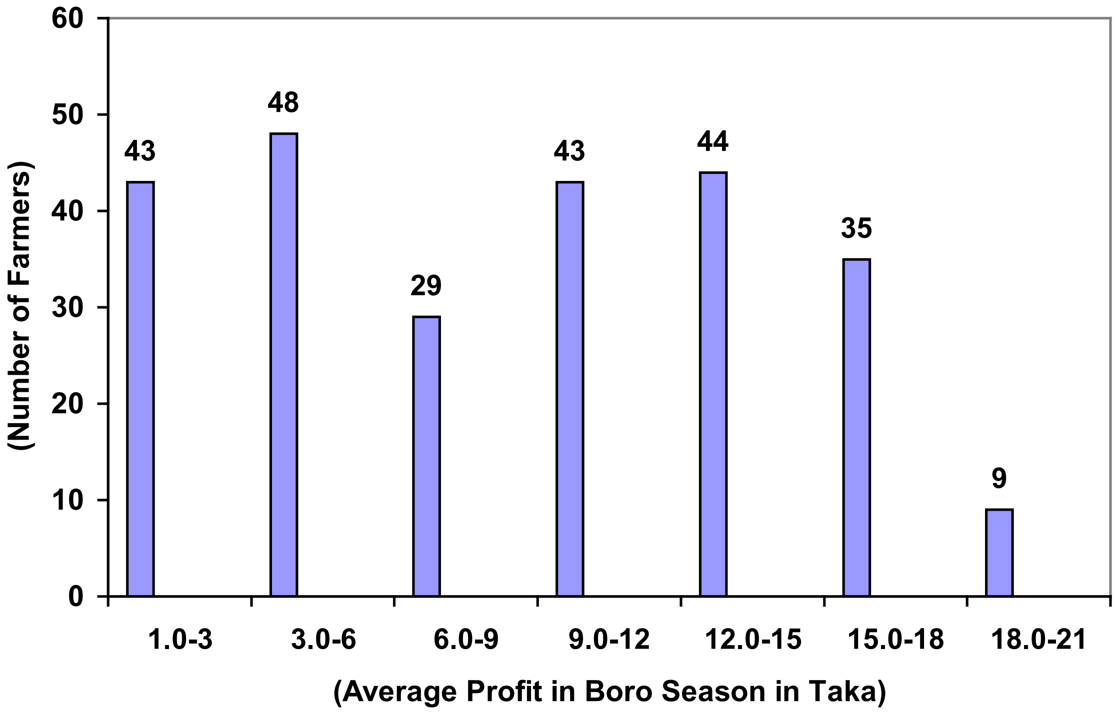
Survey result shows that 17.13 per cent farmers' average profit in boro season (S_2) is less than 4 thousand taka. Another 30.68 per cent farmers' average profit is between 3-9 thousand taka. About 34.66 per cent farmers' average profit in boro season (S_2) ranges 9-15 thousand taka. Only 17.53 per cent farmers' average profit is more than 15 thousand taka during in boro season (S_2). We have shown these results are in Table 4.21 and Figure 4.20.

Table 4.21: Average Profit in Boro Season (S_2) of the Farmers

Per acre profit (Thousand Tk)	No. of farmers	Percentage of farmers	Per acre profit (In Taka)	No. of farmers	Percentage of farmers
1-3	43	17.13	12-15	44	17.53
3-6	48	19.12	15-18	35	13.94
6-9	29	11.55	18-21	9	3.59
9-12	43	17.14	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.20: Average Profit in Boro Season (S_2) of the Farmers



4.3.22. Average Total Profit of both Aman and Boro Seasons (S_1+S_2) Together

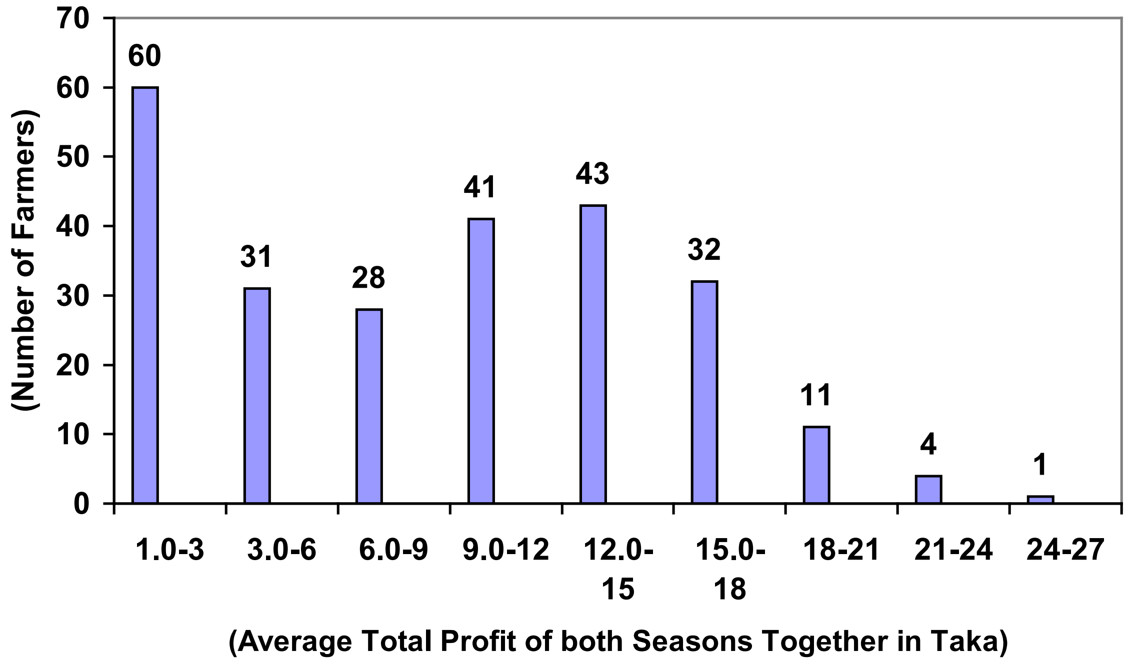
Survey result shows that 36.25 per cent farmers' make a profit less than 7 thousand taka on average total both aman and boro seasons (S_1+S_2) together. Another 27.49 per cent farmers' make a profit is more than 6 thousand taka but less than 13 thousand taka. About 29.88 per cent farmers' average total profit of both aman and boro seasons (S_1+S_2) together is between 12-18 thousand taka. Only 6.37 per cent farmers could be able to make average total profit of both aman and boro seasons (S_1+S_2) is more than 18 thousand taka during survey period in 2009-10. We have shown these results are in Table 4.22 and Figure 4.21.

Table 4.22: Average Total Profit of both Aman and Boro Seasons Together

Average profit (Thousand Taka)	No. of farmers	Percentage of farmers	Average profit (In Taka)	No. of farmers	Percentage of farmers
1-3	60	23.91	15-18	32	12.75
3-6	31	12.35	18-21	11	4.38
6-9	28	11.15	21-24	4	1.59
9-12	41	16.34	24-27	1	0.40
12-15	43	17.13	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.21: Average Total Profit of both Aman and Boro Seasons Together



4.3.23. Total Profit of Aman Season of the Farmers

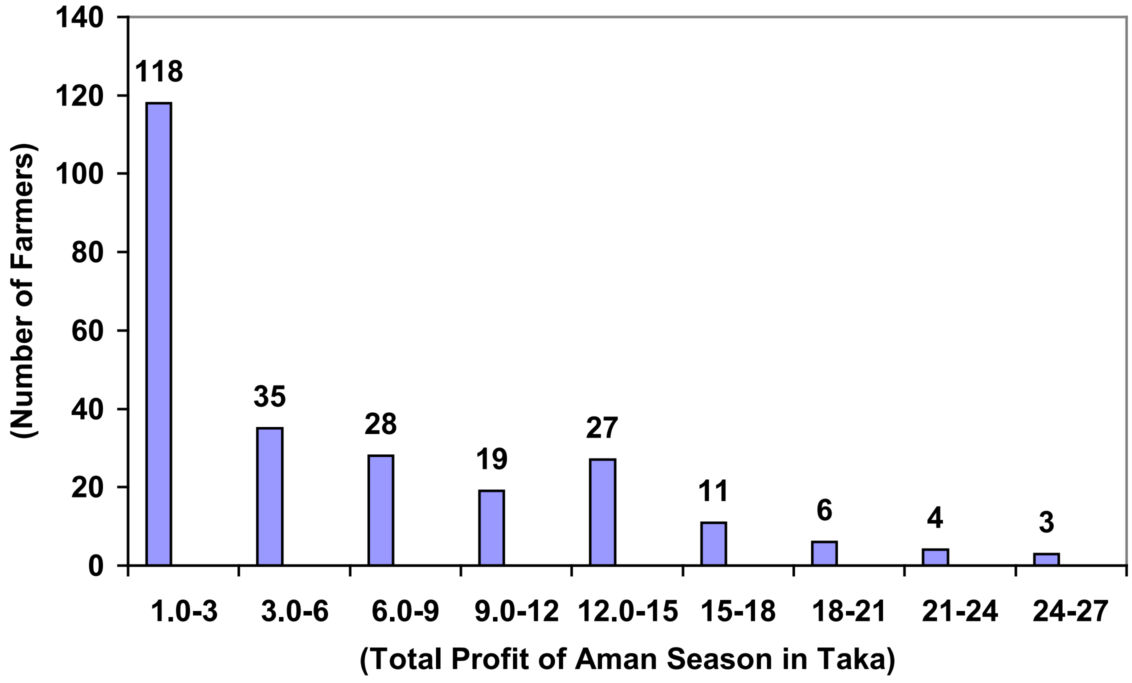
Survey result shows that 60.95 per cent farmers' total profit of aman season is less than 7 thousand taka. Another 18.73 per cent farmers' make a profit is more than 6 thousand taka but less than 13 thousand taka. About 15.14 per cent farmers' total profit of aman season is between 12-18 thousand taka. Only 5.18 per cent farmers' could be able to make total profit of aman season is more than 18 thousand taka during survey period in 2009-10. We have shown these results are in Table 4.23 and Figure 4.22.

Table 4.23: Total Profit of Aman Season of the Farmers

Total profit (Thousand Tk)	No. of farmers	Percentage of farmers	Total profit (In Taka)	No. of farmers	Percentage of farmers
1-3	118	47.01	15-18	11	4.38
3-6	35	13.94	18-21	6	2.39
6-9	28	11.16	21-24	4	1.59
9-12	19	7.57	24-27	3	1.20
12-15	27	10.76	Total	251	100.00

Source: Field survey data, (2009-2010).

Figure 4.22: Total Profit of Aman Season of the Farmers



4.3.24. Total Profit of Boro Season of the Farmers

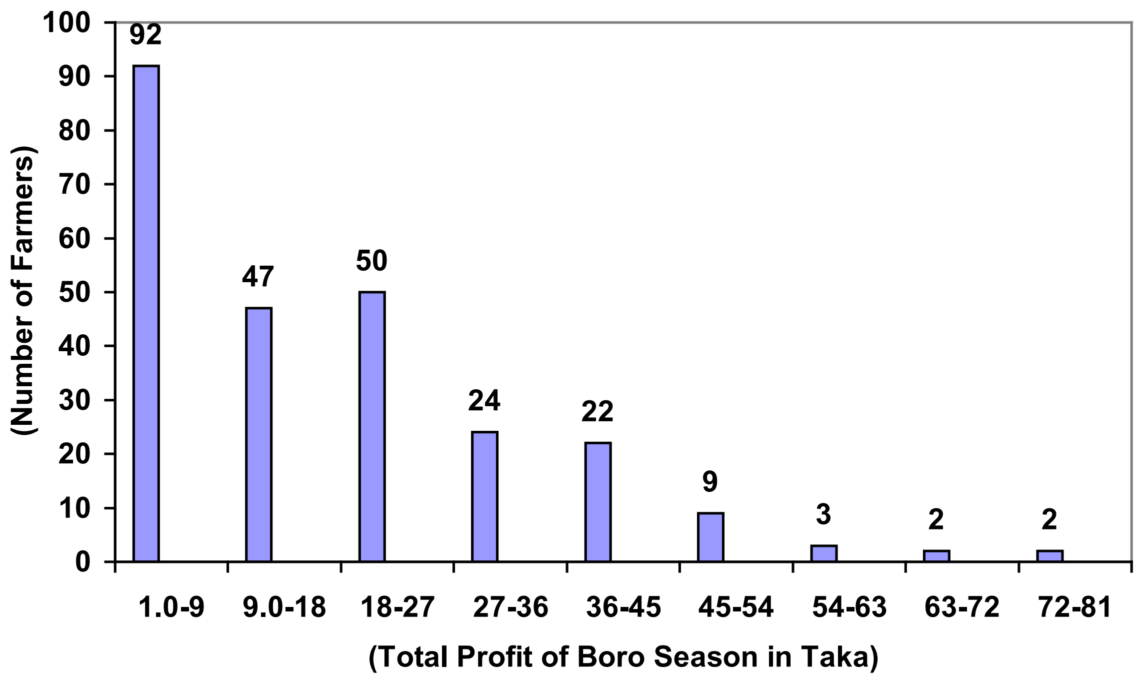
Survey result exhibits that 55.38 per cent farmers' total profit of boro season is less than 19 thousand taka. Another 41.43 per cent farmers' make total profit of boro season is more than 18 thousand taka but less than 37 thousand taka. About 12.35 per cent farmers' total profit of boro season is between 36-54 thousand taka. Only 2.79 per cent farmers could be able to make total profit of boro season is more than 54 thousand taka during survey period in 2010. We have shown these results in Table 4.24 and Figure 4.23.

Table 4.24: Total Profit of Boro Season of the Farmers

Total profit (Thousand Taka)	No. of farmers	Percentage of farmers	Total profit (In Taka)	No. of farmers	Percentage of farmers
1-9	92	36.65	45-54	9	3.58
9-18	47	18.73	54-63	3	1.19
18-27	50	19.93	63-72	2	0.80
27-36	24	9.56	72-81	2	0.80
36-45	22	8.76	Total	251	100.00

Source: Field survey data, (2010).

Figure 4.23: Total Profit of Boro Season the Farmers



4.4. Summary and Conclusions

In this chapter, we have shown survey methods of collecting data and survey results. Job of selecting samples is carefully done. In this study, purposive and stratified random sampling techniques are chosen.

A sample of 251 rice farmers from ten villages of three upazilas from three different districts in Northern Bangladesh is drawn using stratified sampling technique after selecting the upazila applying purposive sampling methods. We have mainly collected data on farmers' ownership of total cultivable land, total aman and total boro cultivated land, data on farm output and output prices, input and input prices socioeconomic characteristics and other information. Participatory Rural Appraisal technique compliments the survey by helping to identify factors associated with inefficiency. We have used seven structural or ordinary variables such as, land, labour, plough, seed, irrigation, fertilizer and pesticides. Inefficiency variables with some socio-economic characteristics and infrastructural variables are given special attention. There are three dummy variables used in analyze, viz, credit facilities, extension services and land degradation dummy. We have also collected personal information which may affect the performance of rice farmers like age, year of schooling, experience and other rice related information. Average total variable costs of production, revenue and profit of aman and boro seasons are different from farmers to farmers.

During collection of data, the researcher faces some difficulties like, most of the rice farmers depend upon their memory recall system for answering the questions asked by the researcher, different measuring units in different region of the survey area. Despite all these difficulties, we become able to tackle the situation successfully and collect required data and information. The comprehensive field work survey is held in the period of December-February for aman season (S_1) 2009-10 and June-August for boro season (S_2) 2010.

Chapter 5

Theoretical Issues: Production Function and Efficiency

5.1. Introduction

In this chapter we shall conduct an analysis about production function and some related issues of efficiency of rice farms in Northern Bangladesh. We discuss clear and concrete concepts about production function and efficiency. Neo-classical production function is the main basis of estimating efficiency of a production unit and the idea starts with Farrell (1957). To measure productive efficiency Farrell conducted an empirical study on U.S. agriculture and disclosed fundamental concept of technical efficiency wherein he argued that failure to produce the maximum output from a given input mix at minimum cost results in inefficiency. A farm is technically inefficient, if and only if, it is not possible to produce more of any output without producing less of some other output (Koopman,1951). The cause of inefficiency may arise from the constraints of access to technology, lack of knowledge, minimum access to extension services, an inaccurate scale of production and sub-optimal allocation of resources. Technical efficiency means the ability of a farm to produce maximum output from a given set of inputs using existing technology. Some important issues of production function and its essential properties in conjunction with related concepts are described in this chapter.

The outline of this Chapter is as follows: Section 5.2 discusses production function; Section 5.3 describes estimation of production function; Section 5.4 gives some important concepts related to production function; Section 5.5 describes cost minimizing input combination; Section 5.6 discusses efficiency concepts and Section 5.7 gives summary and conclusions.

5.2. Production Function

A production function shows the maximum output that can be produced from any given combination of inputs. This means that a production function is defined in terms of the maximum output that can be produced from a specified set of inputs, given the existing technology available to the farms (Battese, 1998).

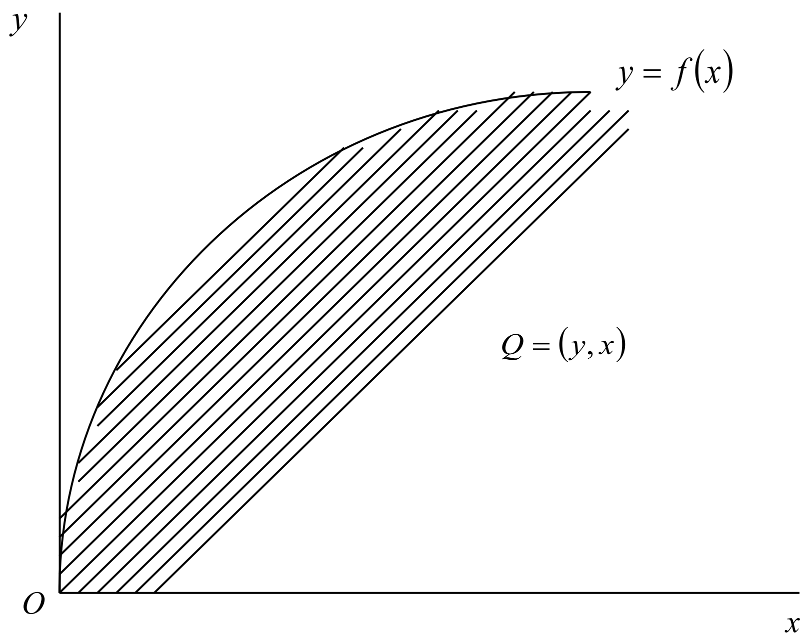
In microeconomic theory, the production function explains the technical or physical relationship between outputs and inputs. Specifically it shows the maximum output obtainable from a given set of inputs. Inputs are rates of resource use and output is the rate of production over a specific time period. Let $(x_1, x_2, ..., x_q)$ denote the inputs used in the production function for producing output y_i; the production function can be represented by a mathematical function as:

$$y_i = f(x_1, x_2, ..., x_q) \tag{5.1}$$

This formulation excludes the possibility of technical inefficiency because output is a maximum for any level of inputs.

The production function given in (5.1) shows the borderline of the production set. As shown in Figure 5.1, a two dimensional input output production technology is described for the sake of simplicity. One input x is used to produce a single output y. The production set Q, denotes the technically feasible production set (y, x), that is, $Q = (y, x)$. The shaded region in Figure 5.1 shows the production set.

Figure 5.1: The Production Function



The production combinations which maximize y for a given x or minimize x for given y are technically efficient combinations constitute the borderline to the production set $Q=(y,x)$. Therefore, the production function $y=f(x)$ is the set of technically efficient combinations, and all technically inefficient combinations belong to the interior portion of the production set.

5.3. Estimation of Production Function

Production function can be estimated from sample data. This data may be of cross-sectional type, which involves observation on a number of farms in a particular time period say one year. Or the data may be of time-series type which involves aggregate farm-level data observed over a number of time period. Or the data may be of panel type which involves observation on a number of farms in a number of time period.

To estimate a production function, information on output and input quantities is essential. Production function can be estimated either by using econometric methods which is often referred to as parametric function or this can be estimated using mathematical programming method, which is suggested by Farrel (1957). According to mathematical programming method, the production function can be estimated from sample data using a nonparametric piece-wise-linear technology often called as non-parametric function. This research involves application of both parametric and nonparametric approaches to analyze rice farms efficiency performance in Northern Bangladesh using the same set of data.

5.4. Some Important Concepts Related to Production Function

Production function recognizes some fundamental characteristics, such as marginal productivity of the factor of production, output elasticities, the marginal rate of technical substitution, the elasticity of substitution and return to scale. These are described below.

Marginal product: The marginal product of a factor of is defined as the change in output for an infinitesimal change of this factor, holding all other factors constant. Mathematically, the marginal productivity of each input is obtained by the partial derivative of the production function with respect to this input. Consider the production function in (5.1), the marginal productivity of x_i is:

$$f_i = \frac{\partial f}{\partial x_i} \qquad (i = 1,2,3,...,q)$$

The prime focus of the production theory centers around the range of output over which the marginal productivity is positive and diminishing, that is:

$$f_i > 0 \text{ and } f_{ii} = \frac{\partial^2 f}{\partial x_i^2} < 0 \qquad (5.2)$$

Where f_{ii} denotes the second order derivative.

In economics, elasticity is the ratio of proportional change in one variable with respect to proportional change in another variable. Elasticity is a negative number but shown as a positive value.

Elasticity: Output elasticity measures the percentage change in output resulting from a percentage change in an input, holding all other inputs remaining constant. Considering the production function in (5.1), this is defined as:

$$E_i = \frac{\partial f_i}{\partial x_i} \times \frac{x_i}{y_i}$$

This is a unit free measure of marginal productivity (Chambers, 1988, p.18).. Important features of output elasticity can be attributed as follows:

When $E_i = 1,$ it indicates that proportional increase in input i results in the same proportional increase in output;

When $E_i > 1,$ a proportional increase in output is larger than the proportional increase in input i;

When, $E_i < 1,$ the proportional increase in output is less than the proportional increase in the input i; and

if $E_i = 0$, then it expresses perfect inelastic output, and when $E_i = \infty$, then the output elasticity shows perfectly elastic situation.

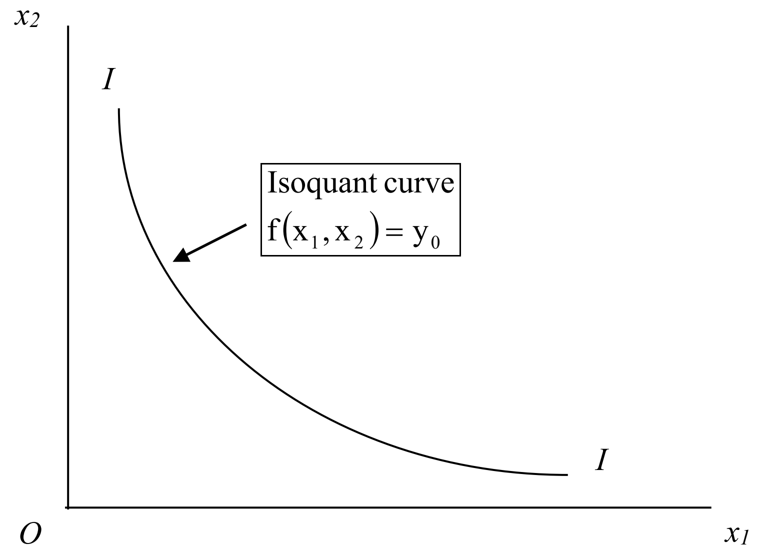
Isoquant: An isoquant or production indifference curve is defined as the locus of all the technical efficient combinations of inputs which produce the equal amount of output. Any point on the isoquant curve is technically efficient. This displays the rate at which inputs are substituted in production keeping output constant. For simplicity, consider the two variable production function. Let the production function be:

$$y = f(x_1, x_2) \quad (5.3)$$

The equation of an isoquant can be obtained by the production function (5.3) when output is held constant at say y_0:

$$y_0 = f(x_1, x_2) \quad (5.4)$$

Figure 5.2: Isoquant Curve



This represents the isoquant, which displays all combinations of inputs that can be used to produce output y_0. This can be explained by the curve *II* in Figure 5.2. To get the slope of the isoquant at any point, it is requires to differentiate equation (5.4) with respect to an input say, x_i. Accordingly, it can be written as:

$$f_i + f_2 = \frac{\partial x_2}{\partial x_1} = 0 \quad \text{or} \quad \frac{\partial x_1}{\partial x_2} = \frac{f_1}{f_2}$$

Marginal Rate of Technical Substitution (MRTS): The negative sign of the slope of an isoquant is the Marginal Rata of Technical Substitution (MRTS), which measures the rate at which inputs can be substituted, holding output constant. The marginal rate of technical substitution (MRTS) or the Technical Rate of Substitution (TRS) is the amount by which the quantity of one input can be reduced $(-\partial x_2)$ when one extra unit of another input is used (∂x_1), so that output remains constant $(y = y_0)$

$$MRTS(x_1, x_2) = \frac{dx_1}{dx_2} = -\frac{f_1}{f_2} = -\frac{MP_1}{MP_2}$$

Where MP_1 and MP_2 are the marginal products of input x_1 and input x_2 respectively.

Along an isoquant, the MRTS shows the rate at which one input (e.g. capital or labour) may be substituted for another, while maintaining the same level of output. The MRTS can also be seen as the slope of an isoquant at a point. Since the isoquant is generally downward sloping and marginal products are generally positive, the MRTS is negative. The MRTS is not independent of units of measurement.

Elasticity of Substitution: The elasticity of factor substitution is a better measure of factor substitution since it does not depend on the units of measurement. It can be defined as the proportional rate of change in the input ratio divided by the proportional rate of change in MRTS.

$$\sigma = \frac{d(f_1 / f_2)/(f_1 / f_2)}{d(MRTS)/(MRTS)}$$

The larger the value of σ exhibits greater the degree of substitutability between the two factors of production. It is commonly expected that variable elasticity of substitution exists in the production function. However, constant elasticity of substitution may exist in some production functions. For example, Cobb-Douglas production function has been characterized by an unitary elasticity of substitution and this substitution does not depend upon the assumption of $\alpha + \beta = 1$. The elasticity of substitution of the production function $Q = AL^{\alpha} K^{\beta}$ is unitary even if $\alpha + \beta \neq 1$.

Returns to Scale: Returns to scale refers to a technical property of production function that examines change in output resulting from a proportional changes in all inputs. If output increases by the same proportional change as the inputs change then there exists a constant return to scale (CRTS). If output increases by less than that proportional change, there is decreasing returns to scale (DRS). If output increases by more than that proportion, there are increasing returns to scale (IRS). It can be shown mathematically as:

$$\varepsilon = \sum_{i=1}^{q} \frac{\partial y}{\partial x_i} \times \frac{x_i}{y} \tag{5.5}$$

Important three characterizations of returns to scale are as follows:

When $\varepsilon = 1,$ then the production function shows constant returns to scale (CRS).

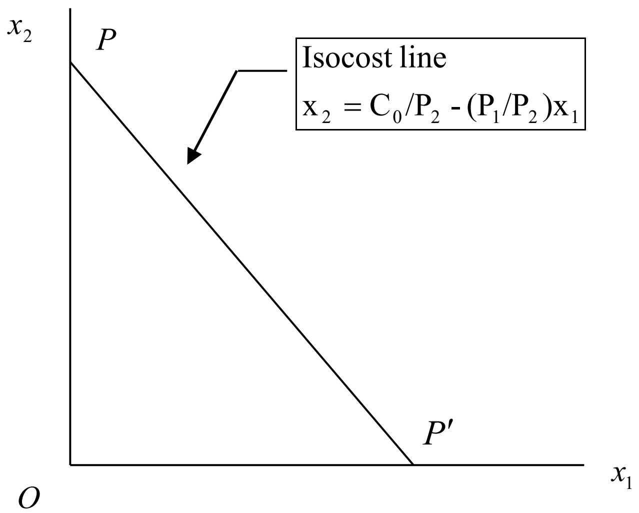
When $\varepsilon < 1,$ then the production function displays decreasing returns to scale (DRS).

When $\varepsilon > 1,$ then the production function exhibits increasing returns to scale (IRS).

Isocost line shows all the combinations of inputs that have the same total cost. The line shows the rate at which inputs are exchanged in the market. The isocost line is shown in Figure 5.3. It is the focus of all combination of inputs that can be bought with a given cost expenditure say C_0. The equation of the isocost line can be written as:

$$C_0 = p_1x_1 + p_2x_2 \tag{5.6}$$

Figure 5.3: Isocost Line



Where p_1 and p_2 are the prices of input x_1 and x_2. This can be explained by the curve PP' in Figure 5.3. The slope of isocost line can be obtained by differentiating equation (5.6):

$$\frac{dx_2}{dx_1} = -\frac{p_1}{p_2}$$

This is the negative ratio of the input prices. It tells us how many units of x_2 have to be given up to purchase one more units of x_1.

5.5. Cost Minimizing Input Combination

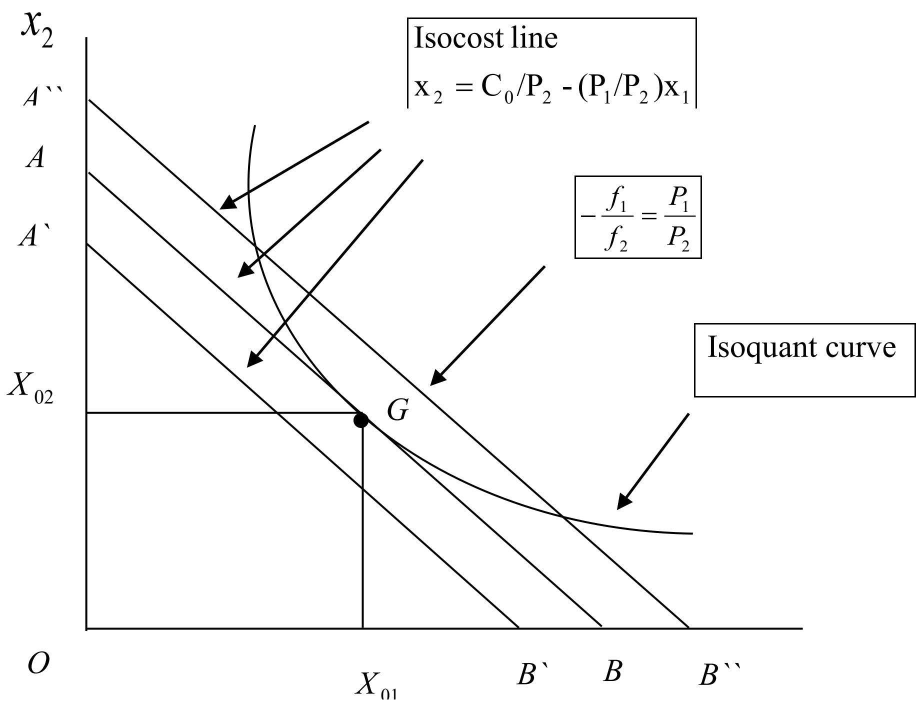
The choice of the least cost input mix is described under graphical presentation and mathematical presentation.

5.5.1. Graphical Presentation

The cost-minimization problem of a farm is to choose an input bundle feasible x_1 and x_2 for a specific output y_0 that costs as little as possible. In terms of the Figure 5.4, a cost-minimizing input bundle is a point on the isoquant that lies on the lowest possible isocost line. Putting differently, a cost-minimizing input bundle must require the tangency of the given isoquant with the lowest possible isocost line. This is shown in Figure 5.4.

The farm minimizes its costs by using input combination (x_{01}, x_{02}) determined by the tangency point of the given isoquant y_0 with the isocost line AB. The isocost line touches the isoquant curve at point G and hence the cost minimizing input mix is obtained at this point. The second order condition for cost minimizing is fulfilled as well at this point as the isoquant curve is convex to the origin.

Figure 5.4: Isoquant, Isocost line and Cost-Minimization



5.5.2. Mathematical Presentation

The conditions for the least-cost combination of inputs can be derived by formulating a minimization problem. This can be done by minimizing the cost in (5.6) subject to the output constraint in (5.4) Hence the Lagrangian function is:

$$Z = p_1x_1 + p_2x_2 + \lambda[y_0 - f(x_1, x_2)]$$

Where λ is the Lagrangian multiplier. The input points are required to satisfy the following simultaneous first-order condition for a minimum cost:

$$p_1 - \lambda f_1 = 0 \qquad (5.7)$$

$$p_2 - \lambda f_2 = 0 \qquad (5.8)$$

$$y_0 - f(x_1, x_2) \qquad (5.9)$$

Equations (5.7) and (5.8) provide conditions which ensure the least-cost combination:

$$\frac{p_1}{f_1} = \frac{p_2}{f_2} = \lambda$$

That is, the input prices to marginal productivity ratio must be the same for each input. This can be written as:

$$\frac{p_1}{p_2} = \frac{f_1}{f_2} \tag{5.10}$$

This indicates that the cost-minimizing input combination is obtained at a point where the slopes of the isoquant curve and the isocost line are equal.

Equation (5.10) provides the first-order conditions for cost minimization. To ensure this minimum cost, the following second-order conditions must hold for the negative bordered Hessian:

$$\begin{vmatrix} 0 & f_1 & f_2 \\ f_1 & \lambda f_{11} & \lambda f_{12} \\ f_2 & \lambda f_{21} & \lambda f_{22} \end{vmatrix} = \lambda(f_{11}f_2^2 - 2f_{12}f_1f_2 + f_{22}f_1^2) < 0$$

Since the optimal value of λ is positive. Therefore, the expression shown in the bracket must be negative when the production function is strictly quasi concave.

5.6. Measures of Efficiency

5.6.1. Defining Efficiency

The term efficiency involves the success with which a firm best utilizes its available resources to produce maximum levels of potential outputs (Dine et al., 1998). Theoretical literature on productivity and efficiency began in the 1950s, with the work of Kopmans (1955), Debrew (1951) and Shapphard (1953). A farm is efficient if and only if it is not possible to increase output (decreasing inputs) without more inputs (without decreasing output) (Cooper et. al., (1995). If the producer fails to produce more potential output with minimum given inputs then inefficiency happens.

Neoclassical theory of production function gives the notion of such efficiency that can be derived from obtaining maximum possible output for a given amount of inputs. It is not sensible to identify this 'maximum' output merely by observing the actual amount of output except the observed output is assumed to be a maximum. Whereas different farms produce different output levels even if they use the same input vector (Kumbhakar, 1994)

Variations in producing output among farms can be explained through differences in efficiency. The commonly perceived efficiency refers to technical efficiency.

The production activities of a producer may create technical inefficiency. The concept of technical inefficiency is due to Farrell (1957). Technical inefficiency indicates the failure of the producer to produce the frontier level of output, given the quantities of inputs (Kumbhakar, 1994). Simply, we may denote that when a producer fails to produce maximum expected output by using given inputs, then he is technically inefficient. Technical efficiency is defined as the ratio of producer's realistic output to technically maximum possible output at the given level of resources. That is, when a producer achieves maximum output by minimum inputs then he is technically efficient.

5.6.2. Technical Efficiency

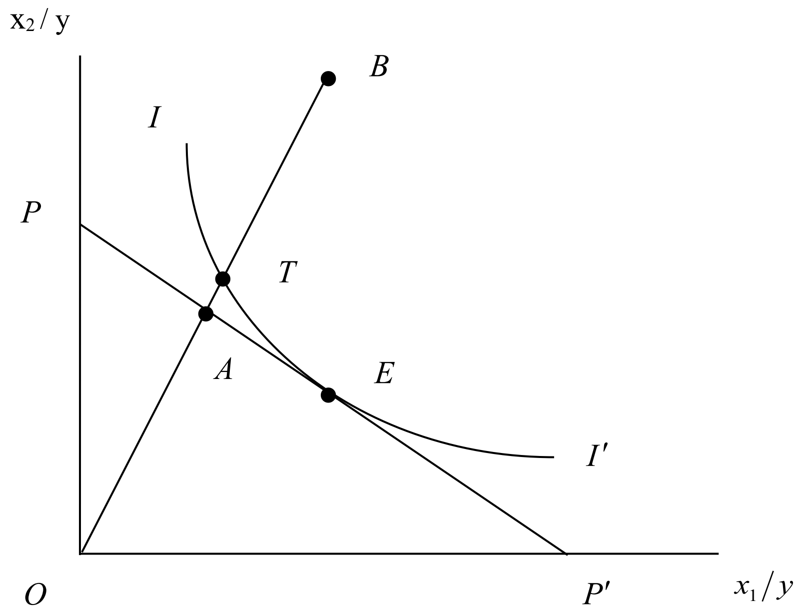
A farm is said to be technically efficient if it produces a maximum output, given the amount of input and technology. Therefore, the production frontier is associated with the maximum attainable level of output, given a level of inputs, or the minimum level of inputs required to produce a given output. Technical efficiency reveals the capability to produce maximum output with a given input mix utilizing the available technologies. In micro economic theory, technical efficiency can be defined as a situation in which it is impossible for a given farm, with given knowledge of technology, to produce a larger amount of output from a given set of inputs or it is impossible to produce a given output with less of one or more inputs without increasing the amount of other inputs. Technical efficiency is associated with the process of conversion of physical inputs such as the services of labours, modern machineries and inputs into outputs relative to "best-practice." The technical efficiency is determined by the difference between the observed ratio of combined quantities of a farm's output to input and the ratio achieved by 'best practice'. It can be expressed as the potential to increase quantities of outputs from given quantities on inputs, or the potential to reduce the quantities of inputs used in producing given quantities of outputs. In other words, given current technology, there is no wastage of inputs whatsoever in producing the given quantity of output. A farm operating at "best-practice" is said to be 100 per cent technically efficient. If operating below "best-practice" levels, then the farms technical efficiency is expressed as percentage of the "best-practice." Farmer's practices and the scale of efficiency affect technical efficiency, which is based on modern innovation of agricultural machineries but not on prices and costs. Technical efficiency of a farm depends on its level of productivity.

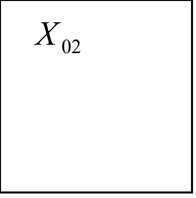
5.6.3. Graphical Representation

Farrell (1957) explained the concept of technical efficiency. This can be explained using a simple example involving a farm that uses two inputs, i.e., x_1 and x_2 to produce a single output, y under the assumptions of constant returns to scale. The constant return to scale assumption allows one to represent the technology using a unit isoquant. As Farrell originally initiated his idea under input/output space with input reduction strategy, it is termed as input-oriented measures. This case may be better illustrated by the Figure 5.5 that permits the measurement of technical efficiency.

To explain diagrammatically the concept of technical efficiency, it is required to reflect on the production activity of a farm, following to Kopp and Diewert (1982). In Figure 5.5, it is assumed that the farm uses two inputs x_1 and x_2 to produce a single output y, and that the production technology is abridged by a linearly homogeneous production function as given by Farrell. The frontier unit isoquant for this technology and an inefficient production activity are depicted by II' and B respectively. Along the ray OB with the isoquant II', represents a technically efficient input combination as it lies on the frontier isoquant.

Figure 5.5: Measures of Technical Efficiency





The technical inefficiency of the farm producing at point B is represented by the distance TB because this is the amount by which both inputs could be proportionally reduced producing the same level of output. In percentage term this is usually written as the ratio TB/OB by which use of all inputs might possibly be reduced.

The technical efficiency of the farm running at point B can be expressed as:

$$TE = \frac{OT}{OB} = 1 - \frac{TB}{OB} = 1 \text{ - Technical efficiency } (0 \leq TE \leq 1).$$

The producer operating at point T is fully technically efficient producer as it is located on the efficient and frontier isoquant and TE $= 1$.

5.7. Summary and Conclusions

This Chapter describes some important concepts of production function, which accommodate the basics to measuring efficiency. We discuss production function, marginal productivity, output elasticity, marginal rate of technical substitution and return to scale. The production function deals with the technical relationship between outputs and inputs. The marginal productivity of an input implies the change of output for an infinitesimal change in that input, keeping all other input constant. The output elasticity is a unit free measure and it explains the percentage change in output resulting from a percentage change in an input, holding all other input fixed. Marginal rate of technical substitution (MRTS) measures the rate at which inputs are substituted, assuming the output constant. The elasticity of substitution is a unit free measure, which estimates the degree of substitution between inputs. Returns to scale indicates the proportional change in output derived from proportional changes in all inputs and is given as the sum of the output elasticities. The farm attains least-cost combination of input at the point where ratio of input prices and the marginal rate of technical substitutions are equal.

We discuss the concept of efficiency. Efficiency means the success with which a production farm produces maximum output using its existing inputs given technology. This implies that a production function expresses the maximum potential output from a given input mix. But failure to achieve this maximum potential output with minimum cost causes inefficiency.

Chapter 6

Empirical Methodology of Efficiency Measurement: The Stochastic Econometric Frontier Model

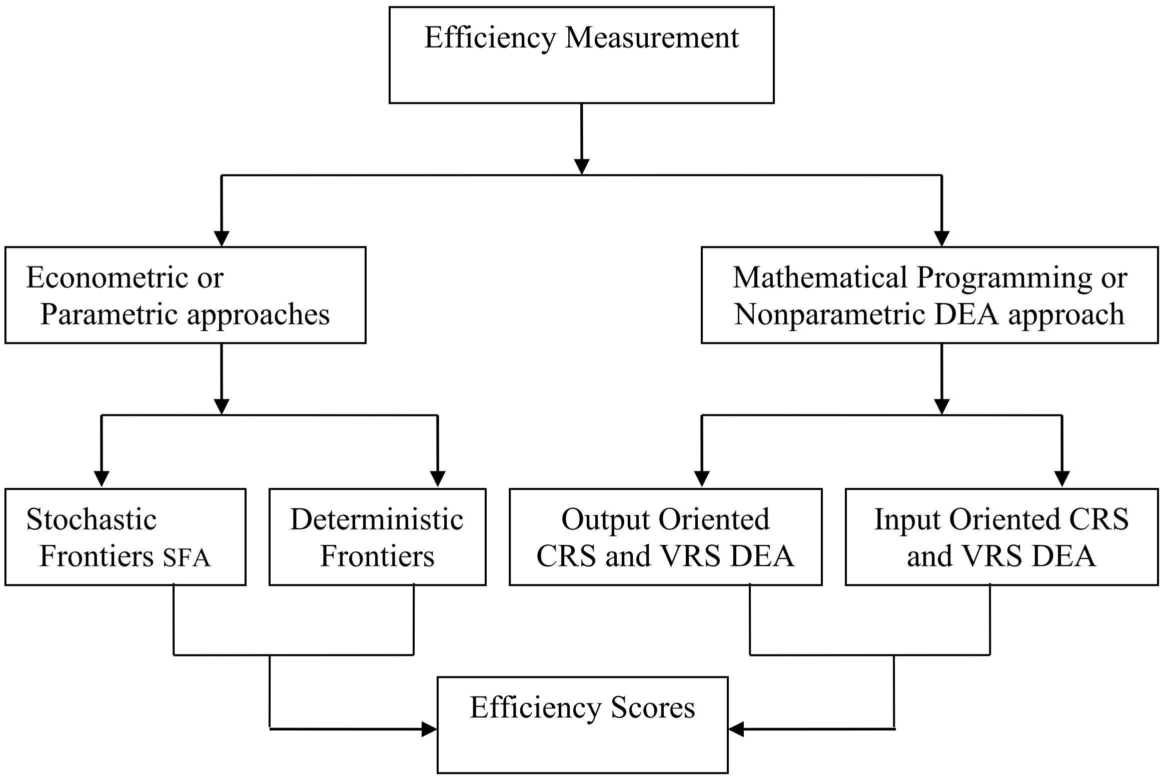
6.1. Introduction

The objective of this Chapter is to provide an introduction to empirical methodology of the Stochastic Frontier Analysis (SFA). This empirical methodology captures the efficiency scores for each individual farm. The efficiency measurement difficulties based on production frontier has led to development of several approaches to efficiency analysis.

The analytical foundation for the definition and measurement of efficiency has been laid by Farrell (1957). Detailed reviews of the concepts and models regarding evolution and development of econometric approaches towards measurement and estimation of productive efficiency are found in Christensen and Greene (1976), Førsund and Jensen (1977), Schmidt and Lovell (1979, 1980), Schmidt (1986), Bour (1990), Greene (1993, 1997), and Cornwell and Schmidt (1996). Modeling and estimation of frontier production function have been an important and potential area of econometric research. These approaches are summarized in Figure 6.1 (Sharma, 1996). Among several approaches, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are the two most popular and presently being used measures of efficiency of production units.

Figure 6.1 shows that the stochastic econometric frontier and mathematical programming frontier are the two approaches. Both the stochastic frontier and deterministic frontier are econometric methods. The principal difference between deterministic frontier and stochastic frontier model is that the deterministic frontier approach does not permit for a stochastic random error term while the later allows for the same. Therefore, deterministic frontier approach has been subject to a severe criticism on the ground that all deviations of the observed outputs from the frontier output are ascribed to inefficiency (Wadud, 2006). Accordingly, this Chapter focuses on the stochastic econometric approach to measuring efficiency.

Figure 6.1: Approaches to Efficiency Measurement



Production function models measured by ordinary least squares (OLS) assumes that farmers maximize their expected profit so that a stochastic error term, with zero mean, accounts for the difference between observed and expected output and are ascribed to factors outside the control of the cultivators (Zellner et. al., 1996). Thus all farmers are equally efficient. However it is unlikely that all cultivators are equally efficient. Productivity differs because of difference in technology, the efficiency of the production process, and the environment in which production process happens (Lovell, 1993), and managerial ability (Dawson and Lingard, 1982). A frontier production function relaxes the assumption of equal efficiency and hence the assumption of stochastic error terms with zero means.

The stochastic approach tries to distinguish the effects of stochastic noise from effects of inefficiency. The main strengths of the stochastic approach are the power to capture stochastic noise associated with deterministic frontier. Its major disadvantages are the assumptions about the parametric functional form of the stochastic frontier technology and the distributional assumption for the technical inefficiency term. Coelli (1995) presents a review of the studies and application of the stochastic frontier technology of efficiency measurement. Førsund et. al. (1980), Schmidt (1985), Bauer (1992), Brevo-Ureta and Pinheiro (1993), Fired et. al., (1993) and Green (1993) provide detailed reviews of the stochastic frontier functions and econometric estimation of frontier model.

Some empirical applications of stochastic frontier have applied a two-stage approach to investigate the sources of efficiency. The first stage estimates a stochastic frontier by maximum likelihood (ML) technique and calculates the technical efficiency for each producer under the assumption that these inefficiency effects are identically distributed. It ignores the fact that the technical inefficiency is a function of producer-specific variables. Once technical inefficiency is estimated, it is further regressed in the second stage on a set of producer-specific factors that may explain differences in technical inefficiency among producers using OLS. The OLS result in the second step contradicts the assumption of identically distributed inefficiency effects in the stochastic frontier model since the technical inefficiency the depended variable is one side (Kumbhakar et. al., 1991). Thus in the second stage, the estimated technical inefficiency effects are modeled as a function of some producer-specific characteristics that implies that inefficiency effects are, not identically distributed unless the coefficient of the producer-specific factors are simultaneously equal to zero (Coelli et. al., 1998). Heshmati and Kumbhakar (1997), Kalirajan (1981) and Pitt and Lee (1981) have applied this two-stage approach, for pseudo panel data, and Sharma et. al (1999) for cross sectional data. Timmer (1970) was one of the first to apply this approach albeit using covariance analysis in stage one.

The problem of this two-stage method can be addressed using a one-stage formulation. This specifics the technical inefficiency effects (Kumbhakar et. al., 1991) and estimates the stochastic frontier and the inefficiency effects simultaneously, given appropriate distributional assumptions (Battese and Coelli, 1995). The simultaneous estimation of the stochastic production frontiers and models of technical inefficiency using maximum likelihood techniques has been proposed by Kumbhakar (1991), Huang and Lui (1994), Battese and Coelli (1995). Thus one-stage approach is statistically consistent and leads to more efficient inference with respect to the parameters (Coelli and Battese, 1996). The approach has been applied empirically by among others, Coelli and Battese (1996), Coelli

(1996), Battese and Broca (1997), Ajibefun (1996) and Seyoum (1998). We now explain the single-stage approach in more details as it forms the basis of the empirical analysis.

The outline of this Chapter is as follows: Section 6.2 discusses the stochastic frontier approaches to efficiency measurement; Section 6.3 gives some functional form of production function and Section 6.4 gives a summary and conclusions.

6.2. Stochastic Frontier Production Function and Efficiency Estimation

Stochastic Frontier Analysis 9SFA) originated with two papers, published nearly simultaneously by Meeusen and van den Broeck (MB, 1977) appeared in june, and Aligner, Lovell and Schmidt (ALS, 1977) appeared a month later. The ALS and MB papers are very similar. Both papers need three years in making, and both appeared shortly before a third SFA paper by Battese and Corra (1977).

The model applied in thses three original papers used the composed error structure and each was developed in a production frontier context. The general stochastic frontier production model is defined as:

$$y_i = f(x_i;\beta)e^{u_i} \quad (6.1)$$

$$u = \xi_i - \zeta_i \;; \quad \text{i} = 1, 2, 3, ..., \text{q}$$

$$-\infty \le \xi_i \le \infty and \zeta \ge 0$$

Where y_i =Observed output of the *ith* farm;

x_i = Input vectors of the *ith* farm;

β = Unknown parameter to be estimated;

u_i = the error term which analyzes a stochastic random disturbance and an asymptotic non negative random error term.

The stochastic random disturbance and the symmetric random errors ξ_i, take account of measurement error, other exogenous pressure and factors not under producers' control; ξ_i may take any real value and when added to the deterministic frontier, $f(x_i;\beta)$, gives rise to the stochastic frontier. The asymmetric non-negative random error ζ_i, which is called technical inefficiency effects, account for technically inefficiency in production. When $\zeta_i = 0$, the production function shows the best practice frontier which yields the maximum output given the inputs; and when $\zeta_i > 0$, it expresses that the output is less than this maximum due to technical inefficiency. The greater the quantity by which the actual output falls short of the stochastic frontier output, the higher the level of technical inefficiency. The observed variations in output may happen due to either stochastic disturbances or technical inefficiency or both. A model without ζ_i is the average frontier model criticized by Farrell (1957). Further, a model without the random component, ξ_i, results in a deterministic or full frontier model and can be estimated by linear programming techniques.

Assuming probability density function for both ξ_i and ζ_i, we can estimate (6.1) by maximum likelihood methods. This approach yields a means by which we can statistically examine the sources of differences between the producer's output and frontier output by calculating the variance parameters which relate the variance of ξ_i to the composed variance of u_i (Kalirajan, 1981).

The variance parameters are expressed as:

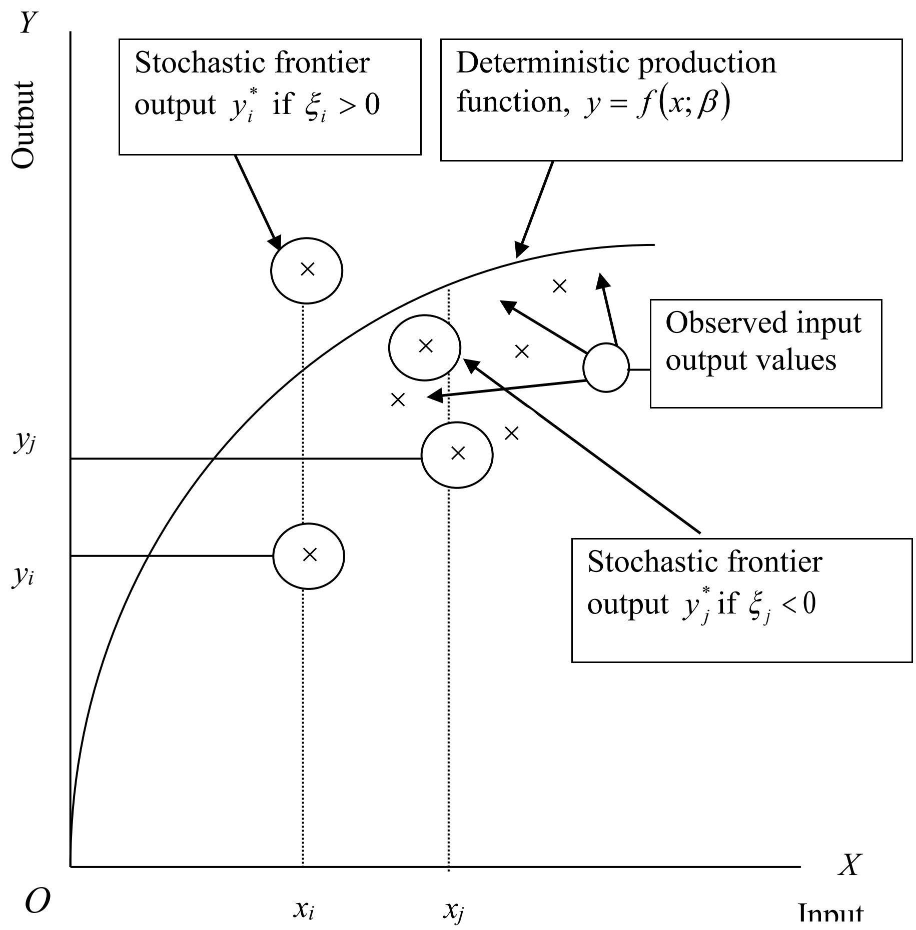
$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2 \qquad (6.2)$$

$$\gamma = \sigma_\zeta^2 / \sigma_u^2 \;\; and \;\; 0 \le \gamma \le 1$$

Battese and Corra (1977) define γ as the total variation of output from the production frontier which might be attributed to technical inefficiency. When $\gamma \to 0$, then $\sigma_\zeta^2 \to 0$ and $\sigma_\xi^2 \to \sigma_u^2$, which indicates that the symmetric error term ξ_i dominates the composed error term and output differs from the frontier output mainly because of measurement errors and the effect of other external factors on production. If $\gamma \to 1$ then $\sigma_\xi^2 \to 0$ and $\sigma_\zeta^2 \to \sigma_u^2$ which implies that the asymmetric non-negative error term ζ_i dominates the composed error and the differences between observed and frontier output can be attributed to differences in technical efficiency.

The basic features of the stochastic frontier model are illustrated in Figure 6.2. Inputs are represented on the horizontal axis while outputs are measured on the vertical axis. The deterministic component of the frontier production model $y = f(x;\beta)$ is drawn assuming diminishing return to scale. The observed output and inputs for two farms are presented. The productive activities of two farms are represented by i and j, are illustrated following Battese (1992). Farm i uses inputs x_i to produce output y_i, which exceeds the value on the deterministic production frontier $f(x_i;\beta)$. The frontier output is shown as y_i^*. It is because of the fact that the productive activity of the *ith* farm is accompanied by 'favourable' farming conditions, for which the random error $\xi_i > 0$,. Similarly, the *jth* farm uses the level of inputs x_j, and produce output y_j, which is less than the value on the deterministic production function $f(x_j;\beta)$, because its productive activity is associated with 'unfavourable' farming conditions and the systematic error component $\xi_i < 0$. For both farms, the observed production values are less than the corresponding frontier production values, but the unobservable frontier production values would lie around the deterministic production function related with the farms involved.

Figure 6.2: Frontier Production Function and Technical Efficiency



The stochastic frontier outputs are, obviously, not observed since the random errors are not observed. The observed output may be higher than the deterministic part of the frontier function if the random errors are higher than inefficiency term. The technical efficiency of the *ith* farm is defined as the ratio of the observed output to the corresponding frontier output, given the levels of the inputs (Wadud, 1999). The farm-specific technical efficiency, φ_i , can be measured as:

$$\varphi_i = \frac{y_i}{y_i^*} = \frac{f(x_i, \beta)e^{(\xi_i - \zeta_i)}}{f(x_i, \beta)e^{\xi_i}} = e^{-\zeta_i} \qquad 0 \le \varphi_i \le 1$$

Alternatively, φ_i is defined as the ratio of the mean of production (given x_i and ζ_i) to the corresponding mean of production if there is no technical inefficiency (Battese and Coelli 1988):

$$\varphi_i = \frac{E(y_i / x_i, \zeta_i)}{E(y_i / x_i, \zeta_i = 0)}$$

Again the systematic random error, ξ_i, is assumed to be independently and identically distributed with mean zero and variance, σ_ξ^2 ; and ζ_i are non-negative truncations of the $N(\mu, \sigma_\zeta^2)$ distribution, where:

$$\mu = z_i \delta_i \tag{6.3}$$

where z_i is a $(k \times 1)$ vector of variables which may influence efficiency and δ_i is an $(1 \times k)$ vector of parameters. Furthermore ξ_i and ζ_i are assumed to be independent of each other, i.e., $E(\xi_i, \zeta_i) = 0$ and also independent of the input vector x_i, i.e., $E(\xi_i, x_i) = E(\zeta_i, x_i) = 0$. The probability density function of the symmetric random error, ξ_i , is defined as:

$$f(\xi_i) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{1}{2\sigma^2}\xi_i^2}$$

The probability density function of the truncated normal distribution of technical inefficiency effects term can be given as follows:

$$f(\zeta_i / \zeta_i \geq 0) = \frac{f(\zeta_i)}{\Pr(\zeta_i \geq 0)} \qquad \zeta_i \geq 0$$

$$= \frac{(2\pi\sigma^2)^{-1/2} e^{-(\zeta_i - \mu)/(2\sigma^2)}}{\{1 - \Pr(\zeta_i \leq 0)\}}$$

$$= \frac{1}{(\sqrt{2\pi})\sigma_\zeta [1 - \Phi(-\mu/\sigma_\zeta)]} e^{-\frac{1}{2\sigma_\zeta^2}(\zeta_i - \mu)^2}$$

$$= \frac{\frac{1}{\sigma_{\zeta_i}} \phi\left(\frac{\zeta_i - \mu}{\sigma_{\zeta_i}}\right)}{1 - \Phi(-\mu/\sigma_{\zeta_i})} \tag{6.4}$$

where $\phi(\cdot)$ stands for the standard normal probability density function (pdf) and $\Phi(\cdot)$ denotes the cumulative distribution function (cdf) for the standard normal random variable. The mean and variance of the truncated normal distribution of ζ_i are respectively (see Appendix 6.1 for details):

$$E(\zeta_i) = \mu + \frac{\sigma_\zeta \phi(-\mu/\sigma_\zeta)}{1 - \Phi(-\mu/\sigma_\zeta)}$$

and:

$$Var(\zeta_i) = \sigma_\zeta^2 \left[1 - \frac{\phi(-\mu/\sigma_\zeta)}{1 - \Phi(-\mu/\sigma_\zeta)} \left\{\frac{\mu}{\sigma_\zeta} - \frac{\phi(-\mu/\sigma_{\zeta_i})}{1 - \Phi(-\mu/\sigma_{\zeta_i})}\right\}\right]$$

Measurement of the farm-specific efficiency, $e^{-\zeta_i}$, depends on the decomposition of u_i, which can be derived from the conditional expectation of $e^{-\zeta_i}$ provided u_i that is:.

$$E(e^{-\zeta_i / u_i}) = \int_0^\infty \zeta_i (f(\zeta_i / u_i) d\zeta_i,$$

where the conditional probability density function $f(\zeta_i / u_i) = \frac{f(\zeta_i, u_i)}{f(u_i)}$ and $f(\zeta_i, u_i)$ is the joint probability density function of ζ_i and u_i and $f\ (u_i)$ is the probability density function of u_i. $E(e^{-\zeta_i / u_i})$ can be re-expressed as:

$$E(e^{-\zeta / u_i}) = \int_0^\infty \zeta_i \frac{f(\zeta_i, u_i)}{f(u_i)} d\zeta_i$$

Since $u_i = \xi_i - \zeta_i$, a joint probability density function of ξ_i and ζ_i can be derived as:

$$f(\xi_i, \zeta_i) = f(\xi_i) f(\zeta_i) = \frac{1}{\sqrt{2\pi\sigma_\xi}\sqrt{2\pi\sigma_\zeta}[1 - \Phi(-\mu / \sigma_\zeta)]} e^{-\frac{1}{2}\frac{1}{\sigma_\xi^2}\xi_i^2} e^{-\frac{1}{2}(\frac{\zeta_i - \mu}{\sigma_\zeta})^2} \tag{6.5}$$

The joint probability density function for ζ_i and u_i, $f(\zeta_i, u_i)$, can be derived by following the joint probability density function of ζ_i in (6.5) as:

$$f(\zeta_i, u_i) = \frac{e^{-\frac{1}{2}(\frac{\zeta_i - \mu}{\sigma_\zeta})^2} e^{-\frac{1}{2}\{\frac{u_i + \zeta_i)'(u_i + \zeta_i)}{\sigma_\xi^2}\}}}{\sqrt{2\pi\sigma_\zeta}[1 - \Phi(-\mu / \sigma_\zeta 0]\sqrt{2\pi\sigma_\zeta}} \tag{6.6}$$

Applying standard integral calculus, the minimum-mean-square-error predictor of the technical efficiency of the ith farm, $\varphi_i = TE_i = e^{-\zeta_i}$ is obtained as:

$$\therefore \qquad \varphi_i = [\frac{1 - \Phi\{\sigma_i^* - (\mu_i^* / \sigma_i^*)\}}{1 - \Phi(-\mu_i^* / \sigma_i^*)}] e^{(-\mu_i^* + \frac{1}{2}\sigma_i^{*2})} \tag{6.7}$$

which produces the measure of techninal efficiency given the specification of the frontier production function model and the inefficiency effects model. Technical inefficiency is estimated by $1 - E\{e^{-\zeta_i} / u_i\}$. The efficiency index of each farm, $e^{-\zeta_i}$ is constructed using (6.7). The mean technical efficiency of all farms in the sample, $\overline{\varphi}$, is obtained as:

$$\overline{\varphi} = [\frac{1 - \Phi\{\sigma^* - (\mu^* / \sigma^*)\}}{1 - \Phi(-\mu^* / \sigma^*)}] e^{(-\mu^* + \frac{1}{2}\sigma^{*2})}.$$

Instead of using the truncated normal distribution defined in (6.4), we can assume that the technical inefficiency term is half-normally distributed, a special case of the truncated normal distribution, so that:

$$f(\zeta_i) = \frac{1}{\sigma_\zeta\sqrt{\frac{1}{2}\pi}} e^{-\frac{1}{2\sigma^2}\zeta_i^2} \quad (6.8)$$

The farm-specific technical efficiencies and mean technical efficiency are obtained respectively as:

$$\varphi_i = E[e^{-\zeta_i/u_i}] = 1 - \Phi(\sigma_i^*)e^{\frac{1}{2}\sigma_i^{*2}} \quad (6.9)$$

and $\overline{\varphi_i} = 1 - \Phi(\sigma^*)e^{\frac{1}{2}\sigma^{*2}}$

(Jondrow et al., 1982), which is equivalent to substituting μ = 0 in (6.7).

Frontier 4.1 program (Coelli, 1996) computes the maximum likelihood estimator of the predictor for the technical efficiency that is based on the conditional expectation of $e^{-\zeta_i}$ given the composed error term of the stochastic frontier production model (Battese and Coelli, 1988). The parameters of the coefficients of stochastic frontier model, β, and the technical inefficiency effects model, δ_i, along with the variance parameters are also estimated. The log-likelihood function for the sample observations, given (6.1), (6.2) and (6.4), is:

$$L(\Omega^*, y) = \sum_{i=1}^{n} \ln[1 - \Phi(-\mu_i^*/\sigma_{i\zeta}^*)] - \frac{1}{2}\sum_{i=1}^{n}\left[\{y_i - f(x_i;\beta)\}'\{y_i - f(x_i;\beta)\}/\sigma_\xi^2\right]^2$$

$$-\frac{1}{2}n(\mu/\sigma_\zeta)^2 + \frac{1}{2}\sum_{i=1}^{n}(\mu_i^*/\sigma_{i\zeta}^*)^2 - \frac{1}{2}n\ln(2\pi) - \frac{1}{2}n\ln(\sigma_\zeta^2 + \sigma_\xi^2)$$

$$-n\ln[1 - \Phi(-\mu/\sigma_\zeta)]$$

where $\Omega^* \equiv (\beta', \sigma_\xi^2, \sigma_\zeta^2, \mu)'$ (see Appendix 6.2 and 6.3 for details).

The foremost disadvantages of this approach are assumptions about the distributions of technical inefficiency and the random term and the nonexistence of an apriori justification of choosing the distributional form of the random term (Coelli, 1992).

The calculation of technical efficiencies of individual farm under stochastic frontier production function as given in equation (6.4) has been made possible by the contribution of Jondrow, Lovell et. al., Materov and Schmidt (1982). Also Aigner and Schmidt (1980) contributed important papers dealing with the deterministic and stochastic frontier models.

The stochastic frontier model as given in equation (6.4) having the inference about the parameters of the model is based on the maximum-likelihood estimators. It has been argued that maximum likelihood estimators satisfy the standard regularity conditions (Battese, 1998). Richmond (1974) has suggested applying of the corrected least-square (COLS) methods to estimate the parameters. Battese (1998) noted that the ML estimator is asymptotically more efficient than the COLS estimator, but the properties of the two estimators in finite samples can not be analytically ascertained.

6.3. Functional Forms of Production Function

One of the general assumptions in the study of productive efficiency is that the production function of a fully efficient farm is supposed to be known. But in practice, production function for efficient farm is never known. In such a situation, Farrell (1957) has suggested that the production function be estimated from sample data using either a non-parametric piece-wise-linear technology or a parametric function, such as the Cobb-Douglas functional form. However, Aigner and Chu (1968) consider the estimation of a parametric production function of the Cobb-Douglas form. Cobb-Douglas production function is widely used in econometrics.

6.3.1. Cobb-Douglas Production Function

The Cobb-Douglas production function can be given as follows:

$$Ly_i = \beta_0 + \sum_{i=1}^{7} \beta_i Lx_i \qquad (6.10)$$

Where y_i = output, β_0 = efficiency parameter, i.e., an indicator of the state of technology, x_i= inputs of production, L = Natural logarithm, β_i $(i = 1,2,3,...,q)$ are the output elasticities with respect to each input and the production function is homogeneous of degree $\sum_{i=1}^{q}\beta_i$. Differentiating (6.10) yields of the marginal product for input of *ith* farm, for example:

$$\frac{\partial y}{\partial x_i} = \frac{\beta_i y_i}{x_i}.$$

which is strictly positive for $x_i > 0$. The marginal rate of technical substitution is:

$$MRTS_{i,j} = \frac{\partial y_i / \partial x_i}{\partial y_i / \partial x_j} = \frac{\beta_i}{\beta_j}\frac{x_j}{x_i}.$$

The elasticity of substitution is $\sigma = 1$ for any input combination and all levels of output, which restricts the flexibility of this functional form. The returns to scale is $\sum_{i=1}^{q}\beta_i$.

6.3.2. Translog Production Function

A production function which does not restrict the elasticity of substitution, σ, is the transcendental logarithmic (Translog) form of the production function (Chirstensen. 1973) which can be written as:

$$Ly_i = \beta_0 + \sum_{i=1}^{7}\beta_i Lx_i + \tfrac{1}{2}\sum_{i=1}^{7}\sum_{j=1}^{7}\beta_{ij} Lx_i Lx_j \qquad (6.11)$$

This function does not presume any restriction on production technology. In (6.11) $\sum_{j=1}^{7}\beta_{ij}$ is included to make the marginal rate of technical substitution homogeneous of degree zero in inputs which yields a Kmenta approximation of CES production function (Kim, 1992). If $\sum_{i=1}^{7}\beta_i = r$ and $\sum_{j=1}^{7}\beta_{ij}$ = 0, (6.11) is homogeneous of degree *r*, and if *r* = 1 it is linearly homogeneous. The translog function in (6.11) is additively separable if β_{ij} = 0 ($(i \neq j)$, Cobb-Douglas is a special case of the translog function if β_{ij} = 0. Differentiating (6.11) yields the marginal product for input *i,* for example:

$$\frac{\partial y}{\partial x_i} = \frac{y}{x_i}[\beta_i + \sum_{i=1}^{7}\beta_{ij} Lx_j]$$

The elasticity of scale = $\partial Ly / \sum_{i=1}^{7} \partial Lx_i$, depends om the factor proportions and the levels of proportion. The elasticity of substitution of this production function is unbounded.

We use the general likelihood ratio (*LR*) test to select the model. This test requires the estimation of the model under both the null and alternative hypotheses and is defined as:

$$LR = -2In[L(H_0)/L(H_A)]$$

Where $L(H_0)$ and $L(H_A)$ are the values of the likelihood function under the null and alternative hypotheses respectively. If the null hypothesis is true, then *LR* has an asymptotic χ^2-distribution with degrees of freedom equal to the number of restrictions imposed under the null hypothesis (Coelli, 1996)

6.4. Summary and Conclusions

This chapter describes econometric approach to estimate technical efficiency. Neo-classical production function is the basis of the stochastic frontier. Hence functional form of production function is a pre-requisite to find efficiency measurement. Production function provides the foundation for econometric approach to estimate technical efficiency, which includes stochastic frontier. We discuss development of parametric models as it form the basic of empirical methodology of estimating productive efficiency. Stochastic frontier analysis (SFA) fulfils necessary criteria for estimating technical efficiency on the basis of a suitable production function. The stochastic frontier model permits the estimation of standard errors and tests of hypothesis using traditional maximum likelihood methods, which has been impossible under the earlier deterministic production frontier model since violation of certain regularity conditions occurs. Stochastic frontier model allows for technical inefficiency, and it also acknowledges the fact that random shocks outside the control of firms can affect the output. Since the error term has two components, the stochastic production frontier model is often referred to as the “composed error” model.

Cobb-Douglas production functional form is very popular and widely used in econometric analysis. Although, it is restricted by unitary elasticity of substitution. We have discussed Cobb-Douglas functional form to find measures of technical efficiency. Under stochastic frontier approach, we have used Cobb-Douglas production frontier to estimate the technical efficiency of individual rice farms in northern Bangladesh. We have applied in our study the Cobb-Douglas stochastic frontier model to estimate efficiency.

Chapter 7

Empirical Results: The Stochastic Frontier Model

7.1. Introduction

In Chapter 6, we have discussed the stochastic econometric frontier model. Now in this Chapter we analyze estimated results of the stochastic econometric frontier model. We measure the technical efficiency using the Cobb-Douglas stochastic frontier model with factors affecting inefficiency in a single stage estimation technique by the maximum likelihood method. We also focused on the technical inefficiency effects model. Then we show some policy implications regarding the introduction of new methods, technologies and in particular, those policies that increase the productivity of the rice farmers. We describe summary statistics of variables and their specific characteristics and also describe average cost, output, revenue and profit (per acre). Maximum likelihood estimates of the Cobb-Douglas stochastic frontier model and their inefficiency and frequency distribution of farm-specific technical efficiency estimates are presented. We also identify and quantify the factors affecting technical efficiency and provide some policy implications regarding the introduction of new technologies and in particular those policies which aim to increase the productivity of rice farmers in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together.

We organize this Chapter as follows: Section 7.2 gives summary statistics and explanation of the variables; Section 7.3 describes per acre output, revenue, cost and profit of a farms; Section 7.4 presents factors determining / affecting rice producers inefficiency; Section 7.5 explains stochastic frontier and technical efficiency results; Section 7.6 gives Cobb-Douglas stochastic frontier results; Section 7.7 presents technical inefficiency results; Section 7.8 explains estimated technical efficiency of rice farms; and Section 7.9 provides summary and conclusions.

7.2. Summary Statistics and Explanation of the Variables

The survey data are collected from three upazilas of three different districts of Northern Bangladesh. The survey is conducted in December-February, 2009-10 for aman season (S_1) and June-August 2010 for boro season (S_2) of rice cultivation. In field survey, we have observed some significant results and behaviours of some used variables. The survey statistics of aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) are presented in Table 7.1 and 7.2.

Table 7.1: Summary Statistics of Variables of Aman Season (S_1)

Variables	Notations	Sample mean	Minimum	Maximum	C.V.
Revenue	y	20073	10875	28620	157.41
Land	x_1	6416	4250	10000	125.27
Labour	x_2	4331	2699	6251	561.46
Plough	x_3	2079	1650	2500	596.52
Seed	x_4	307	270	540	192.83
Irrigation	x_5	1881	900	2400	969.29
Fertilizer	x_6	1880	1052	3564	150.97
Pesticides	x_7	1759	700	2700	234.48
Summary Statistics of Variables of Boro Season (S_2)					
Variables	Notations	Sample mean	Minimum	Maximum	C.V.
Revenue	y	27090	17360	38130	294.45
Land	x_1	6131	3750	9000	105.22
Labour	x_2	5228	3537	7020	598.29
Plough	x_3	1946	1350	2500	917.56
Seed	x_4	307	270	540	194.64
Irrigation	x_5	2143	1800	4500	131.83
Fertilizer	x_6	2440	1471	4800	394.29
Pesticides	x_7	2142	1350	2700	906.89
Farm-Specific Characteristics					
Age (Years)		47	23	66	63.51
Years of schooling		5	0	16	16.19
Experience (Years)		26	6	49	71.82
Land fragmentation (Plot size)		0.28	0.14	0.57	0.009
Credit facilities dummy		0.57	0	1	0.246
Extension services dummy		0.71	0	1	0.205
Land degradation dummy		0.28	0	1	0.191

Source: Field survey data, (2009-2010).

For efficiency analysis we have taken only one output of rice and seven inputs. Output (y) indicates the market value of the observed rice production and are measured in taka. Revenue means quantity of output multiplied by price per mound (1 mounds = 37.32 kilograms (Kg). Land (x_{i1}) denotes the total amount of land used for rice cultivation and the price of land, p_{i1} represents 1 per cent increasing rental value of per acre land. Labour (xi_2) represents the per acre labour used in rice production which includes family and hired both labour and the price of labour, p_{i2} indicates the wage per man-day. Polugh (xi_3) indicates per times of land plough and the price of plough, p_{i3} represents as the money paid to the power tiller holder. Seed (x_{i4}) denotes the amount of seeds used on per acre of land and is measured in Kg. The seeds price, p_{i4} means the average price of seeds per Kg including both HYV and traditional type of seeds. Irrigation (xi_5) is the total amount of land irrigated for rice cultivation and the price of irrigation, p_{i5} represents irrigation price per acre. Fertilizer (xi_6) includes all organic and inorganic fertilizer and is measured in Kg. And the price of fertilizer, p_{i6} indicates the average price of all fertilizer per Kg. Pesticides (xi_7) denotes the total quantity of pesticides used per acre of land is measured also in Kg. The price of pesticides, p_{i7} is the price of all pesticides per Kg. All type of inputs costs are measured in local market price in taka ($ 1 = about 80 Bangladeshi taka). Each input plays as a vital role for rice production. Labour and seed costs are more significant than other variable costs.

Table 7.2: Summary Statistics of Variables of both Aman and Boro Seasons (S_1+S_2) Together

Variables	Notations	Sample mean	Minimum	Maximum	C.V.
Revenue	y	47164	31360	64960	588.19
Land	x_1	12548	8500	18000	352.88
Labour	x_2	8683	5398	12502	209.08
Plough	x_3	4025	3000	5000	205.70
Seed	x_4	614	540	1080	731.71
Irrigation	x_5	4024	2800	6750	286.90
Fertilizer	x_6	4327	2602	6768	544.73
Pesticides	x_7	3901	2350	5400	430.42

Source: Field survey data, (2009-2010).

Costs of different inputs are added and the average total variable costs (ATVC) of aman season (S_1) are calculated. Summary statistics of used variables are shown in Table 7.1 and 7.2. Land is an important input of rice cultivation. A lion share of average total variable cost is calculated of land. One per cent average total variable cost (ATVC) of land is covered of aman season (S_1) and boro seasons (S_2) are Tk 6416 and Tk 6131 respectively. In our study area, minimum one per cent increasing rental cost of aman and boro land are Tk 4250 and Tk 10000 and maximum Tk 3750 and Tk 9000 with coefficient of variation (C.V.) of 125 and 105 respectively. The sample mean of an average land cost in both aman and boro both seasons (S_1+S_2) together are Tk 12548 and with coefficient of variation of 353.

Labour is the second highest expensive and important input of rice cultivation. Sample mean for per man-day labour cost in aman season (S_1) and boro season (S_2) are Tk 4331 and Tk 5228 respectively and their respective coefficient of variations are 561 and 598. Per man-day minimum labour costs per acre rice cultivation taking both seasons together are Tk 2699 and Tk 6251, and maximum Tk 3537 and Tk 7020. In both aman and boro both seasons (S_1+S_2) together average total variable cost of labour is Tk 8683 and the coefficient of variation (C.V.) is 209. In field level survey, we have observed some significant behaviour for labour. It shows that there are already abundant supplies of labour in agriculture sector of Bangladesh, particularly in the study area in northern Bangladesh.

Plough is one of the important cost for rice cultivation. In our study area average total variable cost (ATVC) of plough in aman season (S_1) and boro season (S_2) are Tk 2079 and Tk 1946 with the coefficient of variation are 596 and 917 respectively. Minimum and maximum plough costs in aman season (S_1) are Tk 1650 and Tk 2500 and boro season (S_2) these cost are Tk 1350 and Tk 2500. The sample mean of plough cost in both aman and boro seasons (S_1+S_2) together is Tk 4025 and the coefficient of variation is 206.

Seed is one of the most important input for rice cultivation. Obviously qualitative seed is not available. In our study area average seeds cost of aman season (S_1) and boro season (S_2) are almost the same. It is calculated on an average Tk 307 and with minimum and maximum costs are Tk 270 and Tk 540. Average seed cost in both aman and boro seasons (S_1+S_2) together are Tk 614 and the coefficient of variance is 732. In case of seeds in our study area farmers are used excessive amount of seed, therefore, we have some unusual results and behaviours of seeds.

Irrigation is the most important and vital input of rice cultivation. Particularly it is the life blood for boro rice. Irrigation cost in aman season (S_1) and boro seasons (S_2) are Tk 1881 and Tk 2143 with coefficient of variations 969 and 132 respectively. The sample mean of irrigation cost in both aman and boro seasons (S_1+S_2) together is calculated Tk 4024 and the coefficient of variation 287. Minimum and maximum irrigation costs in aman seasons (S_1) are Tk 900 and Tk 2400 and boro season (S_2) these value are Tk 1800 and Tk 4500 respectively.

Survey results reveal that same percent rice producers are used fertilizer and all of them use chemical fertilizer. Fertilizer is one of the most important and principal input in modern rice cultivation. In our study area average total variable cost of fertilizer in aman (S_1) season and boro seasons (S_2) are Tk 1887 and Tk 2440 and with coefficient of variation 151 and 394 respectively. Collectively average total variable cost of fertilizer in both aman and boro seasons (S_1+S_2) together is Tk 4327 and the coefficient of variation of 545. Minimum and maximum fertilizer costs are for aman season (S_1) Tk 1052 and Tk 3564, and boro season (S_2) these cost calculates Tk 1471 and Tk 4800.

Pesticides are the least cost input of rice cultivation. The sample mean of pesticides cost in both aman and boro both seasons (S_1+S_2) together is Tk 3901 and the coefficient of variation of 430. Average pesticides cost in aman season (S_1) and boro season (S_2) are Tk 1759 and Tk 2142 and with coefficient of variation of 234 and 907 respectively. Minimum and maximum pesticides cost in aman season are Tk 700 and Tk 2700 and for boro season these costs are Tk 1350 and Tk 2700 respectively.

7.3. Summary Statistics of Output, Revenue, Cost and Profit of Farms in our Study Area

In our study area average total variable costs (ATVC) in aman season (S_1) and boro season (S_2) are Tk 18660 and Tk 20340. Minimum and maximum total variable costs are in aman season (S_1) Tk 13732 and Tk 23037, and boro season (S_2) these costs calculates Tk 15589 and Tk 24934 with their coefficient of variations are 351.27 and 239.21 respectively. Average total variable cost of boro season (S_2) is higher than in aman season (S_1). In our survey area per acre average output, revenue, cost and profit are described bellow.

Average output of aman season (S_1) in our survey area is not good in amount. Output of aman season (S_1) of our survey period ranges 21-57 mounds (1 mound = 37.32 Kg). The survey results show that 21.91 per cent producers output of aman season (S_1) is less than 31 mounds. About 69.33 per cent producers' output of aman seasons (S_1) is 31-50 mounds but less than 51 mounds and only 8.76 per cent producers' output of aman season (S_1) is more than 50 mounds during survey period in December-February 2009-10. On the contrary, Output of boro season (S_2) of our survey period ranges from 31-73 mounds. The survey results show that 32.67 per cent cultivators' output of boro season (S_2) is 30-50 mounds. About 51.79 per cent rice producers' output of boro season (S_2) is in between 51-65 mounds but less than 66 mounds and only 15.54 per cent producers' output of boro season (S_2) is more than 65 mounds during survey period in June-August 2010.

Revenue means quantity of output multiplied by price per mound. That is, $R = (Q \times P)$. In both aman and boro seasons production have been affected due to various reasons, which are stated as before. So therefore, output and revenue of both aman and boro seasons during survey period 2009-10 are not satisfactory.

Table 7.3 shows that average revenue of aman (S_1) and boro seasons (S_2) are calculate Tk 20073 and Tk 27090 respectively. Minimum revenue of aman and boro seasons are Tk 10875 and Tk 28620 and maximum revenue are Tk 17360 and Tk 38130 with coefficient of variation (C.V.) 157 and 294. The survey results show that 18.73 per cent rice producers revenue in aman seasons is less than 17 thousand taka. About 51.39 per cent rice producers' revenue exists in the range from 17-22 thousand taka. About 26.29 per cent cultivators' revenue of aman season (S_1) is lies between 23-28 thousand taka. Only 3.59 per cent rice cultivators' revenue of aman season (S_1) more than 28 thousand taka. On the other hand, 26.30 per cent rice producers' of boro season (S_2) revenue is less than 24 thousand taka. About 31.87 per cent producer's revenue is more than 24 thousand taka but less than 30 thousand taka and 36.65 per cent cultivators revenue of boro season (S_2) is lies between 30-35 thousand taka. Only 5.18 per cent farmer's revenue of boro season (S_2) is more than 35 thousand taka.

Profit depends on total output, total cost and price of the related products. As we have seen earlier that, in both aman and boro season's output during survey period in 2009-10 are not satisfactory of our survey area. Cost of rice output is comparatively high. One important thing that the marginal farmers do not get proper price of their rice. In most cases, they take necessary inputs by loan system. After harvesting new rice, they are obliged to pay the loan of inputs first. So, they could not stock their rice for higher price. Consequently, they are forced to sell the rice at minimum price which is lower than the market price. This fact is found in our survey area. So, the farmers of our study area could not become able to get a handsome profit by selling their rice.

The main objective of this section is to show the profitability range of rice producers. Before going to discuss the profitability of producers, at first it is necessary to explain the meaning of profitability, which is the adjective of the word "profit." In economics, profit is the difference between market price of output and the market price of inputs that are employed to produce that output (Todaro, 1985). The main goal of the producers is to get an income either in the farm of direct consumption or in cash. So, that covering all the costs, they can make a profit. A farmers profit can be defined as the difference between the total revenue and total cost. That is,

$$\prod = TR - TC$$

Where, Π = Profit, TR = Total Revenue and TC = Total Cost.

or, it may be defined as the ratio of total revenue to total cost, i,e.

if, $\frac{TR}{TC} = 1$, Then no loss no profit; $\frac{TR}{TC} > 1$, then is profit and $\frac{TR}{TC} < 1$, then there is loss.

Table 7.3 shows that average profit in aman season (S_1) and boro seasons (S_2) are calculate Tk 1413 and Tk 6750 respectively. Minimum and maximum revenue in aman and boro seasons are Tk 133 and Tk 7588, and Tk 458 and Tk 17936 with coefficient of variations (C.V.) in both aman and boro seasons are 111 and 239. The survey result shows in Table 7.3 that 55.38 per cent rice producers in aman season (S_1) have average profit less than 3 thousand taka. Another 28.68 per cent producers profit is in between 3-5 thousand taka. Only 15.94 per cent cultivator's profit is more than 5 thousand taka during survey period 2009-10 in aman season (S_1). On the contrary, 29.48 per cent producer's profit of boro season (S_2) is less than 5 thousand taka. Another 35.46 per cent farmers' profit is in between 5-10 thousand taka. About 28.29 per cent farmers' average profit ranges from 11-14 thousand taka. Only 6.77 per cent farmers profit is more than 14 thousand taka during boro season (S_2) in 2010.

Rice output of all seasons in our study area is found to be low. From inquiry to the grassroots level rice producers, some major reasons have seen found. Firstly, in the beginning stage of the rice cultivation, there is serious shortage of water. Secondly, at the last stage of the production, when the rice almost grew up, there occurs frequently load-shedding which affected rice production. Thirdly, fuel price gradually rose up high and hampered all kinds of rice cultivation. Fourthly, there were seeds crisis, seed played a vital role of production. Good, healthy and improved seed bring more production. HYVs seed bears more cost so maximum farmers of our study area could not bear the excess costs for seed. Generally, farmers' use their indigenous seed. Particularly, each farmer in boro season (S_2) in 2010, has lost their initial seeds ground due to bad weather.

7.4. Factors Determining /Affecting Rice Producer's Inefficiency

Research literature shows that a number of socio-economic and environmental factors determine the efficiency of the rice producers (Seyoum et. al.,1998; Coelli and Battese 1996; Wilson et. al., 1998). These include land use, credit availability, land tenure and the educational level of farmer (Kalirajan and Flinn, 1983; Lingard et. al., 1983; Shapiro and Muller, 1977; Kumbhakar, 1994). Techniques of cultivation, share tenancy, farm holding size may also influence efficiency (Ali and Choudhury, 1990; Coelli and Battese, 1996; Kumbhakar, 1994). Some environmental and non-physical factors like age, level of education, experience, credit facilities, extension services and land degradation may affect the capability of a farmer to utilize the available technology efficiently. We now consider the variables which may affect efficiency of rice farms in Northern Bangladesh.

There is no proper guideline in the literature as to which variables are to be included in the stochastic frontier production function and which in the technical inefficiency effects model. For example, Wilson et. al., (1998) included, among others, the cultivated potato area in the production function and the proportion of the cultivated potato area that is irrigated in the technical inefficiency effects model. Coelli and Battese (1996) included land variable, among others, in the production function and land size, among other, in the technical inefficiency effects model. Parikh and Shah (1994) and Parikh et. al., (1995) included off-farm work, farm assets, non-farm assets and credit in the technical inefficiency effects model. On the basis of this literature we include in the technical inefficiency effects model socioeconomic, infrastructure and environmental degradation variables which have not traditionally been included as input variables in the production function.

In the context of farms within the northern Bangladesh, the age of the farmers, the years of schooling, experience, plot size, credit facilities, extension services and land degradation are relevantly considered. Table 7.1 shows that the age is a considerable factor which have a positive or negative effect the performance of rice producers. In our study area age ranges of the rice producers are 23-66 years with an average age is 47 years. Over aged and more experience farmers are less receptive to new technologies and practices. Because, over aged and more experienced farmers can not adopt proper methods and input ratio. There is an interaction between age and education of farmers because younger farmers tend to be more educated than aged farmers due to gradual improvements in the educational system. So, low-aged farmers may be able to apply new technologies and methods.

Formal education can play a positive role on rice cultivation. A priori, we may consider that more years of formal education will increase efficiency because education enables farmers to acquire and process relevant information more effectively. Basic literacy enables farmers to use modern fertilizer and pesticides and choose input combination. Farmers can be exposed to new technologies and improved techniques with education and extension services. Levels of increased education and extension services are related to the allocative efficiency of Indian farmer by Ram (1980). Extension services availability and education level were found by Huffman (1977) to be important explanatory variables of the rate of adjustment in fertilizer use in response to price changes. In our survey area ranges of education is between 0-16 years with an average 5 years.

Experience of rice cultivation is a considerable factor which also influenced the performance of rice producers. In our study area experience of the rice producers is ranges between 6-49 years with an average of 26 years.

Land fragmentation i. e., land plot size is a considerable matter for rice cultivation. It may have a negative effect on efficiency. Because, the greater the plot size of a farm provides more efficiency of farmer. The rice farmer can easily apply modern technology in greater size of plot and also it is more economic. The better performance of farms with larger plot size is attributed to better application of new technologies such as, power tillers, tractors, modern irrigation system and other modern equipments (Wadud, 1999). The average plot size in our survey area is 0.28 acres with minimum and maximum plot sizes are 0.14 acres and 0.57 acres respectively.

Credit has a positive effect on efficiency of farmer. As we know, the cultivation system has changed. Now, farmers turns their cropping pattern from old natural less costly to new modern mechanical more expensive system. Therefore, if we provide more credit in easiest way to the poor, marginal and small size farmers, they become more efficient in production process. Credit is a useful component to improve the technical efficiency of rice cultivation.

Extension services may have a positive or negative impact on efficiency of the farmers. Because quality extension services could improve the ability of the farmers' to allocate inputs more successfully. Extension services availability and education level were found by Huffman (1977) to be important explanatory variables of the rate of adjustment in fertilizer use in response to price changes.

Land degradation is likely to have a negative effect on efficiency measures. Land degradation is increasing because of more mechanization and unplanned use of chemical fertilizers and pesticides in cultivation. Land degradation is enhanced because of dependency for household fuel on crop residuals and animal dung along with wood, leaves and twigs which, if recycled back to the soils, would reduce the rate of soil erosion, and soil structure degradation (Idris, 1990).

7.5. Cobb-Douglas Stochastic Frontier and Technical Efficiency: Results

The stochastic frontier production model is specified by the Cobb-Douglas production model. A priori, the Cobb-Douglas production model is restricted on the flexibility of functional form of production technology by imposing elasticity of scale to be constant and elasticity of input substitution to be unity. However, to estimate technical efficiency of each farm we need to select a representative functional form. We specify a Cobb-Douglas production function as given in equation (6.10) in Chapter 6. Reviews of the literature on Cobb-Douglas stochastic production frontier and its use in measuring efficiency can be found, for instance, in Schmidt and Lovel (1979); Forsund et. al, (1980); Schmidt (1986); Greene (1993); Battese and Coelli (1995); Gstach (1998); Seyoum et. al., (1998); Son et. al, (1993); Tadesse and Krishnamoorthy, (1997).

For practical purpose we put the empirical Cobb-Douglas stochastic production model as follows:

$$Iny_i = \beta_0 + \sum_{i=1}^{7} \beta_i Inx_i + \xi_i - \zeta_i \quad (7.1)$$

Now, subtracting e^{ξ_i} from both sides of (7.1) yields

$$In\tilde{y}_i = Iny_i - \xi_i = \beta_0 + \sum_{i=1}^{7} \beta_i Inx_i - \zeta_i$$

Where $\tilde{y}_i$ now denotes the farm's observed output adjusted for the stochastic random noise captured by ξ_i. x_1 denotes the total rental value of land utilized for rice cultivation, x_2 represents the total market value of labour used for production, x_3 indicates total plough cost for production. x_4, x_5, x_6 and x_7 are total seed, irrigation, fertilizer and pesticides cost respectively. All of these are presented in the logarithm. ξ_i, are assumed to be independently and identically distributed random errors having normal distribution with mean zero and variance σ_ξ^2 that is, $\xi \sim N(0,\sigma_\xi^2)$ and the technical inefficiency effects, ζ_i, are assumed to be independently distributed of ξ_i such that ζ_i is satisfied by the truncation (at zero from below) of the $N(\mu_{i,}\sigma_\zeta^2)$ where μ_i can be specified and defined as:

$$\mu_i = \delta_0 + \delta_1 z_{i1} + \delta_2 z_{i2} + \delta_3 z_{i3} + \delta_4 z_{i4} + \delta_5 z_{i5} + \delta_6 z_{i6} + \delta_7 z_{i7} \quad (7.2)$$

Where z_i's socio-economic and infrastructural variables which are affects production as well as efficiency of rice producers. The variable z_1 denotes the age of rice producers, z_2 denotes the year of schooling of producers, z_3 indicates rice cultivation experience of rice producer, z_4 represents land fragmentation that is; land plot size, z_5 indicates credit facilities dummy which assumes the value one if farmer takes any kind of credit from government and non-government sources and zero otherwise, z_6 represents extension services dummy which assumes the value one if farmer takes extension services from the related officials and zero otherwise and z_7 denotes the degradation dummy which takes the value one if land is un-degraded and zero otherwise. The value one for z_7 implies that most rice cultivated land of farm households is un-degraded.

7.6. Cobb-Douglas Stochastic Frontier Results

The maximum likelihood estimates of parameters of the Cobb-Douglas stochastic frontier model are obtained using Frontier 4.1 (Coelli, 1996). The sings of the β_i coefficients are all positive as expected and five out of seven coefficients are significant. The highest elasticity of output is for land which indicates that land is the dominant factor of production. Irrigation is the next important input followed by fertilizer. Results are presented in Table 7.4, 7.5 and 7.6 for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together respectively.

7.6.1. Result of the Cobb-Douglas Stochastic Frontier Model for Aman Season (S_1), Boro season (S_2) and both Seasons (S_1+S_2) Together

Table 7.4 shows we have obtained positive β_i coefficients for all seven parameters of aman season (S_1). In aman season (S_1) five coefficients are significant. Significant parameters are land, plough, irrigation, fertilizer and pesticides. Two coefficient such as; labour and seed are positive but insignificant. In field level survey, we have observed some insignificant behaviour for labour and seeds. It shows that there are already abundant supplies of labour in agriculture sector of our survey area like northern Bangladesh. In case of seeds, farmers are used excessive amount of seeds. Therefore, we have some unusual results and behaviours of two coefficients of labour and seeds.

The estimates of the δ_i coefficients associated with the rice producer specific technical inefficiency (TI) effects model is also presented in Table 7.4. We examine whether they have a significant effect on technical inefficiency. The sings of the estimated coefficients of δ_i need to be discussed carefully because variation in technical efficiency of producers arises due to these variables and these are effect the capability of producers to apply the existing technologies properly.

Table 7.4 and 7.5 show that, in our survey area aman season (S_1) and boro season (S_2) the δ_i coefficients from Cobb-Douglas stochastic frontier technical inefficieny (TI) of land fragmentation and land degradation are negative and than significant in both aman season (S_1) and boro seasons (S_2). Two coefficients for technical inefficiency of age and experience are negative and insignificant of both aman season (S_1) and boro seasons (S_2). But there are two coefficients from stochastic Cobb-Douglas frontier TI for years of schooling and credit facilities are positive but insignificant of both aman season (S_1) and boro seasons (S_2).

Table 7.4 and 7.5 exhibited that, in our survey area result from Cobb-Douglas stochastic frontier technical inefficiency (TI) for aman season (S_1) and boro season (S_2), δ_1 and δ_3 coefficients of age and experience are negative and insignificant of both seasons. This implies that the more aged and experienced rice producers are not more technically

Table 7.4 : Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Model for Aman Season (S_1)

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	2.4432	6.5926
Land	β_1	0.1125	5.9513
Labour	β_2	0.2041	2.4737
Plough	β_3	0.4407	3.1399
Seeds	β_4	0.3525	1.8942
Irrigation	β_5	0.4354	5.6698
Fertilizer	β_6	0.5167	4.5145
Pesticides	β_7	0.4326	3.5728
Inefficiency Model			
Constant	δ_0	0.0415	5.1535
Age	δ_1	-0.0089	-1.6415
Years of schooling	δ_2	0.0033	0.3688
Experience	δ_3	-0.0069	-2.5276
Land fragmentation	δ_4	-0.4996	-3.4165
Credit facilities dummy	δ_5	0.0951	0.7803
Extension services dummy	δ_6	-0.0599	-0.5340
Land degradation dummy	δ_7	-0.0253	-3.6159
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1306	3.1304
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.9259	4.1582
	σ_ξ^2	0.0097	
	σ_ζ^2	0.1209	
Log likelihood value		42.2315	

efficient than lower aged and less experienced producers for most of the cases. However new and young rice producers utilize new innovated technologies to increase their production. Some old, aged and experienced producers are conservative and less receptive to newly introduce technology and practices, So they are less efficient. Results of stochastic Cobb-Douglas frontier model (TI) of total aman season, total boro season and total both seasons together are shown in Appendix 7.

Table 7.5 : Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Model for Boro Season (S_2)

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	2.3863	5.1860
Land	β_1	0.2193	6.6461
Labour	β_2	0.6849	2.8674
Plough	β_3	0.3239	3.6088
Seeds	β_4	0.2485	1.6795
Irrigation	β_5	0.7906	5.4596
Fertilizer	β_6	0.3468	3.1320
Pesticides	β_7	0.4594	4.3539
Inefficiency Model			
Constant	δ_0	0.2559	4.9207
Age	δ_1	-0.0072	-1.0417
Years of schooling	δ_2	0.0049	0.3046
Experience	δ_3	-0.0057	-2.3367
Land fragmentation	δ_4	-0.5147	-4.4574
Credit facilities dummy	δ_5	-0.0764	-2.5942
Extension services dummy	δ_6	0.0362	0.4617
Land degradation dummy	δ_7	-0.0305	-4.1059
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1656	5.4656
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.5395	4.1261
	σ_ξ^2	0.0763	
	σ_ζ^2	0.0893	
Log likelihood value		29.2432	

The δ_2 coefficients associated with years of schooling for Cobb-Douglas stochastic frontier technical inefficiency (TI) are positive implying that the farmers with more schooling are more technically inefficient; this is unexpected, but the coefficients are insignificant in both aman season (S_1) and boro season (S_2). This results accords with that obtained for the Indian village of Kanzara by Coelli and Battase (1996). In other words, more formal educated farmers are technically more inefficient. In contrast, less formal educated farmers are comparatively efficient.

Table 7.4 and 7.5 show that, δ_4 coefficient of land fragmentation for technical inefficiency (TI) of rice producers in both aman season (S_1) and boro season (S_2) of our survey area is negative and significant. This indicates that greater plot size provides more efficient for the producers. The better performance of farms with greater plot size is attributed to better application of new technologies like power tillers, tractors, modern irrigation system and other modern equipments (Wadud, 1999). So, the policy implication is that producers could be encouraged to keep their land with greater plot size and therefore, could utilize the benefits of the modern facilities for cultivation, harvesting and irrigation.

The δ_5 coefficients of credit facilities dummy from Cobb-Douglas stochastic frontier technical inefficiency (TI) for aman season (S_1) is positive and insignificant of our survey area and for boro season (S_2) it is negative and insignificant. This implies that it has positive effect on efficiency of rice producers particularly in boro season (S_2). Therefore, if we provide more credits in easiest way to all kinds of marginal and small rice producers, they become more efficient in production process. Credit is a useful component to improve the technical efficiency of rice producers. So, policies in relation to credit facilities should be improved and possibly make available to the rice producers of all crop sectors.

Table 7.4 and 7.5 exhibited that, coefficient of (δ_6) extension services dummy are negative and insignificant of aman season (S_1) but positive in boro season (S_2). This implies that it has a positive effect on efficiency of rice producers in aman season (S_1). As we increase the quality extension services, farmers become able to allocate their inputs more efficiently, and cost of production decreases. So, policy implication is that the quality extension services could be encouraged more to reduce inefficiency.

Table 7.6 : Maximum Likelihood Estimates of the Cobb-Douglas Frontier Model for both Aman and Boro Seasons (S_1+S_2) Together

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	2.2730	6.6228
Land	β_1	0.1214	5.7314
Labour	β_2	0.2136	2.8654
Plough	β_3	0.2947	3.4594
Seeds	β_4	0.4068	2.1307
Irrigation	β_5	0.1313	5.2718
Fertilizer	β_6	0.9571	4.9523
Pesticides	β_7	0.3918	4.2105
Inefficiency Model			
Constant	δ_0	0.4846	5.1620
Age	δ_1	-0.0076	-1.0290
Years of schooling	δ_2	0.0123	0.4072
Experience	δ_3	-0.0059	-2.3992
Land fragmentation	δ_4	-0.4151	-3.3204
Credit facilities dummy	δ_5	0.0798	0.6186
Extension services dummy	δ_6	-0.0918	-0.4188
Land degradation dummy	δ_7	-0.0288	-4.1098
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.6323	4.6248
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.9339	3.3012
	σ_ξ^2	0.0418	
	σ_ζ^2	0.5905	
Log likelihood value		35.2498	

The δ_7 coefficients of land degradation dummy from Cobb-Douglas stochastic frontiers technical inefficiency (TI) are negative and significant of both aman season (S_1) and boro season (S_2). This indicates that the farmers with undegraded land have greater technical efficiency. In this region, top soils degrade through runoff due to heavy rainfall during the rainy season and hence the fertility of soils decreases. The productivity of land depends on soils fertility. So, less soil degradation will increase farms efficiency. Land degradation is not only creates obstacles in applying new technology but also hinders the cost minimizing input utilization in rice production in barind area in northern Bangladesh. More and more degraded lands give more and more inefficiency in production. This result conforms to the result obtained by Wadud and White (2000). Therefore, policies which aim to reduce the land degradation could be applied, so that farmers can enhance their efficiency and as a result, production, revenue and welfare of the farmers could be increased.

7.7. Technical Inefficiency Results

The overall technical inefficiency effects are evaluated in terms of variance parameters σ^2 and the parameters γ reported in Table 7.4, 7.5 and 7.6. The coefficient of the variance parameters σ^2 of aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together of our survey area are 0.13, 0.16 and 0.63, and the parameters γ are 0.92, 0.54 and 0.93 all are highly significant. These indicate that the technical inefficiency effects are a significant component of the total variability of rice producers' output of farm households in northern Bangladesh. This result is consistent with. Coelli and Battese and Sharma et. al., (1996 and 1997).

7.8. Estimated Technical Efficiency of Rice Farms

The estimated farm-specific technical efficiencies (TE) show substantial variability, ranging are between 56 to 98 per cent, 59 to 10 per cent and 57 to 98 per cent of aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together respectively. The mean value of aman season (S_1), boro season (S_2) and both (S_1+S_2) seasons together are 85 per cent, 80 per cent and 87 per cent and with season related standard deviations are 9 per cent, 13 per cent and 8 per cent respectively. The summary statistics of the Cobb-Douglas stochastic frontier for technical efficiency (TE) results are presented in Tables 7.7, 7.8 and 7.9 and Figures 7.7, 7.8 and 7.9 respectively.

7.8.1. Technical Efficiency of Aman (S_1) Season in our Study Area

The frequency distribution of the technical efficiency (TE) estimates of farms in aman season (S_1) and its summary statistics of the Cobb-Douglas stochastic frontier are presented in Table 7.7 and the associated histogram of the efficiency index is also presented in Figure

7.1. Table 7.7 shows that 18.72 per cent farmers are below of 76 per cent technical efficiency index in aman season (S_1). On the other hand, 49 per cent farmers are above 75 per cent and below 91 per cent technical efficiency index in aman season (S_1). Only 32.28 per cent farmer's efficiency score is lies 90-100 per cent technical efficiency index in aman season (S_1). Table 7.7 also shows that on an average efficiency, minimum and maximum efficiency scores and with their standard deviations of aman season (S_1). Average efficiency and with standard deviation of aman season (S_1) are 85.17 per cent and 9.23 per cent.

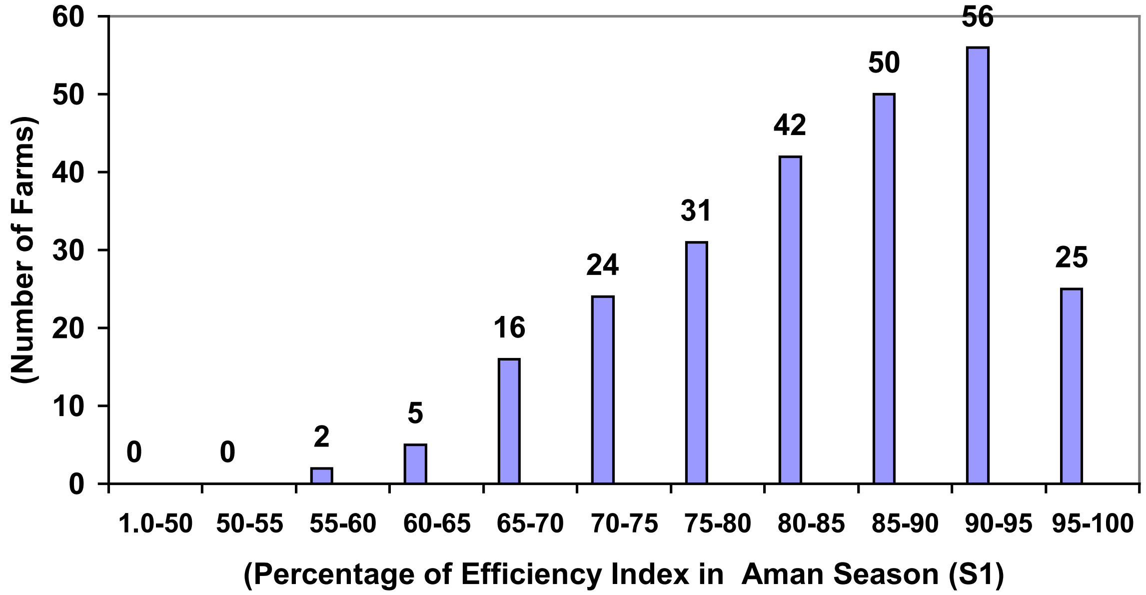
Table 7.7: Frequency Distribution of Farm-Specific Technical Efficiency Estimates from the Cobb-Douglas Stochastic Frontier Model of Aman Season (S_1)

Efficiency index (percentage)	Number of farms	Percentage of farms
1 – 50	0	0
50 – 55	0	0
55 – 60	2	0.80
60 – 65	5	1.99
65 – 70	16	6.37
70 – 75	24	9.56
75 – 80	31	12.35
80 – 85	42	16.73
85 – 90	50	19.92
90 – 95	56	22.32
95 – 100	25	9.96
Total	251	100.00

Summary Statistics of Technical Efficiency of Aman Season (S_1)

Statistics	Technical Efficiency of Stochastic Frontier
Mean	85.17
Minimum	55.73
Maximum	98.22
Standard deviation	9.23

Figure 7.1: Frequency Histogram of Technical Efficiency Index of Aman Season (S_1)



7.8.2. Technical Efficiency of Boro Season (S_2) and both Seasons (S_1+S_2) Together in our Study Area

Table 7.8 and 7.9 show that 36.26 per cent and 10.37 per cent farmers are below 76 percent technical efficiency index of boro season (S_2) and both aman and boro seasons (S_1+S_2) together respectively. On the other hand, 37.04 per cent and 45.02 per cent farmers are above 75 per cent and below 91 per cent technically efficiency index of boro season (S_2) and both seasons (S_1+S_2) together. Only 26.70 per cent and 44.62 per cent farmer's efficiency scores are lie 90-100 per cent technical efficiency index of boro season (S_2) and both aman and boro seasons (S_1+S_2) together. Table 7.8 and 7.9 also show that on an average efficiency, minimum and maximum efficiency scores and with their standard deviations of boro season (S_2) and both aman and boro seasons (S_1+S_2) together. Average efficiency of boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 80.42 per cent and 86.85 per cent and with standard deviations are 13.01 and 8.49 per cent respectively.

Frequency histogram of technical efficiency index for boro season (S_2) and both aman and boro seasons (S_1+S_2) together are explored in Figure 7.2 and 7.3 to have a quick look at technical efficiency index.

Table 7.8: Frequency Distribution of Farm-Specific Technical Efficiency Estimates from the Cobb-Douglas Stochastic Frontier Model of Boro Season (S_2)

Efficiency index (percentage)	Number of farms	Percentage of farms
1 – 50	4	1.59
50 – 55	6	2.39
55 – 60	10	3.98
60 – 65	34	13.55
65 – 70	20	7.98
70 – 75	17	6.77
75 – 80	29	11.55
80 – 85	35	13.94
85 – 90	29	11.55
90 – 95	41	16.34
95 – 100	26	10.36
Total	251	100.00

Summary Statistics of Technical Efficiency of Boro Season (S_2)

Statistics	Technical Efficiency of Stochastic Frontier
Mean	80.42
Minimum	48.73
Maximum	99.93
Standard deviation	13.01

Figure 7.2: Frequency Histogram of Technical Efficiency Index of Boro Season (S_2)

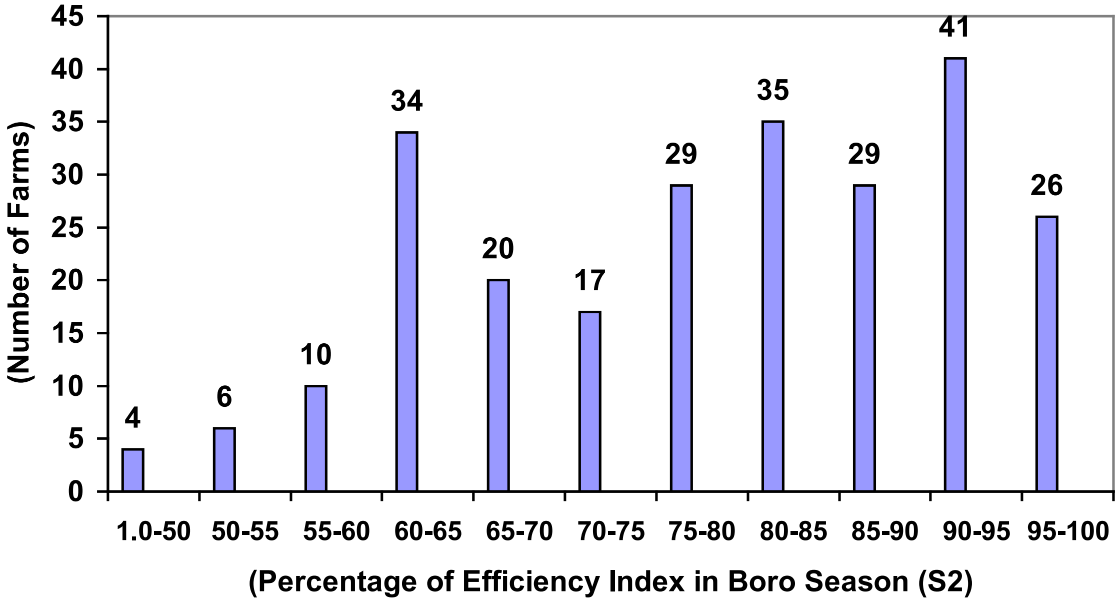


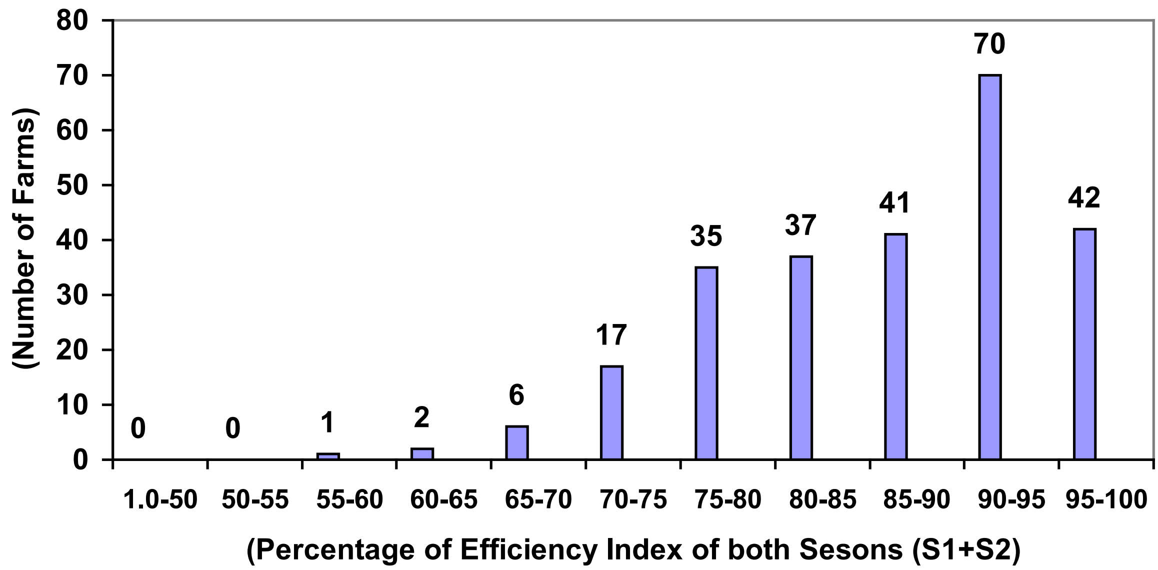
Table 7.9: Frequency Distribution of Farm-specific Efficiency Estimates from the Cobb-Douglas Stochastic Frontier Model of both Seasons (S_1+S_2) Together

Efficiency index (percentage)	Number of farms	Percentage of farms
1 – 50	0	0
50 – 55	0	0
55 - 60	1	0.40
60 – 65	2	0.80
65 – 70	6	2.39
70 – 75	17	6.78
75 – 80	35	13.94
80 – 85	37	14.74
85 – 90	41	16.34
90 – 95	70	27.89
95 – 100	42	16.73
Total	251	100.00

Summary Statistics of Technical Efficiency of both Seasons (S_1+S_2) Together

Statistics	Technical Efficiency of Stochastic Frontier
Mean	86.85
Minimum	57.51
Maximum	98.50
Standard deviation	8.49

Figure 7.3: Frequency Histogram of Technical Efficiency Index of both Seasons (S_1+S_2) Together



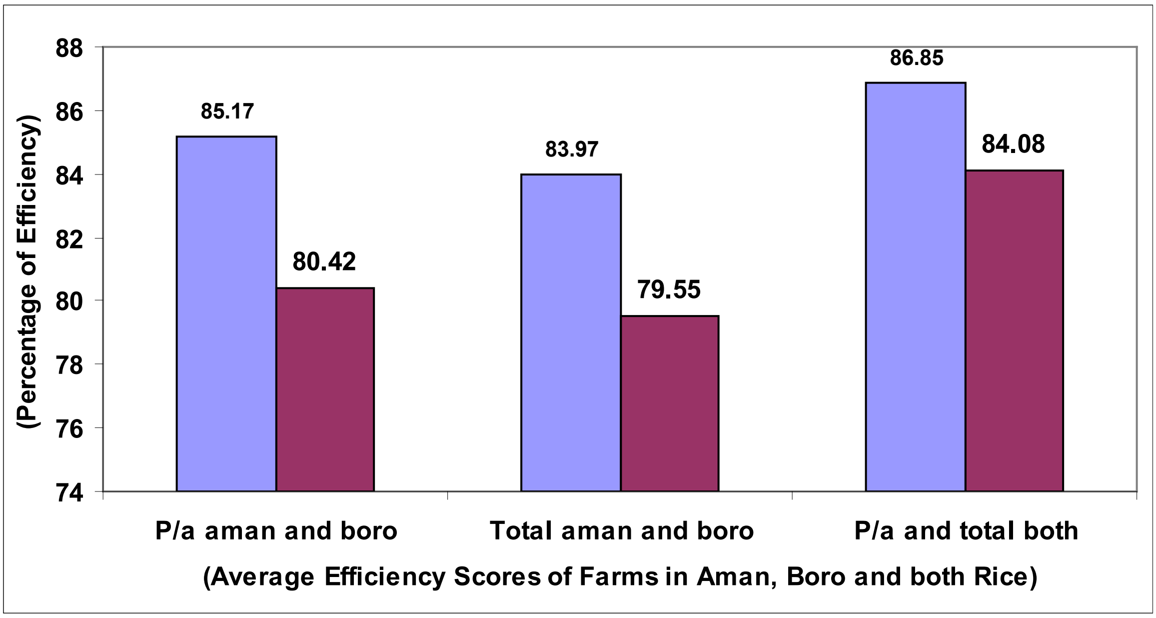
7.8.3. Average Technical Efficiency Index of Farms in per acre, Total and both Aman and Boro Seasons (S_1+S_2) Together in our Study Area

The frequency distribution and summary statistics of the estimated technical efficiency of farms in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) and total aman, total boro and total both rice together are presented in Table 7.10 and Figure 7.4. Table 7.10 shows that the estimated mean or average technical efficiency in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 85.17 per cent, 80.42 per cent and 86.85 per cent and total aman season, total boro season and total both seasons together are 83.97 per cent, 79.55 per cent, 84.08 per cent respectively. This indicates that there is considerable inefficiency in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together in our survey area like in northern Bangladesh and therefore rooms for production gain through efficiency improvement.

Table 7.10: Average Efficiency Index of Farms of Aman, Boro and both Seasons

About Aman seasons	Average efficiency scores	About Boro seasons	Average efficiency scores
Per acre Aman (S_1) season	85.17	Per acre Boro (S_2) season	80.42
Total Aman season	83.97	Total Boro season	79.55
Per acre both seasons (S_1+S_2)	86.85	Total both seasons	84.08

Figure 7.4: Average Technical Efficiency Index of Farms in per acre (P/a) Aman (S_1) and Boro (S_2), Total Aman, Total Boro and Total both Seasons (S_1+S_2) Together



More specifically, it can be said that rice farm households could reduce their production cost by 14.83 per cent, 19.58 per cent and 13.15 per cent for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together if they could operate at full technical efficiency levels respectively. Technical efficiency index of total aman season, total boro season and total both seasons together are exhibit in Appendix 7.2.

The mean or average estimates technical efficiency in aman season (S_1) and total aman, boro season (S_2) and total boro, per acre both seasons (S_1+S_2) and total both aman and boro seasons are exhibits in Table 7.10 and Figure 7.4. We have a comparison of technical efficiency scores between aman season (S_1) and total aman, boro season (S_2) and total boro, per acre both seasons (S_1+S_2) and total both aman and boro seasons. Table 7.10 and Figure 7.4 show that technical efficiency scores are slightly higher in aman season (S_1), total aman and per acre both (S_1+S_2) seasons than that boro season (S_2), total boro and total both aman and boro seasons.

7.9. Summary and Conclusions

We estimate the Cobb-Douglas stochastic frontier production model with technical inefficiency effects model being determined by age, education, experience, plot size or land fragmentation of the rice producers, agricultural credit facilities, extension services and land degradation are applying maximum likelihood single stage estimation methodology. The technical efficiency among the rice producers in our survey area in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together almost similar stochastic frontier and ranges between 50 to100 per cent. The mean or average technical efficiency of aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 85.17 per cent, 80.42 per cent and 86.85 per cent respectively. The minimum efficiency scores of aman season (S_1), boro season (S_2) and both seasons (S_1+S_2) together are 55.73 per cent, 48.73 per cent and 57.51 per cent and the maximum scores are 98.22 per cent, 99.93 per cenr and 98.50 per cent. The technical efficiency scores in aman season (S_1) is slightly high in our survey area. It can be explained that the rice farmers are more serious about aman rice cultivation. As a result, productivity and efficiency of aman season (S_1) is higher than boro season (S_2). About 49.00 per cent, 37.04 per cent and 45.02 per cent rice producers are in aman season (S_1), boro season (S_2) and both aman and boro season (S_1+S_2) in our survey area belong to the technical efficiency scores of 76 to 90 per cent. In our survey area most of the cultivated land is used under rice cultivation and the producers also use more labour, more seed, more fertilizer and more pesticides in rice cultivations. About 14.83 per cent, 19.58 per cent and 13.15 per cent technical efficiency could be improved in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together without any changing or improving cultivation technologies if rice farmers operate at full efficiency scale. So, it is clear that there is some scope to enhance the productivity of rice cultivation as for as efficiency concerned.

The inefficiency effect results of the analysis from Cobb-Douglas stochastic frontiers technical inefficiency (TI) by socio-economic factors exhibit that the lower aged and less experienced farmers are capable of managing inputs efficiently. On the other hand, more educated farmers are more technically inefficient. Less fragmented land gives more opportunity to use modern technology. Better and appropriate land tenure policy will be helpful for the producers to improve efficiency. Credit has a positive effect on efficiency of rice producers. Therefore, if we provide more credit in easiest way to the farmers, they become more efficient in production process. Quality extension services, farmers become able to allocate their inputs more efficiently, and cost of production decreases. Lastly, Land degradation not only creates obstacles in applying new technology but also hinders the cost minimizing input utilization in rice production in our survey area. So, policy makers could think to improve the quality extension services and to the environment of the soil as well as working conditions of the study area.

Chapter 8

Empirical Methodology: Data Envelopment Analysis

8.1. Introduction

This Chapter is introduces Data Envelopment Analysis (DEA) as a methodology that has been used to find estimates of technical efficiency (TE) of the rice farms of Bangladesh. Application of any analytical approach is the art of reckoning. As such, the application of DEA, as a methodology, in a particular study requires knowledge about formulation of data envelopment analysis (DEA) models, choice of variables as well as underlying assumptions, data representations, interpretation of results, and knowledge of limitations, as it is required equally in any study with application of a particular methodology. This Chapter provides some fundamental concepts, methods, related techniques and essential issues of DEA.

Frontiers can be estimated using many different methods. Two principal methods are data envelopment analysis (DEA) and stochastic frontier (SF). DEA involves mathematical programming and SF uses econometric methods. In this chapter we present theoretical concepts of DEA.

The story of DEA begins with Edwardo Rhodes's Ph.D. dissertation research at Carnegie Mellon University's School of Urban and Public Affairs (now the H.J.Heinz III School of Public Policy and Management). Under the supervision of Professor W.W. Cooper, Edwardo Rhodes evaluates an educational program (called Program follow Through) for disadvantage students (mainly black and Hispanic) undertaken in U.S. public schools with support from the Federal Government. In the Program Follow Through, Rhodes tries to estimate the relative technical efficiency of schools involving multiple outputs and inputs. He has recorded the performance of schools in terms of outputs such as "increased self-esteem in a disadvantaged child" and inputs such as "time spent by mother in reading with her child". It is challenging because he has done the job without using the usual information on prices. Charnes, Cooper, and Rhodes (CCR) formulate DEA model by using results of the educational program and publish their first paper introducing DEA in European Journal of Operations Research in 1978. CCR uses the optimization method of mathematical programming to generalize the Farrel (1957) single input /output technical efficiency measures to the multiple-input /multiple-output case by constructing a single "virtual" output to a single "virtual" input relative efficiency measures. Thus, DEA begins as a new Management Science Tool for technical efficiency analysis of public-sector decision-making units (DMUs).

This Chapter is segmented into several sections. Section 8.2 discusses foundation of DEA; Section 8.3 gives DEA frontier; Section 8.4 introduces basic DEA models; Section 8.5 gives parametric SFA versus nonparametric method of DEA; Section 8.6 provides some advantage of DEA model; Section 8.7 describes application of DEA in agriculture; Section 8.8 gives returns to scale and orientations in DEA; Section 8.9 and Section 8.10 provides input and output oriented measures; Section 8.11 and 8.12 describes input and output oriented DEA model; Section 8.13 gives computation of scale efficiency; Section 8.14 describes efficiency measurement and slacks; Section 8.15 discusses estimating the determinants of inefficiency and Section 8.16 gives summary and conclusions.

8.2. Foundation of Data Envelopment Analysis (DEA) Model

In microeconomic theory, the specification of a production function (e.g., Cobb-Douglas or any other forms) determines the description of input-output relationship. The underlying assumptions of such a specification is the existence of transformation technology that determines what maximum amount of outputs can be produced from a combination of various inputs. However, Seiford and Thrall (1990) observed that this description of the production technology would be provided by the production function, if it were known. But in realty, the production function is never known. The analyst has only data-observation about various inputs and their magnitudes and various achieved outputs and their magnitudes. Therefore, the point of departure for DEA is the construction, from the observed data, of a piecewise empirical production frontier (Charnes et. al. 1994). While production function for a fully efficient farm is not known, in practice, Farrell's (1957) suggestion to obtain an efficient production function has been on the point that the production frontier can be estimated from sample data using a nonparametric piece-wise-linear technology (Battese et. al., 1998). Originally, Farrell's approach to estimating efficient unit isoquant has been centered on constructing a free disposal convex hull of the observed input-output ratios by linear programming technique with a subset of sample observations lying on it and rest of the sample lying above it. The production frontier attained in this way provides the boundary of the free disposal convex cone of the data set (Førsund et. al., 1980). Since this procedure involves linear programming model and the process does not include any disturbance term or residual, it can, therefore, be said as 'nonparametric'. Thereafter, the idea of efficiency by Farrell (1957), caught up by Charnes, Coopers, Rhodes (1977) ultimately found its course into development of a self-sufficient separate methodology which for the first time coined the term DEA approach and the methodology has been put forward as CCR (Charnes, Coopers and Rhodes, 1978) ratio form of DEA.

Charnes, Coopers and Rhodes (1978) extended Farrell's (1957) idea by connecting the estimation of technical efficiency and production frontiers. The CCR model generalized the single input /output ratio measures of efficiency for a single farm in terms of fractional linear programming formulation transforming the multiple input /output characterization of each farm to that of a single 'virtual' input and virtual output. The relative technical efficiency of any farm is calculated by forming the ratio of a weighted sum of input to a weighted sum of output, where the weights (multipliers) for both inputs and outputs are to be selected in a manner that calculates the Pareto efficiency measure of each farm subject to the constraint that no farm can achieve a relative efficiency score greater than unity. DEA makes it possible for the data to 'speak for themselves' rather than speak in the idiom of some imposed functional form (such as Cobb-Douglas or Translog or any other functional form). In DEA 'data speak for themselves' means the analysis is focused on maximizing each individual observation, in contrast to fitting a single regression in a plane that is assumed to describe the behaviour of each observation on an average (Charnes et. al. 1994). DEA model is applied to estimate technical efficiency on the basis of the type of data and variables specified in a farm under the industry. Technical efficiency is calculated from quantity data or value data for inputs and outputs. The DEA model expresses either the maximum output for a given level of input or uses minimum input for a given level of output.

8.3. Data Envelopment Analysis (DEA) Frontier

Since Data Envelopment Analysis (DEA) is a linear programming technique that identifies the apparent best 'production unit' of outputs of farms (DMUs) by their ability to produce the highest level of outputs with a given set of inputs or to produce given outputs with the least amount of inputs, therefore it is possible to draw a frontier of the best production units relative to other production units of outputs.

Suppose that there are *n* farms engaged in production and every farm utilizes *q* inputs to produce *r* outputs. The *ith* farm uses $x_i = \{x_{ki}\}$ of inputs (k = 1,2,3,....,q) and produces $y_i = \{y_{mi}\}$ of outputs (m = 1,2,3,....,r). Suppose that $x_{ki} > 0$ and $y_{mi} > 0$. The ($k \times n$) input matrix is denoted by X and the ($m \times n$) output matrix is denoted by Y for all n farms. The column vector x_i and y_i represent inputs and outputs for the *ith* farm respectively. Therefore, the DEA frontier can be written as:

$$F(y_1, y_2, y_3, ..., y_r) = \{(x_1, x_2, x_3, ..., x_q)$$

$$y_{mi} \le \sum_{i=1}^{n} \varpi_i Y_{mi}$$

$$x_{ki} \ge \sum_{i=1}^{n} \varpi_i x_{ki}$$

$$\varpi_i \ge 0; \quad \sum_{i=1}^{n} \varpi_i = 1\}$$

Where $\varpi = (\varpi_1, \varpi_2, \varpi_3, ..., \varpi_n)$ is an intensity vector that forms convex combinations of observed input and output vectors and represents the percentage of other farms used to construct the virtual efficient farm. For example, if the efficient farm *A* is competent of producing output $y_{(A)}$ using input $x_{(A)}$, then other farms should as well be competent of producing in the same production schedule. Likewise, if the efficient farm *B* produces output $y_{(B)}$ using input $x_{(B)}$, then the other farm should again be able to produce in the same production schedule if the farms were to produce efficiently. Farms A, B and others can be combined to form a composite farm with composite output and inputs. Since this composite farm does not necessarily exist, it is sometimes called "virtual farm".

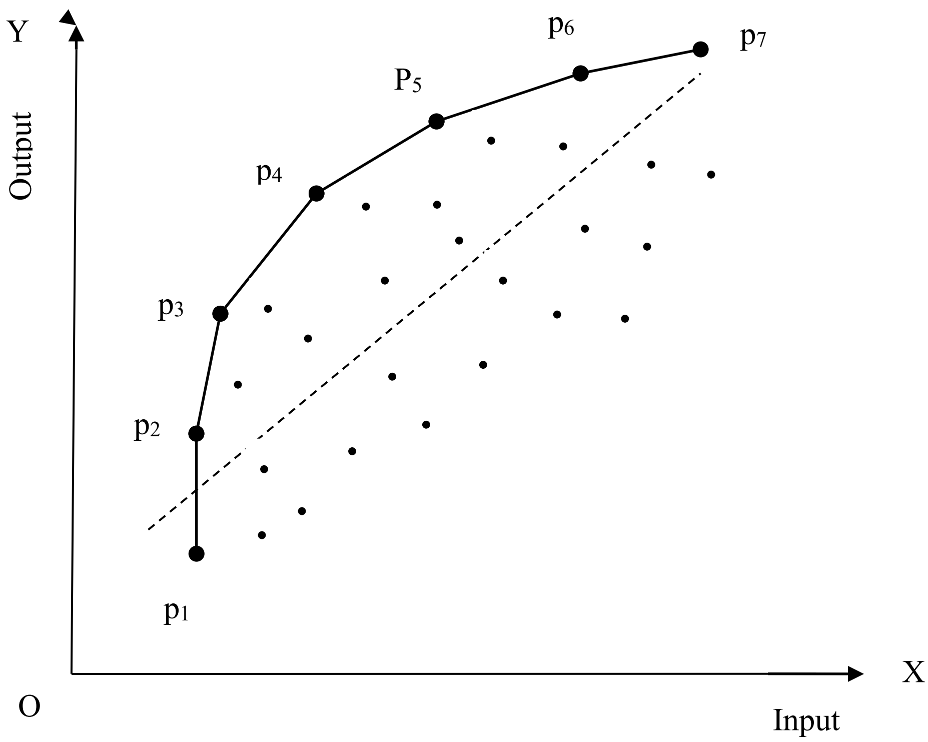
8.4. Basic Data Envelopment Analysis (DEA) Model

Charnes et. al.. (1978) proposes a model on the basis of input-orientation under constant returns to scale (CRS) assumption. This model is popularly known as CCR ratio model (1978). The model yields an objective evaluation of overall efficiency. Subsequent developments in DEA consider alternative sets of assumptions, such as variable returns to scale (VRS) model which has been initiated by Bankers et al. (1984). This model is known as BCC model (1984). The model distinguishes between technical and scale inefficiencies by estimating pure technical efficiency at the given scale of operation and identify whether the operation is on increasing or decreasing, or constant returns to scale.

8.5. Parametric SFA Versus Nonparametric Method of DEA-a Comparison

Data Envelopment Analysis methodology has some basic difference from the regression methodology. DEA involves an alternative principle for extracting information about a population of observations. In contrast to parametric approaches whose objective is to optimize a single regression plane through data. DEA optimizes on each individual observation with an objective of calculating a discrete piece-wise frontier determined by the set of Pareto-efficient decision making units (DMUs or farms). Both parametric and nonparametric (mathematical programming) approaches use all information contained in data. In parametric analysis, the single optimized regression equation is assumed to apply to each farm. In contrast, DEA optimizes the performance of each farm. The focus of DEA is on the individual observation as presented by *n* optimizations (one for each observation) required in DEA analysis, in contrast to the focus on the advantage and estimation of parameters that are associated with single-optimization statistical approaches.

Figure: 8.1: Parametric Regression Line and Nonparametric DEA



The parametric approach requires the imposition of a specific functional form (e.g., a regression equation, a production function, etc.) relating the independent variables to the dependent variables. The functional form selected also requires specific assumptions about the distribution of the error terms (e.g., independently and identically normally distributed) and many others restrictions, such as factors earning the value of their marginal product. In contrast, DEA does not require any assumption about the functional form. DEA calculates a maximum performance for each farm relative to all other farms in the observed population with the sole requirement that each farm lies on or below the frontier.

The solid line in Figure 8.1 represents a frontier derived by DEA data on population of farms, each utilizing different amounts of a single-input. It is pertinent to note that the DEA calculations produce only relative efficiency measures since DEA points are generated from actual observed data for each farm. The relative efficiency of each farm is calculated in relation to all the other entire farms, using the actual observed values for the outputs and inputs of each farm. The DEA calculations are devised to maximize the relative efficiency score of each farm, subject to the condition that the set of weights obtained in this manner for each farms, essentially be feasible for all the other farms included in the calculation.

More precisely, DEA produces a piecewise empirical external production surface (e.g., the solid line in Figure 8.1 drawn by the points $p_1, p_2, p_3, p_4, p_5, p_6, p_7$), which in economic terms represents the revealed best practice production frontier. The maximum output empirically obtainable from any farm in the observed population, given its level of inputs.

It is to note that, the foremost shortcoming of DEA is that it is deterministic and assumes a zero value for the stochastic random error component. Hence, technical efficiency measure is liable for reflection of all unexplained variations of population and the inefficiency of the observed producer is biased upward (Wadud, 2006).

Charnes, Cooper and Rhodes (1978) extend Farrell's (1957) idea linking the estimation of technical efficiency and production frontiers. The CCR (Charness, Cooper and Rhodes) model generalized the single input /output ratio measures of efficiency for each single farm. The fractional linear-programming formulation is used for transforming the multiple input /output characterization of each farm to a single "virtual" output and "virtual" input. The relative technical efficiency of any farm is calculated by forming the ratio of a weighted sum of inputs to a weighted sum of outputs subject to the constraint that no farm can have a relative efficiency score greater than unity.

For each inefficient farm (one that lies below the frontier), DEA identifies the sources and level of inefficiency for each farm of the inputs and outputs. The level of inefficiency is determined by comparison to a single referent farm or a convex combination of other referent farms located on the efficient frontier that utilizes the same level of inputs and produces the same or higher level of outputs.

8.6. Some Advantage of Data Envelopment Analysis Model

Data Envelopment Analysis (DEA) can handle multiple inputs and multiple outputs model while it does not require an assumption of a functional form relating to inputs and outputs to calculate technical efficiency. DEA methodology only requires information on output and input quantities (not prices). This makes DEA particularly suitable for analyzing the efficiency of farms where it is difficult to assign prices to inputs.

Under DEA methods farms are directly compared against a peer or combination of peers. Inputs and outputs can have very different units but it is not a problem for DEA. For example, X_1 could be in units of lives saved and X_2 could be in units of dollars without requiring an *a priori* tradeoff between the two. DEA focuses on individual observations in contrast to population averages. It produces a single aggregate measure for each farm in terms of its utilizations of input factors as independent variables to produce desired outputs as dependent variables. DEA can simultaneously utilize multiple inputs sand multiple outputs with each being stated in different units of measurement. It can be found for exogenous variables and can incorporate categorical or dummy variables. Thus DEA calculations do not require specification or knowledge of a *priori* weights or prices for the inputs or outputs or about units. DEA can accommodate judgment when desired. This can produce specific estimates for desired changes in inputs and /or outputs for projecting farms below the efficient frontier onto the efficient frontier. It allows technical inefficiency to be decomposed into scale effects, the effects of unwanted inputs, which the farm can not dispose of.

Moreover, DEA calculations are considered as Pareto optimal. DEA calculation focuses on revealed 'best-practice' frontiers rather than on central tendency properties, and DEA computation satisfies strict equity criteria in the relative evaluation of each decision-making unit (DMU).

8.7. Application of Data Envelopment Analysis (DEA) in Agriculture

Data Envelopment Analysis (Charnes et. al., 1978; Fare et. al., 1985, 1994) is used to derive technical, allocative, economic and scale efficiencies measure. DEA approach to frontier estimations have been developed almost independently of the stochastic frontier literature in the late 1970s. Only a small percentage of agricultural frontier applications have used the data envelopment analysis (DEA) approach to frontier estimation. This is, in one sense, surprising, given the popularity of mathematical programming methods in other areas of agricultural economics research during the 1970s. However, DEA has largely used in other professions especially in management science and applications to service industries where there are multiple outputs, such as banking, health, telecommunications and electricity distribution. The DEA approach suffers from the criticism that it takes no account of the possible influence of measurement error and other noises in data. On the other hand, it has advantage of removing the necessity to make arbitrary assumptions regarding the functional form of the frontier and the distributional form of the u_i.

8.8. Returns to Scale and Orientations in DEA

The choice of DEA model depends on two basic issues. The first is whether the problem formulation justifies an assumption of constant returns to scale (CRS) or variable returns to scale (VRS) in production. And the second is whether the problem formulation is oriented towards output maximization or input minimization, or on equal emphasis on inputs and output. For details in both input minimization and output maximization models reviews can be found in Ali and Seiford, Fried and Schmidt, (1993).

8.8.1. Charnes, Cooper and Rhodes (CCR) Model

The CCR (ratio) model is probably the most widely used and best-known DEA model. It is named after Charnes, Coopers and Rhodes (CCR) (1978) who first introduced it. This DEA model is used when a constant returns to scale relationship is assumed between inputs and outputs. This model calculates the overall efficiency for each unit, where both pure technical efficiency and scale efficiency are aggregated in one value. As the model assumes constant returns to scale (CRS) it is referred to as CRS DEA model. It can be noted that the CCR model yields the same efficiency score regardless of whether it is input or output oriented.

8.8.2. Banker, Charnes and Cooper (BCC) Model

When a variable returns to scale relationship is assumed between inputs and outputs the BCC DEA (ratio) model is used. It is named after Banker, Charnes and Cooper (1984: 1078-1092) who first introduced it. The BCC model measures technical efficiency. The convexity constraint in the model formulation ensures that the composite unit is of similar scale size as the unit being measured. The efficiency score obtained from this model gives a score, which is at least equal to the score obtained using the CCR model. As the model relaxes the assumption of CRS to variable returns to scale (VRS), hence it is referred to as VRS DEA model. The VRS DEA model is different from CES DEA model in that the VRS DEA envelopes data more strongly, thus producing technical efficiency estimates greater than or equal to that obtained from the CRS DEA.

Table 8.1: DEA Model

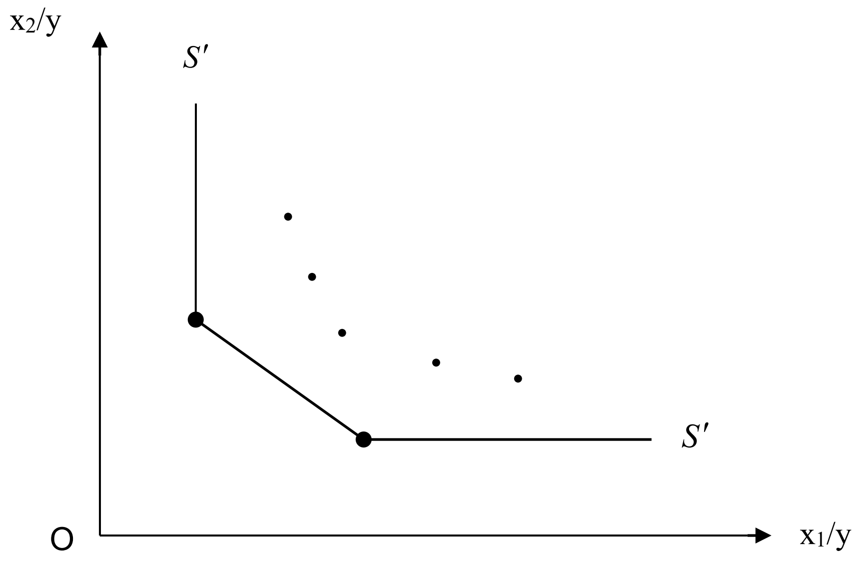
Assumptions of Returns to Scale	Orientations	
Constant Returns to Scale (CRS)	Input-Orientation	Output-Orientation
Variable Returns to Scale (VRS)	Input-Orientation	Output-Orientation

Sources: Charnes et al., 1994

8.9. Input-Oriented Measures

Input-oriented CRS DEA model has been described here first because this model is applied in the preliminary stage of DEA initiation.

Figure 8.2: Piecewise Linear Convex unit Isoquant

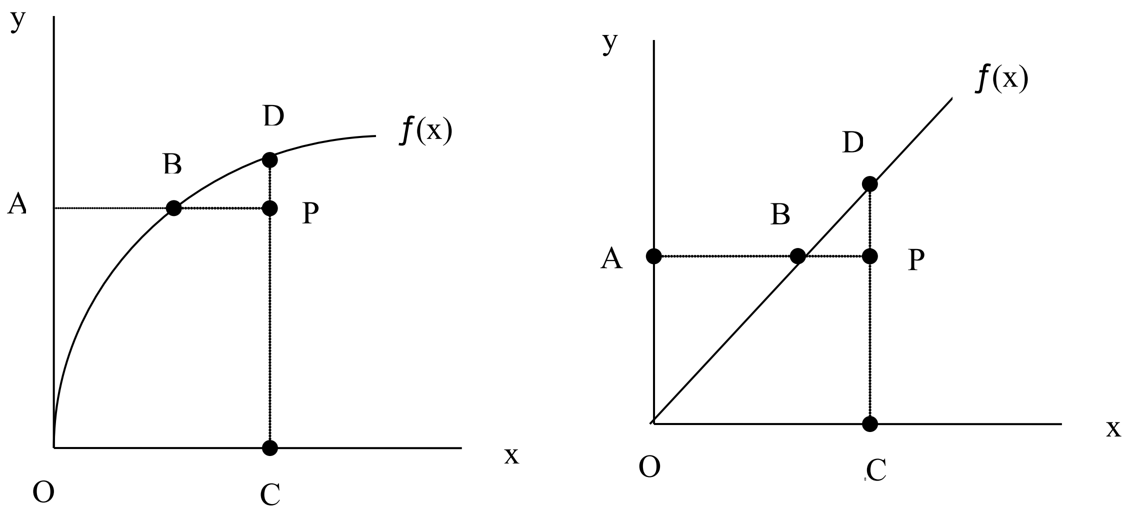


The efficiency measure only assumes that the production function of the fully efficient farm is known whereas the fully efficient production frontier of a farm is never known (Coelli, 1998). Instead, for obtaining an efficient isoquant, according to Farrell (1957), a non-parametric piece-wise-linear convex isoquant could help construct production frontier from sample data so that no observed point should lie to the left or below it as shown in Figure 8.2. Farrell (1957) has also made an illustration of the method using agricultural data for the 48 continental states of US. The above mentioned efficiency measures have been defined in the context of the assumptions of constant returns to scale technology. The measures of technical efficiency can be equivalently defined for the non constant returns to scale case. To explain technical efficiency under non constant returns to scale case, Figure 8.3 can be adjusted by changing the axes labels x_1 and x_2 with the assumptions that the isoquant represents the lower bound of the input set related with the production of a particular level of output. The efficiency measures are then defined comparably to the previous measures as in Chapter 6 Figure 6.2. The above input-oriented technical efficiency measure deals with the question that by how much input quantities can be proportionally reduced without changing the output quantities produced. Ultimately solution of this question gives rise to input-oriented technical efficiency measures.

8.10. Output-Oriented Measures

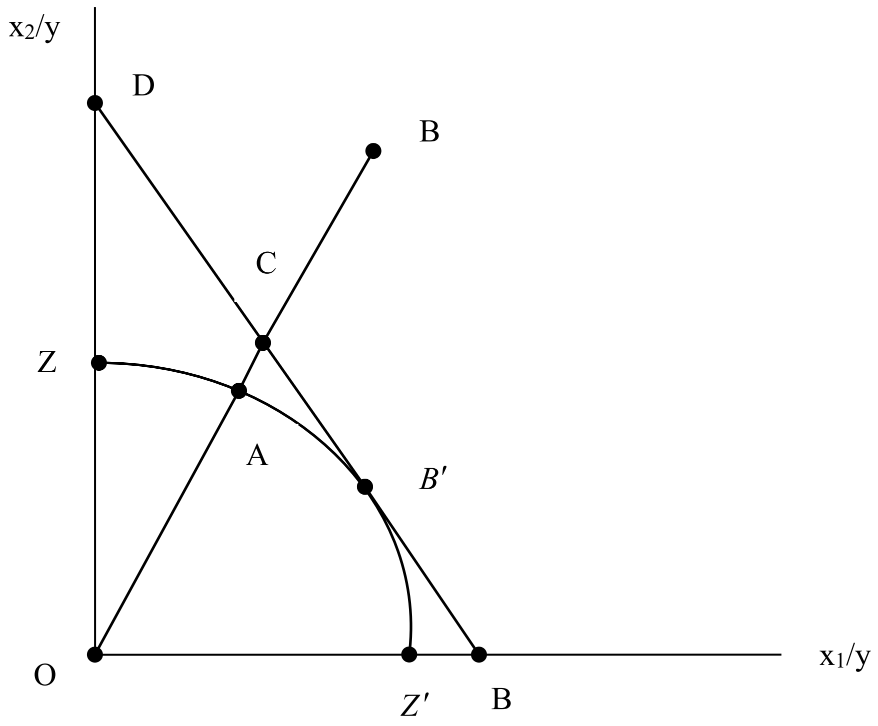
The above input oriented production efficiency can be put forward by a different question. That is, one can ask, "By how much can output quantities be proportionally expanded without altering the input quantities used?" This question gives rise to the issues of output-oriented measure as against the input oriented measure. The difference between input and output orientation measures can be explained using a simple graph with an example of one input and one output where a decreasing return to scale technology has been shown by *f(x)*, and an inefficient farm operating at point *P*. This is shown in Figure 8.3. According to Figure, Farrell's (1957) input-oriented technical efficiency measure would be equal to ratio *AB/AP*, while the output-orientation measure of technical efficiency would be *CP/CD*. The output-oriented and input-oriented measure will only provide equivalent measures of technical efficiency when constant returns to scale is present, but would be unequal when increasing or decreasing returns to scale are present (Fare and Lovell, 1978). The case of constant returns to scale is depicted in Figure 8.3 where it is observed that *AB/AP* = *CP/CD*, for any inefficient point *P*.

Figure 8.3: Input-oriented and Output-oriented Technical Efficiency Measures and Returns to Scale



It can further be considered with output-oriented measure where production involves two outputs (say, y_1 and y_2) and a single input (*say,* x_1). This illustration is portrayed in Figure 8.4 where the line ZZ' is the unit production possibility curve and the point *A* corresponds to an inefficient farm. It can be noted that, the inefficient point, *A* lies below the curve in this case because ZZ' represents the upper bound of production possibilities.

Figure 8.4: Technical Efficiency from an Output-Orientation



Farrell's (1957) output-oriented efficiency measures (Färe, Grosskopf and Lovell, 1985, 1994) would be defined as follows: In Figure 8.4, distance *AB* represents technical inefficiency. That is, the amount by which outputs could be increased without requiring extra input. Hence a measure output-oriented technical efficiency is the ratio:

$$TE_0 = OA/OB \tag{8.1}$$

It can be noted that the technical efficiency measure is bounded by zero and one. It can also be observed that the output-oriented technical efficiency measure is exactly equal to the output distance functions (Shepherd, 1970). Details can be found in Lovell (1993), Färe and Primont (1995). Further, it can be mentioned here that technical efficiency has been measured along the ray from the origin to the observed production point. Therefore, it holds the relative proportions of inputs (or outputs) constant. One advantage of the radial efficiency measure is that it is unit invariant. That is, changing the units of measurement does not change the value of the efficiency measure. For example, one can measure quantity of labour in per man-day instead of hours.

8.11. Input-Oriented Model

8.11.1. Input-Oriented Constant Returns to Scale (CRS DEA) Model

Suppose there are data on *k* inputs and *m* outputs for each of *n* farms. For the *ith* farm these are represented by the column vectors x_i and y_i, respectively. The $k \times n$ input matrix. *X*, and the $m \times n$ output matrix, *Y* represent the data for all *n* farms. A way to introduce DEA is via the ratio form. For each farm, to obtain a measure of the ratio of all outputs over all inputs, such as $u'y_i / v'x_i$, where *u* is an $m \times 1$ vector of output weights and *v* is a $k \times 1$ vector of input weights obtained by solving the mathematical programming problem:

$$\max_{u,v} (u'y_i / v'x_i \tag{8.2}$$

$$\text{subject to} \quad u'y_j / v'x_j \leq 1, \quad j = 1, 2, 3, ..., n,$$

$$u, v \geq 0$$

This involves finding values for *u* and *v*, such that the efficiency measures for the *ith* farm is maximized, subject to the constraints that all efficiency measures must be less than or equal to one. One problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this, one can impose the constraint $v'x_i = 1$, which provides:

$$\max_{u,v} (u'y_i), \tag{8.3}$$

$$\text{subject to} \quad v'x_i = 1,$$

$$u'y_j - v'x_j \leq 0, \quad j = 1, 2, 3, ..., n,$$

$$u, v \geq 0$$

where, the change of notation from *u* and *v* to μ and *v* is used to stress that this is a different linear programming problem. The form in equation (8.3) is known as the multiplier form of the DEA linear programming problem.

Using the duality in linear programming, an equivalent envelopment form this problem can be derived:

$$\min_{\theta,\lambda} \theta \qquad (8.4)$$

$$\begin{aligned} \textit{subject to} \quad & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & \lambda \geq 0, \end{aligned}$$

Where, θ is a scalar constant and λ is $n \times 1$ vector of constant. This envelopment form involves fewer constraints than the multiplier form ($k + m < n + 1$) and thus is generally the preferred form to solve. However, the multiplier form has been used in a number of studies. The value of θ obtained would be efficiency score for the *ith* farm. It satisfies $\theta \leq 1$, with the value of 1 indicating a point on the frontier and thus a technically efficient farm according to Farrell's definition. It should be noted that the linear programming problems must be solved *n* times, once for each farm in the sample. *A* value of θ is then obtained for each farm.

The DEA problem given in equation (8.3) takes the *ith* farm and then seeks to radially contract the input vector, x_i, as much as possible, whilst still remaining within the feasible input set. The radial contraction of the input vector, x_i, produces a projected point, ($X\lambda$, $Y\lambda$), on the surface of this technology. This projected point is a linear combination of these observed data points. The constraints of equation (8.4) occur that this projected point can not lie outside the feasible set.

8.11.2. Input-Oriented Variable Returns to Scale (VRS DEA) Model

Imperfect competition, constraints on financial support, etc. may causes a farm to be not operating at optimal scale whereas in CRS DEA model farms are assumed to be operating at optimal scale. In such a circumstance, Banker, Charnes and Cooper (1984) have put forward an extension of CRS DEA model to explain variable returns to scale situation. Since the measures of technical efficiency under CRS specification is likely to generate scale efficiency if farms are not operating at optimal scale. The introduction of VRS specification permits technical efficiency to be free from scale efficiency effects. This has been done in the following way:

The CRS linear programming problems have been modified to explain for VRS by adding convexity constraint: $NI`\lambda = 1$ to equation (8.4) to provide:

$$\min_{\theta,\lambda} \theta, \qquad (8.5)$$

$$subject\ to \qquad -y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

Where, *NI* stands for an $n \times 1$ vector of one's of the model. This method gives a convex hull of intersecting planes which envelope the data point more tightly than the CRS conical hull. This gives technical efficiency scores which are greater than or equal to those obtained by using the CRS model.

Calculation of scale efficiency measures are, naturally, only relevant when specifying variable returns to scale frontier. Specifically, scale inefficiency is due to either decreasing or increasing returns to scale. Since no assumptions are made about the technologies of the observations, it is important to ask what the scale properties of the observations are. Rather, it is important to ask about scale properties of points on the frontier (Førsund and Hernacs, 1995).

8.12. Output-Oriented Model

In the preceding input-oriented models, the method seeks to identify technical inefficiency as a proportional reduction in input usage, with output level held constant. This corresponds to Farrell's input-based measure of technical inefficiency. It is also possible to measure technical inefficiency as a proportional increase in output production, with input levels held constant. The two measures provide the same value under CRS but different values when VRS is assumed. Given that linear programming does not suffer from such statistical problems as simultaneous equation bias, the choice of an appropriate orientation is not crucial as in case of econometric estimation. In a number of studies, analysis has tended to select input-oriented models because many farms have particular orders to fill and hence the input quantities appear to be the primary decision variables, although this argument may not be as strong in all sectors. In some sectors, farms may be given a fixed quantity of resources and asked to produce as much output as possible. In this case, an output-orientation would be more appropriate. More importantly, one should select the orientation according to which quantities (inputs or outputs) the manager have most control over. Furthermore, in many instances, the choice of the orientation has only a minor influence upon scores obtained (Coelli and Perelman,1996).

8.12.1. Output-Oriented Constant Returns to Scale (CRS DEA) Model

The output-Oriented DEA model implies how much amounts of output can be proportionally expanded without any change in quantity of inputs. We may formulate CRS output-oriented problem in ratio form by considering the ratio of virtual input to virtual output as follows:

$$\min\left(\sum_{k=1}^{q} v_k x_{ki} / \sum_{m=1}^{r} \vartheta_m y_{mj}\right)$$

$$\textit{subject to} \qquad \left(\sum_{k=1}^{q} v_k x_{kj} / \sum_{m=1}^{r} \vartheta_m y_{mj}\right) \geq 0$$

$$\vartheta_m \geq 0, \quad for\ m = 1,2,....,r$$

$$v_k \geq 0, \quad for\ k = 1,2,....,q$$

Scaling the denominator of the objective function equal to unity, we obtain the linear programming problem as follows:

$$\min\left(\sum_{k=1}^{q} v_k x_{ki}\right)$$

$$\textit{subject to,} \qquad \sum_{m=1}^{r} \vartheta_m y_{mj} = 1$$

$$\sum_{k=1}^{q} v_k x_{kj} - \sum_{m=1}^{r} \vartheta_m y_{mj} \geq 1$$

In matrix notation,

$$\min imise_{\theta'\vartheta} \quad \theta' x_i$$

$$\textit{subject to,} \qquad \vartheta y_i = 1$$

$$\theta_i^{/} x_j - \vartheta y_j \geq 0$$

$$\vartheta \geq 0 \text{ and } \theta_i^{/} \geq 0$$

The corresponding dual function may be written as follows:

$$\max imise_{\varphi_i^{0,CRS},\omega} \ \varphi_i^{0,CRS} \tag{8.6}$$

$$\begin{aligned} & -\varphi_i^{0,CRS} y_i + Y\omega \geq 0 \\ \textit{subject to,} \quad & x_i - X\omega \geq 0 \\ & \omega \geq 0 \end{aligned}$$

where $\varphi_i^{0,CRS}$ is a scalar which measures farm-specific efficiency under the output-oriented CRS method; $\varphi_i^{0,CRS} = 1$ indicates that the farm is efficient and lies on the frontier and $\varphi_i^{0,CRS} \langle 1$ implies that the farm is inefficient and lies outside the frontier.

8.12.2. Output-Oriented Variable Returns to Scale (VRS DEA) Model

The output-orientation is very similar to its input-orientation counterpart. The following is an example of output-orientated VRS model:

$$\max_{\phi,\lambda} \ \phi_i^{VRS} \tag{8.7}$$

$$\begin{aligned} \textit{subject to,} \quad & -y_i + Y\lambda \geq 0 \\ & \phi x_i - X\lambda \geq 0 \\ & NI'\lambda = 1 \\ & \lambda \geq 0 \end{aligned}$$

where ϕ is the proportional increase in output that could be achieved by the *ith* farm, with input quantities held constant. Output-oriented and input-oriented models will estimate exactly the same frontier and therefore, by definition, identify the same set of farms as being efficient. It is only the efficient measures associated with the inefficient farms that may differ between the two methods. It is observed that the two measures provide equivalent values under constant returns to scale. The output-oriented VRS model gives technical efficiency scores greater than or equal to those achieved from the CRS model.

8.13. Computation of Scale Efficiencies

Many studies have decomposed the TE scores obtained from a CRS DEA into two components, the first is scale inefficiency and the other is 'pure' technical inefficiency.

When farms are operating at optimal scale, under the assumptions of CRS DEA, there exists no concept of scale inefficiency. But when the production technology is VRS, it is possible to obtain a scale efficiency measure for each farm. The measure of scale efficiency can be obtained by carrying out operations for both a CRS DEA TE score and a VRS DEA TE score. If there is a difference between the two TE scores for a particular farm, then it indicates that the farm has scale inefficiency. This scale inefficiency can be derived from the difference between the VRS TE score and the CRS TE score. Measures of scale efficiency for each rice farm can be obtained by solving both the CRS and VRS DEA. Technical inefficiency scores from the CRS DEA (CRS TI) thus, can be decomposed into pure technical inefficiency (VRS TI) and scale inefficiency. The CRS TI is greater than that of VRS TI the difference in the CRS and VRS technical inefficiency scores for a particular rice farm provides a measure of scale inefficiency.

This scale efficiency measure itself does not indicate whether the farm is operating at increasing or decreasing returns to scale. The presence of potential economies of scale at any input can only be determined by solving a DEA problem with imposition of additional constraint on non increasing returns to scale (NIRS) condition. Therefore, finding efficiency scores for the CRS, VRS and NIRS frontiers are very important.

The scale efficiency score obtained for each farm from the three DEA frontiers (CRS, VRS and NIRS) can be ordered relative to each other and this ordering provides information regarding existence of the types of scale economies at any observed output. The CRS, VRS and NIRS technologies are explained in Figure 8.5. In an input-oriented framework, the CRS approach measures the input-oriented technical inefficiency of the farm operating at point *D* by the distance *BD*. However, the VRS approach estimates technical inefficiency as *CD*, which is smaller than the technical inefficiency *BD* from the CRS approach since the VRS approach envelops the data more closely. The difference, *BC*, measures scale inefficiency ($(SE_i^{input,CRS}$).

These notions can be expressed as:

$$TE_i^{input,CRS} = \frac{AB}{AD}$$

$$TE_i^{input,VRS} = \frac{AC}{AD} \qquad (0 \le TE_i^{input,VRS} \le 1)$$

and:

$$SE_i^{input} = \frac{AB}{AC}. \quad (0 \le SE_i \le 1)$$

Again it can shown that,

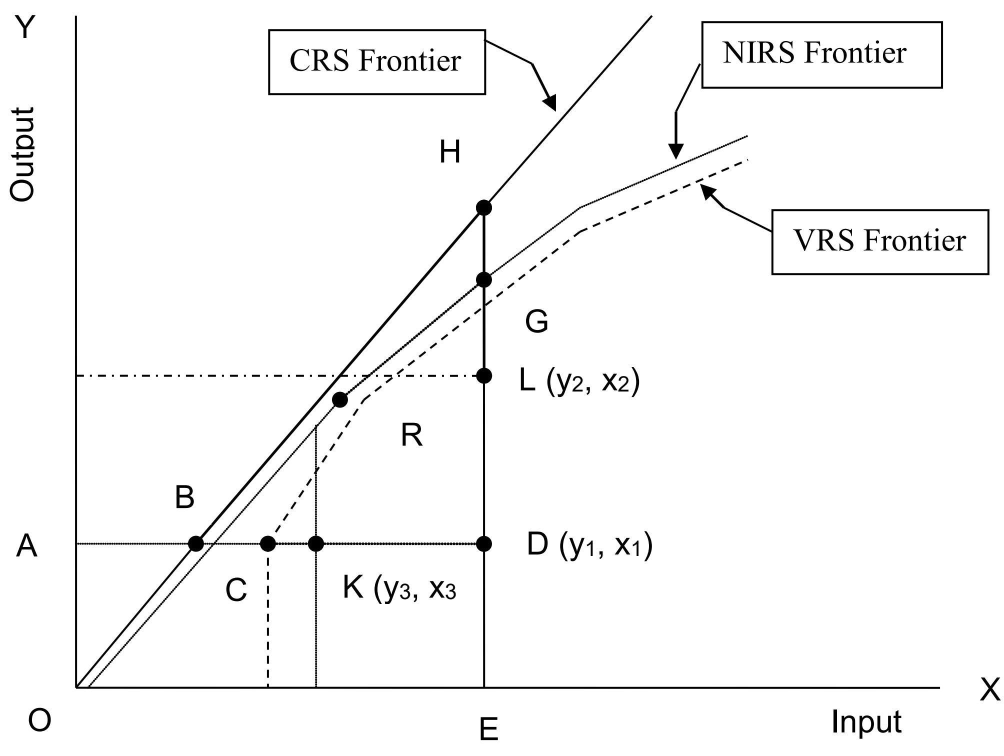
$$TE_i^{input,VRS} \times SE_i^{input} = \frac{AC}{AD} \times \frac{AB}{AC} = \frac{AB}{AD} TE_i^{input,CRS}$$

$$\therefore \qquad TE_i^{input,CRS} = TE_i^{input,VRS} \times SE_i$$

That is, the CRS TE measure is decomposed into 'pure' technical efficiency and scale efficiency. Therefore,

$$SE_i^{input} = \frac{TE_i^{input,CRS}}{TE_i^{input,VRS}} \tag{8.8}$$

Figure 8.5: Estimation of Scale Economies in DEA



For the farm (y_1, x_1) at point *D*, the CRS and NIRS technologies provide the same measure of efficiency scores, but the VRS technology yields a higher level indicating that the VRS technology envelops the data more closely than the CRS and NIRS technologies at output vector y_1. So increasing returns to scale (IRS) prevails. If we consider the farm (y_2, x_2) at point *L*, the efficiency measures are equal relative to both the VRS and NIRS technologies, but lower for the CRS technology, which implies that the CRS technology does not envelop the data as closely as the other two predicting decreasing returns to scale (DRS) at output vector y_2.

In an output-oriented framework, the CRS DEA estimates technical inefficiency of the farm operating at *D* is measured by the distance *DH* and the VRS by the by the distance *DG*. The distance *GH* is due to scale inefficiency SE_i^{out}.

Therefore the measures of efficiency are:

$$TE_i^{output,CRS} = \frac{ED}{EH}$$

or

$$TE_i^{output,VRS} = \frac{ED}{EG}$$

$$SE_i^{output} = \frac{EG}{EH}$$

Again in supplement:

$$\therefore \quad TE_i^{output,CRS} = TE_i^{output,VRS} \times SE_i^{output}$$

or

$$SE_i^{output} = \frac{TE_i^{output.CRS}}{TE_i^{output.VRS}} \tag{8.9}$$

The scale efficiency itself does not indicate if decreasing or increasing returns to scale exist. The presence of potential economies of scale at any input is predicted by observing the order of efficiency scores of CRS, VRS and NIRS frontiers.

Consider the farm (y_1, x_1) at point *D* in Figure 8.5 where measures of efficiency are equivalent for both VRS and NIRS technologies, but less for CRS technology. This shows that CRS technology does not envelops the data as closely as the other two technologies at input x_1 and hence DRS exist. Now consider the farm (y_3, x_3) at point *K* where the efficiency measures are equivalent for both the CRS and NIRS technologies, but greater relative to the VRS technology. This implies that the VRS technology envelops the data more closely than the other two technologies at input vector x_3 and thus IRS exist.

To summarize:

Input orientation: $TE_i^{input.CRS} \leq TE_i^{input.NIRS} \leq TE_i^{input.VRS}$

Output orientation: $TE_i^{output.CRS} \leq TE_i^{output.NIRS} \leq TE_i^{output.VRS}$

For both orientations: $TE_i^{NIRS} < TE_i^{VRS}$ implies IRS

$TE_i^{CRS} < TE_i^{NIRS}$ implies DRS

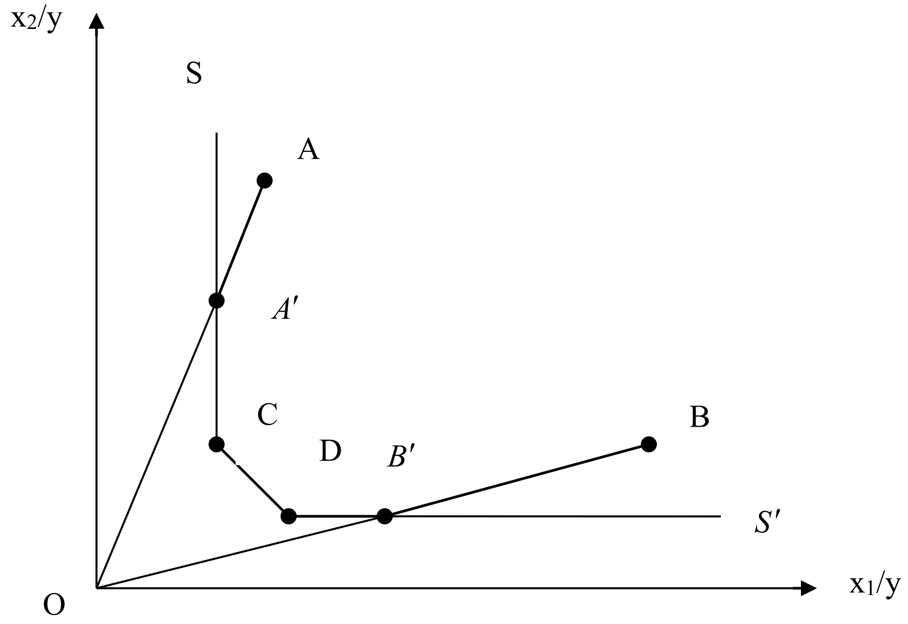
And: $TE_i^{CRS} = TE_i^{NIRS} = TE_i^{VRS}$ entail the restrictive property of NIRS.

Alternatively, scale economies arises due to either increasing or decreasing returns to scale and can be determined by inspecting the sum of the weights S $= \sum_{i=1}^{n} \lambda_i$ with CRS technology (Banker, 1984). Therefore, *S = 1* implies constant returns to scale (optimal scale). *S >1* indicates decreasing returns to scale (super-optimal scale) and *S <1* implies increasing returns to scale (sub-optimal) (Löthgren and Tambour, 1996; Banker and Thrall, 1992; and Førsund and Hernaes, 1994).

8.14. Efficiency Measurement and Slacks

The piece-wise linear form of the nonparametric frontier in DEA can causes few difficulties in efficiency measurement. The problem arises because of selections of the piece-wise linear frontier which runs parallel to the axes (Figure 8.6) which do not occur in the most parametric functions.

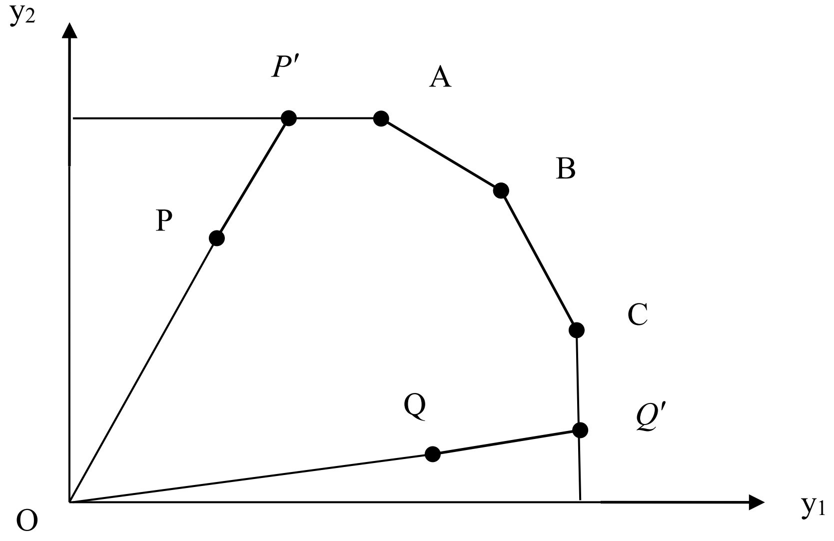
Figure: 8.6: Efficiency Measurement and Input Slacks



To illustrate the problem, we refer to Figure 8.6 where farms using input combinations *C* and *D* are two efficient farms which are defined in the frontier, and *A* and *B* are two inefficient farms. The Farrell (1957) measure of technical efficiency gives the efficiency of farms *A* and *B* as OA'/OA and OB'/OB respectively. However, It is questionable as to whether the point A' is an efficient point since one could reduce the amount of input x_2 used by the amount CA' and still produces the same amount. The farm operating at point *B* with input mix B' can decrease input x_1 by the amount DB' and both farms are still capable of producing the same amount. This is known as the input slack in the literature. The amount CA' is input slack of farm operating at point *A* and the amount DB' is input slack of farm operating at point *F*. Therefore, both farms are inefficient. It is argued that both the Farrell's measure of technical efficiency and any non-zero input or output slacks should be reported to provide an accurate indication of technical efficiency of a farm in a DEA analysis.

A two-output example of an output-oriented DEA could be represented by a piece-wise linear production possibility curve in Figure 8.7. Here the observations lie below this curve, and selections of the curve which are at right angles to the axes result in output slack being calculated when a production point is projected on to those parts of the curve by a radial expansion in outputs.

Figure: 8.7: Output-Oriented DEA and Output Slacks



For example, the point *P* is projected to the point P' which is on the frontier but not on the efficient frontier, because the production of y_1 could be increased by the amount AP' without using any more inputs. Similarly the point *Q* is the projected to the point Q' which is on the frontier but not on the efficient frontier, because the production of y_2 could be increased by the amount CQ' without any increase in point use. This is simply known as output slack in DEA model. In the present context, there are output slacks of AP' in output y_1 and CQ' in output y_2.

The VRS DEA models can be re-expressed with input and output slacks as follows:

Input-oriented	Output-oriented
$Min_{\theta_i^{inputVRS}, \lambda} \ \theta_i^{input.VRS}$	$Max_{\phi_i^{output,VRS}, \lambda} \ \phi_i^{output,VRS}$
Subject to $y_i + Y\lambda - S_{input} = 0,$	Subject to $\phi_i^{output,VRS} y_i + Y\lambda - S_{output} = 0$
$\theta_i^{input,VRS} x_i - X\lambda - S_{input} = 0$	$x_i - X\lambda - S_{output} = 0$
NI $\lambda = 1$	NI $\lambda = 1$
$\lambda \geq 0$	$\lambda \geq 0$

where S_{input} and S_{output} are (k×1) vectors of inputs and output slacks respectively.

The linear programming may not always allow identification of all efficiency slacks. Hence, identification of nearest efficient frontier point and the estimation of slacks are not straightforward if there are multiple inputs and outputs. A second-stage *LP* problem can be formulated to identify the nearest efficient point which maximizes the sum of slacks required to shift from the first stage projected point (inefficient point, such as point B in Figure 8.7) to a second-stage efficient point (such as point, C in Figure 8.7).
This second-stage *LP* problem is formulated as:

$$\underset{\lambda_{input}, S_{output}, S_{input}}{Min} \; -(MI \; S_{output} + KI \; S_{input}) \qquad (8.10)$$

$$subject\ to\ -y_i + Y\lambda - S_{output} = 0$$

$$\theta x_i - X\lambda - S_{input} = 0$$

$$\lambda \geq 0, \quad S_{output} \geq 0, \quad S_{input} \geq 0,$$

where *M* and *K* are $(m \times 1)$ and $(k \times 1)$ unit vector respectively. In this second stage LPs are solved for each farm where the first step gives the value of θ which is used in the second stage. However, one of the major problem with this second-stage approach is that it is not invariant to units of measurement (Lovell and Pastor, 1995); changing the units measurement might results in identification of different efficient boundary points and thus different output slacks and different values of λ and slacks. As a result, many studies solve the first-stage, which does not explicitly include slacks, for the measure of Farrell technical efficiency for each farm and report the values of technical efficiency and the residual slacks as $S_{output} = -y_i + Y\lambda$ and $S_{input} = \theta x_i - X\lambda$. This removes the problem relating to the units of measurement and involves less programming. Again, this obviously does solve the immediate problem, but does another, in that there is no clear rationale for the slacks to give weights in this fashion (Coelli, 1998). However, these two issues are not problem in simple cases, as there is only two points to choose from the vertical facet but if slacks occurs in two or more dimensions (which is frequently the case) then the above mentioned problems are relevant. To overcome such a problem Coelli (1997) suggests using a multi-stage DEA method to avoid the problems inherent in the two-stage method. This multi-stage method involves a sequence of a radial DEA models and therefore more computationally demanding than the other two methods. The benefits of the approach are that it identifies efficient projected points which have input and output mixes as similar as possible to those of the inefficient points, and that is also invariant to unit measurement. For details on multi-stage methods can be found in Coelli (1997).

8.15. Estimating the Determinants of Inefficiency

Nonparametric linear programming (LP) methods can not incorporate farm-specific effects directly into the estimation of an efficient frontier. We first measure efficiency measures using DEA model and then regress them against a set of farm specific factors to analyze and quantify the effects of these farm-specific factors of inefficiency. We postulate the regression equation as follows:

$$IE_i = \delta^{/} z_i + w_{i,} \qquad w_i \sim N(0, \sigma_w^2)$$

where δ_i denotes a ($k \times 1$) vector of unknown parameters, z_i is a ($k \times 1$) vector of variables defined in Chapter 6 and and w_i is a ($k \times 1$) vector of residuals that are independently and normally distributed with mean zero and variance σ_w^2. However there are a number of farms for which inefficiency is zero and hence the estimation of δ and σ_w^2 using ordinary least squares (OLS) producers biased and inconsistent estimates. Tobin (1958) developed the censored regression model which can be specified as:

$$IE_i = \delta^{/} z_i + w_i \qquad \text{if } (\delta^{/} z_i + w_i) > 0\text{, i.e., inefficiency is not zero}$$

and:

$$IE_i = 0 \qquad \text{otherwise, i.e., inefficiency is zero}$$

Assumed that N_0 be the number of rice producers for which IE_i = 0 and N_1 be the number of rice producers for which IE_i > 0. We can define the following for convenience:

$$\phi_i^t = \phi^t(\delta^{/} z_i, \sigma_w^2) = (1/\sigma_w\sqrt{2\pi})e^{-(1/2\sigma_w^2)(\delta' z_i)^2}$$

and:

$$\Phi_i^t = \Phi^t(\delta^{/} z_i, \sigma_w^2) = \int_{-\infty}^{\delta^{/} z_i} (1/\sigma_w\sqrt{2\pi})e^{-(1/2\sigma_w^2)(\delta' z_i)} d\delta' z_i$$

where ϕ_i^t and Φ_i^t are respectively the density function and distribution of the standard normal evaluated at $\delta^{/} z_i / \sigma_w$ (see Maddala, 1983, p. 151 for details). For the inefficiencies IE_i that are zero we know that.

$$Pr\,(IE_i = 0) = \Pr(w_i \langle -\delta^{/} z_i) = \int_{-\infty}^{-\delta'^{/} z_i} f_t(w_i) dw_i = \int_{\delta'^{/} z_i}^{\infty} f_t(w_i) dw_i = 1 - \Phi_i^t$$

and:

$$Pr\,(IE_i \rangle 0) f_t(IE_i / IE_i \rangle 0) = \Phi_i^t \{ f_t(IE_i - \delta_i^{/} z_i \sigma_w^2) / \Phi_i^t \}$$

Hence the log likelihood function is:

$$\log L = \sum_0 \log(1 - \Phi_i^t) + \sum_1 \log(1/\sqrt{2\pi\sigma_w^2}) - \sum_1 (1/2\sigma_w^2)(IE_i - \delta^{/} z_i)^2$$

where the first summation is over N_0 producer units for which $IE_i = 0$ and the second summation is over N_1 producer units for which $IE_i > 0$. This Tobit model is estimated using maximum likelihood methods.

8.16. Summary and Conclusions

A brief introduction to the basics of DEA has been provided in this Chapter. DEA has been defined as a nonparametric mathematical programming methodology estimating efficiencies of farms in production. DEA can handle multiple inputs and multiple outputs while it doesn't require an assumption of a functional form relating inputs to outputs. Inputs and outputs can have extremely dissimilar units but it is not at all a problem for DEA. DEA is formulated for two types of orientations such as input orientation and output orientation.

In the input orientation models, the technique seeks to identify technical efficiency as a proportional reduction in input usage with output level held constant. And in the output orientation model, the method identifies technical efficiency as a proportional increase of output in production, while input levels are held fixed. The output-oriented DEA models yields alike estimates to their input-oriented counterparts. The CCR DEA model (1978) is the first DEA formulation. The BCC model (1984) is the later development in DEA model.

When a variable returns to scale relationship is assumed between inputs and outputs the BCC DEA (ratio) model is used to measure technical efficiency. Notably, the VRS DEA model is different from CRS DEA model in that the VRS DEA envelopes data more robustly, producing technical efficiency (TE) estimates greater than or equal to that obtained from the CRS DEA. The input and output oriented CRS and VRS models have been described and pointed out as to how these models can be used to measure technical and scale efficiencies. Scale efficiency measures can be obtained by conducting both a CRS DEA and a VRS DEA upon the same data. A through discussion has been made as to how scale efficiency can be used to NIRS DEA to help identify the nature of scale economics. The piecewise linear form of the non-parametric frontier in DEA can give rise to some difficulties in efficiency measurement which has been termed as 'slacks'. The problems arises because of the piecewise linear frontier that runs parallel to the axes provide more than one efficient point. It has been discussed that the linear programs may not always allow identification of all efficiency slacks thus it requires treatment. There are some another constraints, for example, year of schooling of farmers, experience of rice cultivation, fragmentation of lands, limitation of credit facilities, and limitation on using extension services and degradation of soils etc. That is why, a farm may not be operating at an optimal scale. To solve this problem, Banker, Charnes and Cooper (1984) suggest VRS DEA model. The VRS specification has been the most commonly used specification in recent years. It is important to know that which orientation (input-orientation or output-orientation) should be selected depends on to which quantities producers have most control over, though, Coelli and Perenlman (1996) suggest that the choice of the orientation has only a small influence upon the scores obtained. Finally, the Tobit regression model can be used to identify and quantify the effects of farm-specific factors on efficiencies, as efficiency ranges from zero to one.

Chapter 9

Data Envelopment Analysis (DEA) Frontier Results

9.1. Introduction

In this Chapter we discuss results obtained from the non-parametric approach to measuring efficiency of 251 rice farms in Northern Bangladesh with the application of data envelopment analysis (DEA). Here we estimate constant returns to scale (CRS) and variable returns to scale (VRS) input-oriented and output-oriented DEA frontier. The CRS frontier produces the measures of overall technical efficiency (TE) and the VRS frontier produces estimates of pure technical efficiency. We compute scale efficiency (SE) as the ratio of CRS TE and VRS TE. We compare efficiency scores obtained from CRS and VRS technologies to find rice farms operational levels. We use Tobit analysis to analyze factors which affect technical inefficiency.

The CRS and VRS input-oriented DEA frontier assumes that farmers produce output at minimum cost whereas the frontier for estimating technical efficiency only assumes that farmers produce maximum output from a given input mix, given existing technology. The VRS frontier envelops data more closely than the CRS does so that efficiency measures derived from the former are greater than or equal to those obtained from the latter.

We have given some comparison between results of data envelopment analysis (DEA) and stochastic frontier analysis (SFA) models. From both models we have got some mixed results. But it is interesting to see what kind of different result has been found as far as technical efficiency is concerned. In this Chapter we describe results of input-output oriented data envelopment analysis (DEA) model, summary statistics of efficiency estimates from DEA methods, frequency distribution of efficiency from DEA frontier, average estimated technical efficiency under input-output oriented CRS, VRS DEA and SE and factor associated with technical inefficiency effects for rice farms in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together, it also gives a comparison between results from SFA and DEA models and lastly discusses summary and conclusions.

9.2. Results of Input and Output Oriented Data Envelopment Analysis (DEA) Model

9.2.1. Input-Oriented Results

In our study, the sample size consists of 251 farms; they produce rice using seven inputs, which are land, labour, plough, seed, irrigation, fertilizer, and pesticides, measured in value terms. We have got DEA results by using the program DEAP, version 2.1 (Coelli, 1996). Table 9.1, 9.2 and 9.3 and Table 9.4, 9.5 and 9.6 show results for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together results show that input-oriented and output-oriented measures have little differences. In aman season (S_1), input-output oriented results from CRS and VRS DEA methods are exactly the same. But in boro season (S_2), there are some differences in input-output oriented results of the same DEA methods.

In Table 9.1 input-oriented CRS DEA results for aman season (S_1) shows that 69.32 per cent farms are over 80 per cent technically efficient and VRS DEA shows that 75.30 per cent farms are over 80 per cent technically efficient.

Table 9.1: Frequency Distribution of TE and SE from DEA Frontier for Aman Season (S_1)

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	1	0.40	0	0	0	0
50-55	1	0.40	1	0.40	0	0
55-60	4	1.59	1	0.40	0	0
60-65	12	4.78	1	0.40	1	0.40
65-70	26	10.36	13	5.18	6	2.39
70-75	13	5.19	22	8.76	8	3.19
75-80	20	7.97	24	9.56	12	4.78
80-85	22	8.76	21	8.37	19	7.57
85-90	41	16.33	39	15.54	28	11.16
90-95	44	17.53	49	19.52	32	12.75
95-100	67	26.69	80	31.87	145	57.77
Total	251	100.00	251	100.00	251	100.00

Only 30.68 per cent farms are less than 81 per cent efficient in case of input-oriented CRS DEA for aman season (S_1) and only 24.70 per cent are less than 81 per cent efficient in case of input-oriented VRS DEA for aman season (S_1).

In Table 9.2 input-oriented CRS DEA results for boro season (S2) show that 58.94 per cent farms are over 80 per cent technically efficient and VRS DEA shows that 61.75 per cent farms are over 80 per cent technically efficient. About 41.06 per cent farms are less than 81 per cent efficient in case of input-oriented CRS DEA for boro season (S_2) and 38.25 per cent are less than 81 per cent efficient in case of input-oriented VRS DEA for boro season (S_2).

Table 9.2: Frequency Distribution of TE and SE from DEA Frontier for Boro Season (S_2)

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	0	0	0	0	0	0
50-55	7	2.79	6	2.39	0	0
55-60	12	4.78	9	3.59	0	0
60-65	14	5.58	12	4.78	1	0.40
65-70	23	9.16	21	8.37	3	1.20
70-75	25	9.96	23	9.16	5	1.99
75-80	22	8.76	25	9.95	6	2.39
80-85	26	10.37	26	10.36	8	3.19
85-90	27	10.76	28	11.16	23	9.16
90-95	29	11.55	30	11.96	27	10.76
95-100	66	26.29	71	28.28	178	70.92
Total	251	100.00	251	100.00	251	100.00

Table 9.3 provides the input and output-oriented CRS and VRS DEA results for both aman and boro seasons (S_1+S_2) together. In input-oriented CRS DEA results show that 66.13 per cent farms are over 80 per cent technically efficient and VRS DEA show that 78.09 per cent farms are over 80 per cent technically efficient. About 33.87 per cent farms are less than 81 per cent efficient in case of input-oriented CRS DEA of both aman and boro seasons (S_1+S_2) together and 21.91 per cent farms are less than 81 per cent efficient in case of input-oriented VRS DEA of both aman and boro seasons (S_1+S_2) together.

Table 9.3: Frequency Distribution of TE and SE from DEA Frontier of both aman and boro Seasons (S_1+S_2) Together

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	1	0.40	0	0	0	0
50-55	2	0.80	0	0	0	0
55-60	4	1.59	1	0.40	0	0
60-65	8	3.19	2	0.80	1	0.40
65-70	17	6.77	11	4.38	3	1.20
70-75	24	9.56	15	5.98	6	2.39
75-80	29	11.55	26	10.36	18	7.17
80-85	31	12.35	32	12.75	24	9.56
85-90	34	13.55	35	13.94	34	13.55
90-95	40	15.94	48	19.12	45	17.93
95-100	61	24.30	81	32.27	120	47.81
Total	251	100.00	251	100.00	251	100.00

9.2.2. Output-Oriented results

Output-oriented CRS and VRS results of technical efficiency (TE) and scale efficiency (SE) for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are given in Table 9.4, 9.5 and 9.6 respectively.

That output-oriented CRS DEA results for aman season (S_1) as shown in Table 9.4 exhibits that 68.52 per cent farms are over 80 per cent technically efficient and VRS DEA shows 75.30 per cent farms are over 80 per cent technically efficient. Only 31.48 per cent farms are less than 81 per cent efficient in case of output-oriented CRS DEA of aman season (S_1) and only 24.70 per cent are less than 81 per cent efficient in case of output-oriented VRS DEA for aman season (S_1).

In Table 9.5 the output-oriented CRS DEA results for boro season (S_2) show that 58.56 per cent farms are over 80 per cent technically efficient and VRS DEA shows that 76.09 per cent farms are over 80 per cent technically efficient. About 41.44 per cent farms are less than 81 per cent efficient under the output-oriented CRS DEA for boro season (S_2) and 23.91 per cent are less than 81 per cent efficient under the output-oriented VRS DEA of boro season (S_2).

Table 9.4: Frequency Distribution of TE and SE from DEA Frontier for Aman Season (S_1)

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	1	0.40	1	0.40	0	0
50-55	1	0.40	1	0.40	0	0
55-60	3	1.20	2	0.80	1	0.40
60-65	10	3.98	8	3.19	2	0.80
65-70	26	10.36	12	4.77	4	1.58
70-75	17	6.77	14	5.58	7	2.79
75-80	21	8.37	24	9.56	9	3.59
80-85	20	7.97	21	8.37	15	5.98
85-90	42	16.73	19	7.57	23	9.16
90-95	45	17.93	39	15.54	49	19.52
95-100	65	25.90	110	43.82	141	56.18
Total	251	100.00	251	100.00	251	100.00

Table 9.5: Frequency Distribution of TE and SE from DEA Frontier for Boro Season (S_2)

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	0	0	0	0	0	0
50-55	10	3.98	8	3.19	0	0
55-60	7	2.79	2	0.80	7	2.79
60-65	12	4.78	9	3.59	10	3.98
65-70	23	9.16	10	3.98	12	4.78
70-75	25	9.96	13	5.18	16	6.37
75-80	27	10.76	18	7.17	12	4.78
80-85	28	11.16	24	9.55	19	7.57
85-90	30	11.95	28	11.16	36	14.34
90-95	35	13.94	45	17.93	56	22.32
95-100	54	21.51	94	37.45	83	33.07
Total	251	100.00	251	100.00	251	100.00

Table 9.6 depicts the output-oriented CRS, VRS TI and scale efficiency measures for both aman and boro seasons (S_1+S_2) together. Output-oriented CRS DEA result for both seasons (S_1+S_2) together that 65.34 per cent farms are over 80 per cent technically efficient and VRS DEA shows that 74.90 per cent farms are over 80 per cent technically efficient. About 34.66 per cent farms are less than 81 per cent efficient under the output-oriented CRS DEA for both aman and boro seasons (S_1+S_2) together and 25.10 per cent farms are less than 81 per cent efficient in case of output-oriented VRS DEA of both aman and boro seasons (S_1+S_2) together.

Table 9.6: Frequency Distribution of TE and SE from DEA Frontier of both aman and boro Seasons (S_1+S_2) Together

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms	Number of farms	Percentage of farms
01-50	0	0	0	0	0	0
50-55	0	0	0	0	0	0
55-60	4	1.59	3	1.20	0	0
60-65	8	3.19	6	2.39	1	0.40
65-70	18	7.17	10	3.98	2	0.80
70-75	25	9.96	18	7.17	4	1.59
75-80	32	12.75	26	10.36	7	2.79
80-85	21	8.37	18	7.17	4	1.59
85-90	31	12.35	27	10.76	13	5.18
90-95	45	17.93	37	14.74	40	15.94
95-100	67	26.69	106	42.23	180	71.71
Total	251	100.00	251	100.00	251	100.00

Summary statistics of efficiency estimates from DEA model are presented in Table 9.7, 9.8 and 9.9. Mean technical efficiency of input-oriented method for CRS DEA model for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 86 per cent, 83 per cent and 86 per cent respectively. Mean technical efficiency obtained by CRS DEA output-oriented method for all seasons are equal. Mean technical efficiency of input-oriented method for VRS DEA model of aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 88 per cent, 85 per cent and 89 per cent respectively.

On the contrary, mean technical efficiency of output-oriented method under VRS DEA model for all seasons are equal. It is 89 per cent. Overall technical efficiency score ranges for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together from input-oriented method give same result. Estimated technical efficiency score for CRS DEA method ranges from 49 to 100 per cent for aman season (S_1), 53 to 100 per cent for boro season (S_2) and 50 to 100 per cent of both aman and boro seasons (S_1+S_2) together with standard deviations of 12 per cent in aman season (S_1), 14 per cent of boro season (S_2) and 11 per cent of both aman and boro seasons (S_1+S_2) together respectively. For VRS DEA score ranges from 55 to 100 per cent for aman season (S_1), 54 to100 per cent for boro season (S_2) and 89 to 100 per cent of both aman and boro seasoms (S_1+S_2) together with standard deviations of 10 per cent in aman season (S_1), 14 per cent of boro season (S_2) and 10 per cent for both aman and boro seasons (S_1+S_2) together. Scale efficiency (SE) estimates range from 64 to 100 per cent in all seasons, with standard deviations of 5 per cent, 4 per cent and 5 per cent in aman season (S_1) boro season (S_2) and both aman and boro seasons (S_1+S_2) together respectively.

Table 9.7: Summary Statistics of Efficiency Estimates from DEA Method for Aman Season (S_1)

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	86	88	97	86	89	96
Minimum	49	55	64	49	50	58
Maximum	100	100	100	100	100	100
Standard deviation	12	10	5	12	12	5

Table 9.8: Summary Statistics of Efficiency Estimates from DEA Method for Boro Season (S_2)

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	83	85	97	83	89	93
Minimum	53	54	64	53	53	54
Maximum	100	100	100	100	100	100
Standard deviation	14	14	5	14	14	11

Table 9.9: Summary Statistics of Efficiency Estimates from DEA Method of both aman and boro Seasons (S_1+S_2) Together

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	86	89	97	86	89	96
Minimum	50	59	64	55	57	63
Maximum	100	100	100	100	100	100
Standard deviation	11	10	5	11	11	6

Graphical presentations of estimated technical efficiency (TE) and scale efficiency (SE) scores under CRS and VRS DEA from input-output orientation for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are given in Figure 9.1 to Figure 9.18. In aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together input-output oriented methods show almost the same results. So, we show input-output oriented results by Figure separately below.

Figure 9.1: TE from Input-Oriented CRS DEA Frontier Model for Aman Season (S_1)

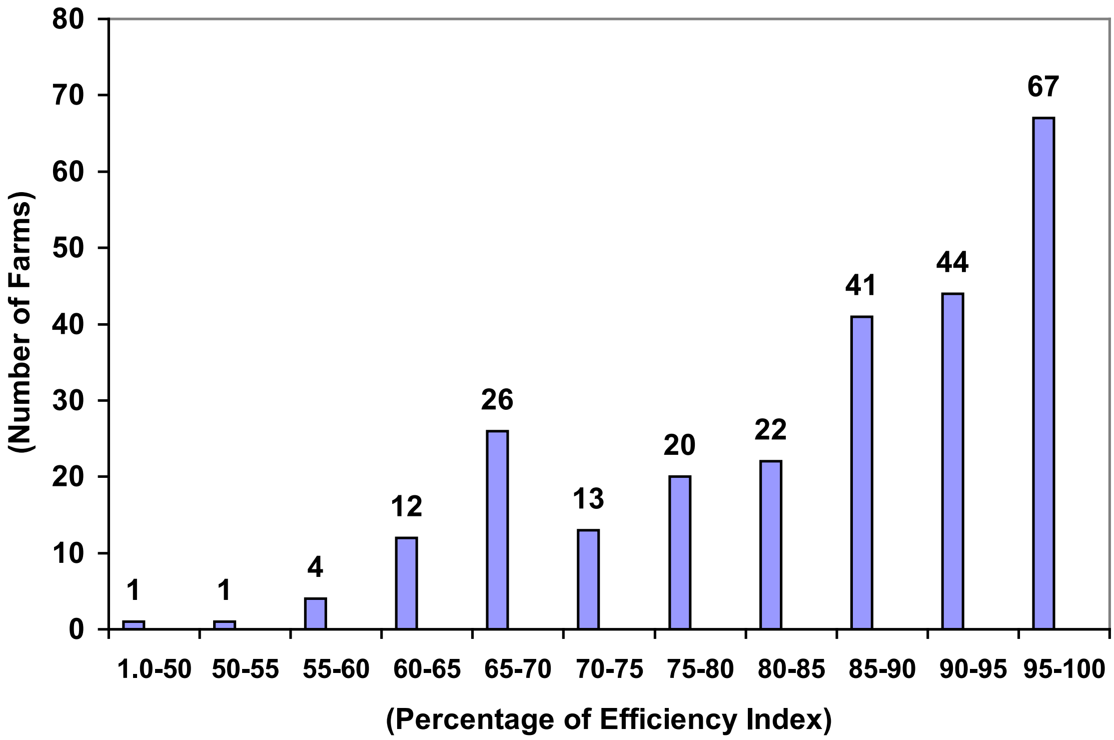


Figure 9.2: TE from input-Oriented CRS DEA Frontier Method for Boro Season (S_2)

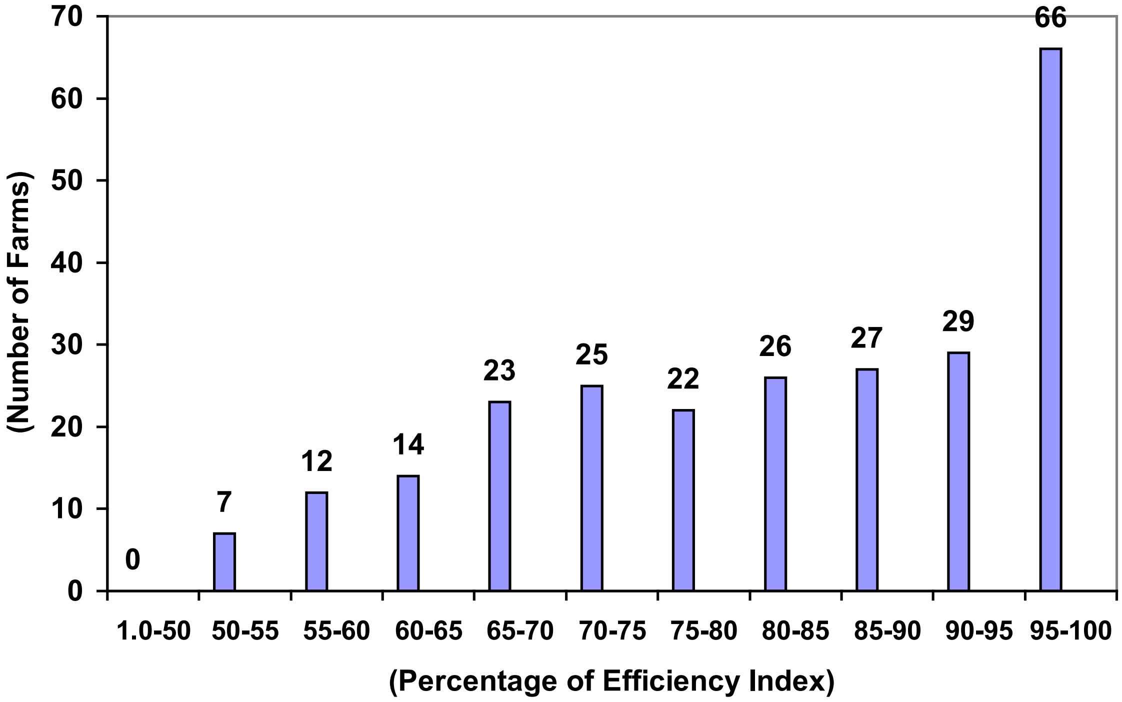


Figure 9.3: TE from Input-Oriented CRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together

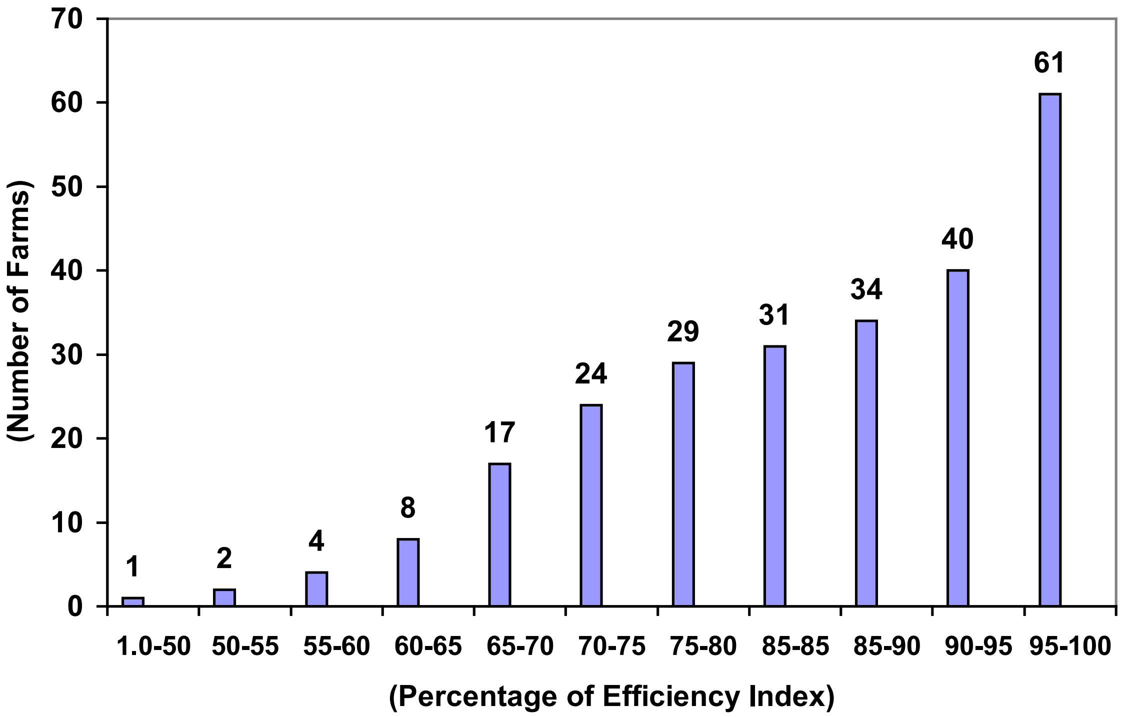


Figure 9.4: TE from Input-Oriented VRS DEA Frontier Method for Aman Season (S_1)

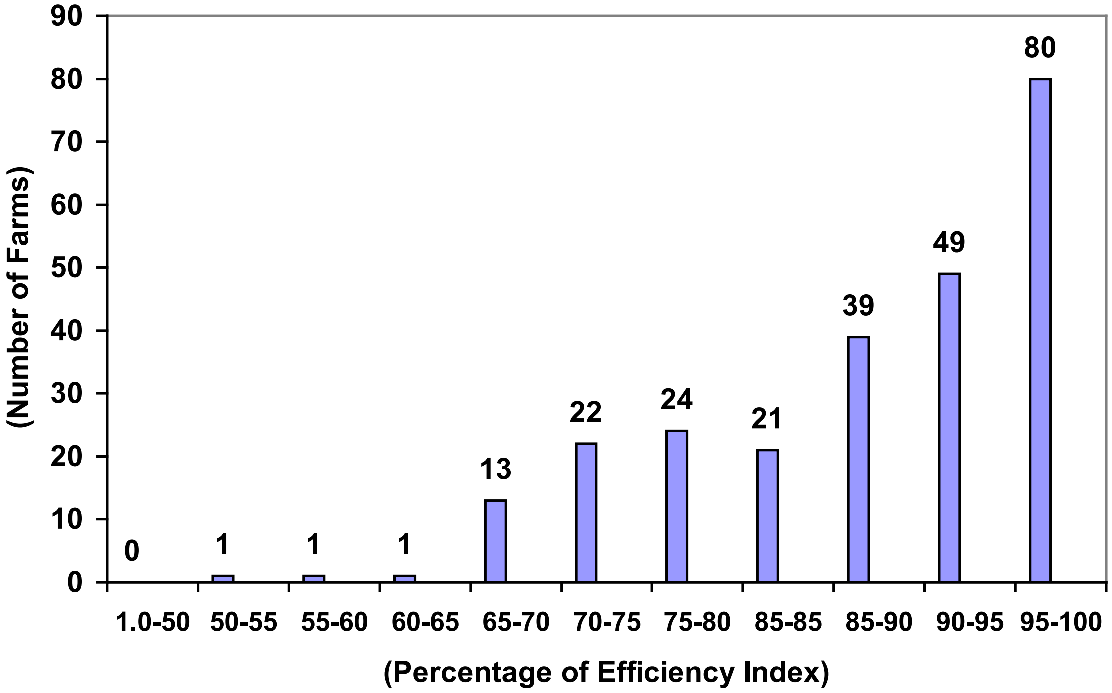


Figure 9.5: TE from Input-Oriented VRS DEA Frontier Method for Boro Season (S_2)

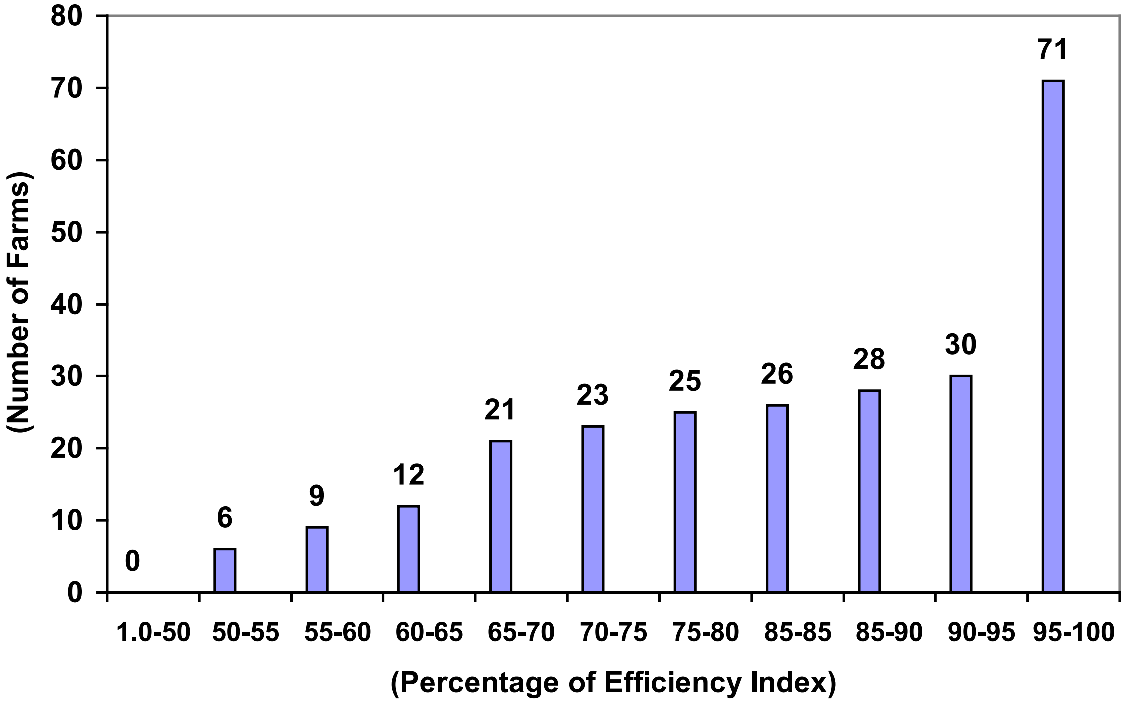


Figure 9.6: TE from Input-Oriented VRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together

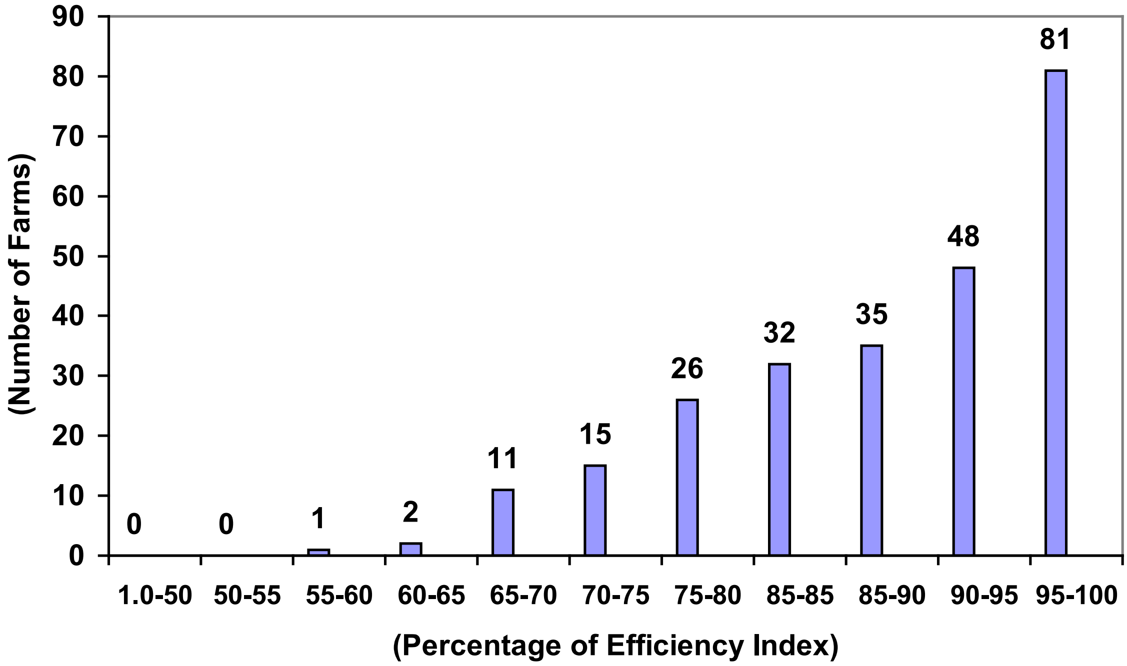


Figure 9.7: SE from Input-Oriented DEA Frontier Method for Aman Season (S_1)

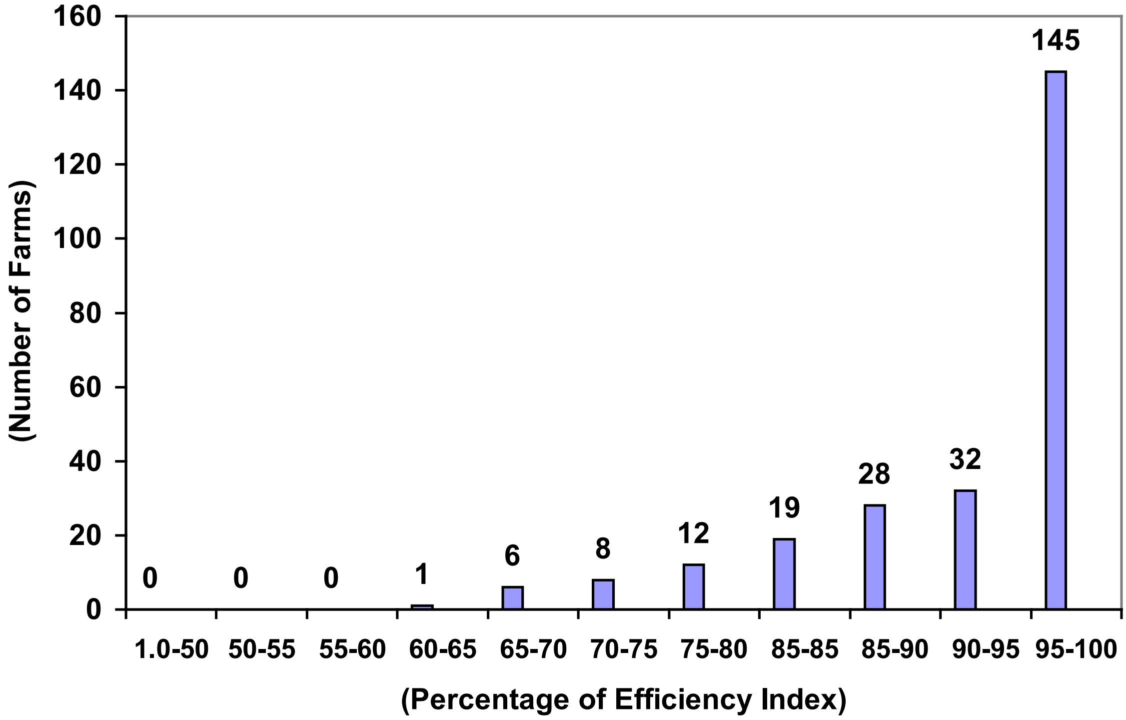


Figure 9.8: SE from Input-Oriented DEA Frontier Method for Boro Season (S_2)

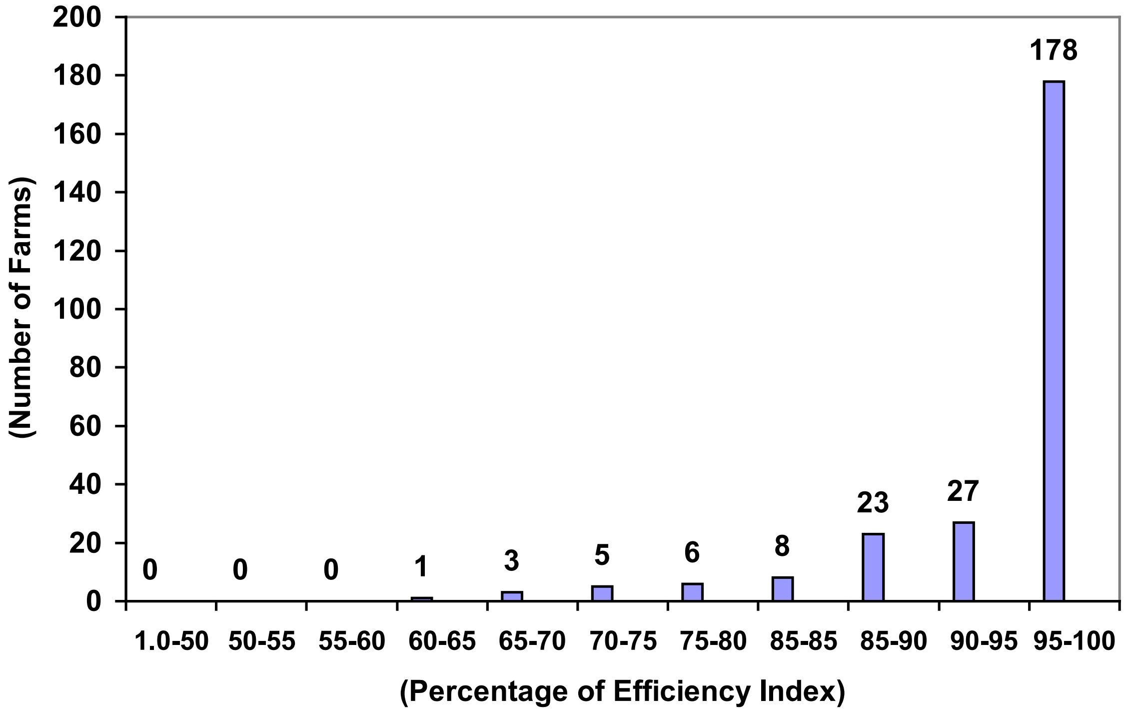


Figure 9.9: SE from Input-Oriented VRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together

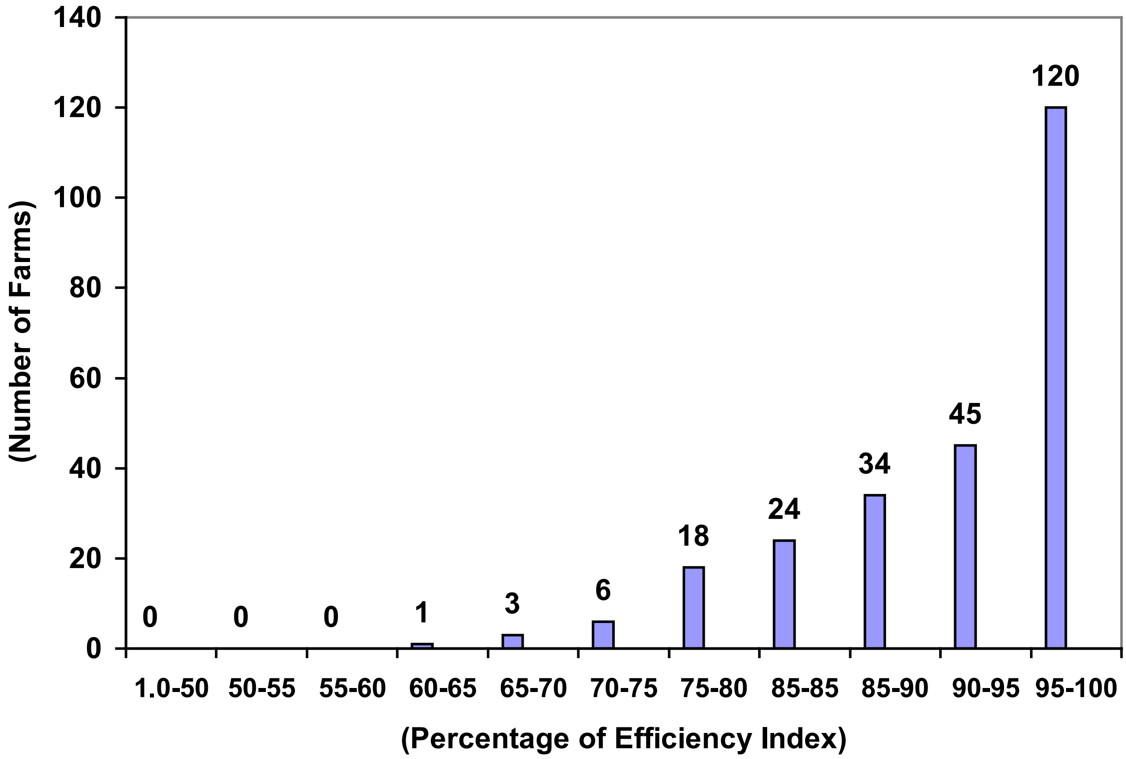


Figure 9.10: TE from Output-Oriented CRS DEA Frontier Method for Aman Season (S_1)

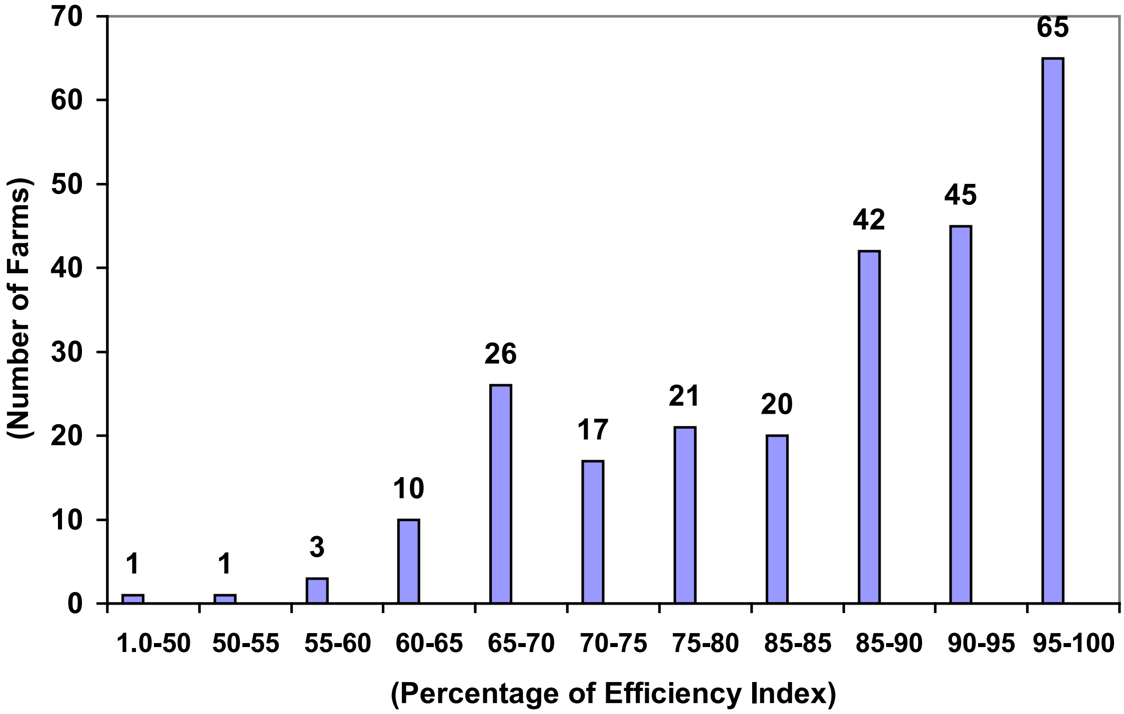


Figure 9.11: TE from Output-Oriented CRS DEA Frontier Method for Boro Season (S_2)

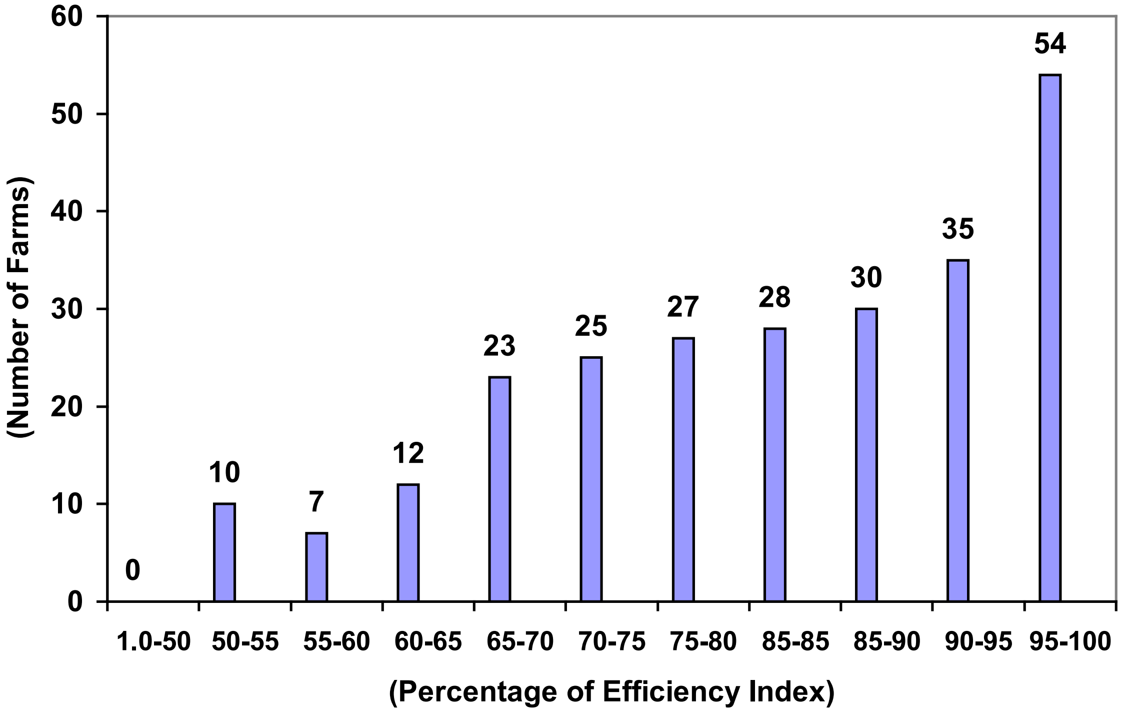


Figure 9.12: TE from Output-Oriented CRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together

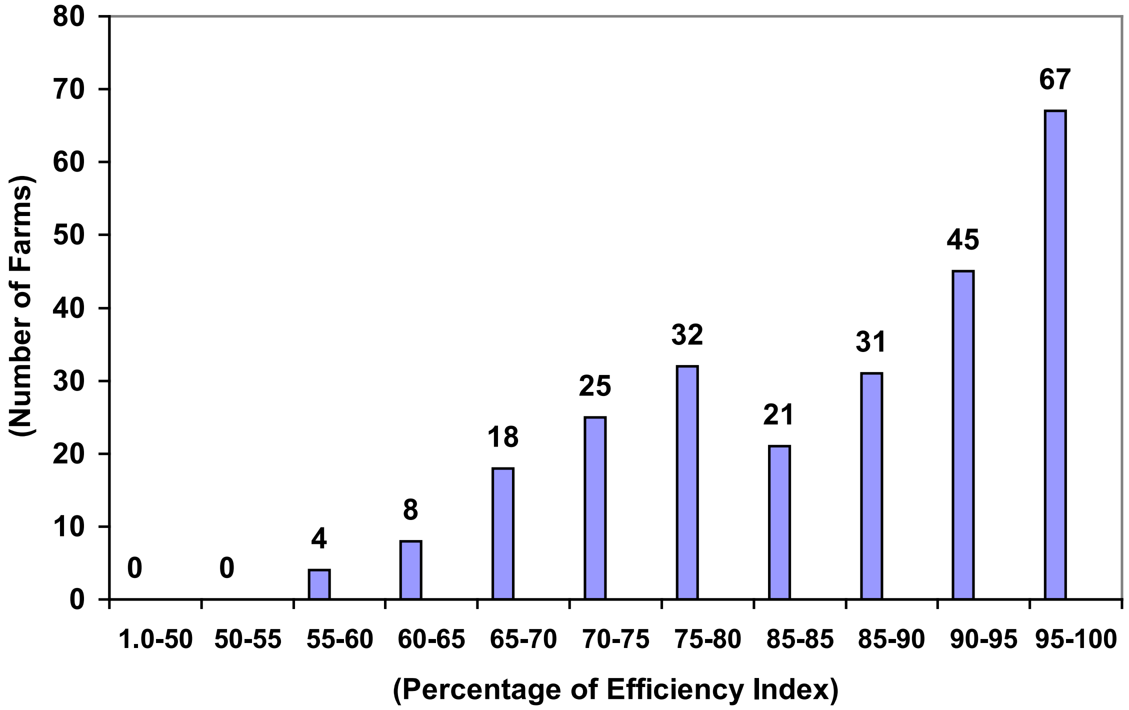


Figure 9.13: TE from Output-Oriented VRS DEA Frontier Method for Aman Season (S_1)

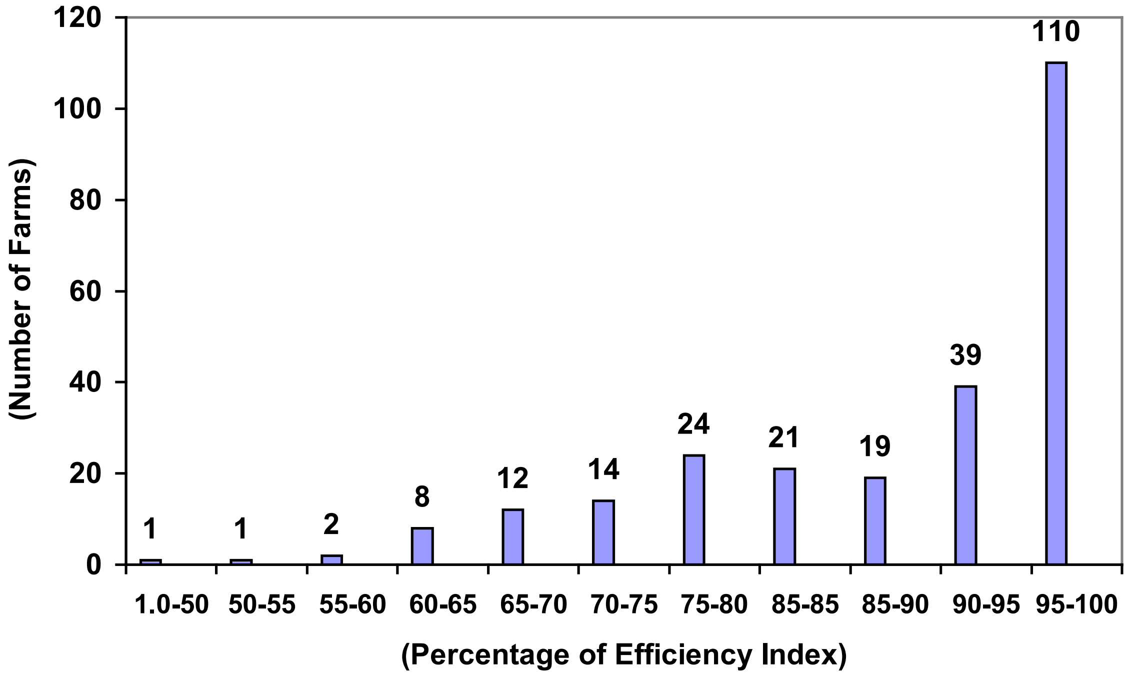


Figure 9.14: TE from Output-Oriented VRS DEA Frontier Method for Boro Season (S_2)

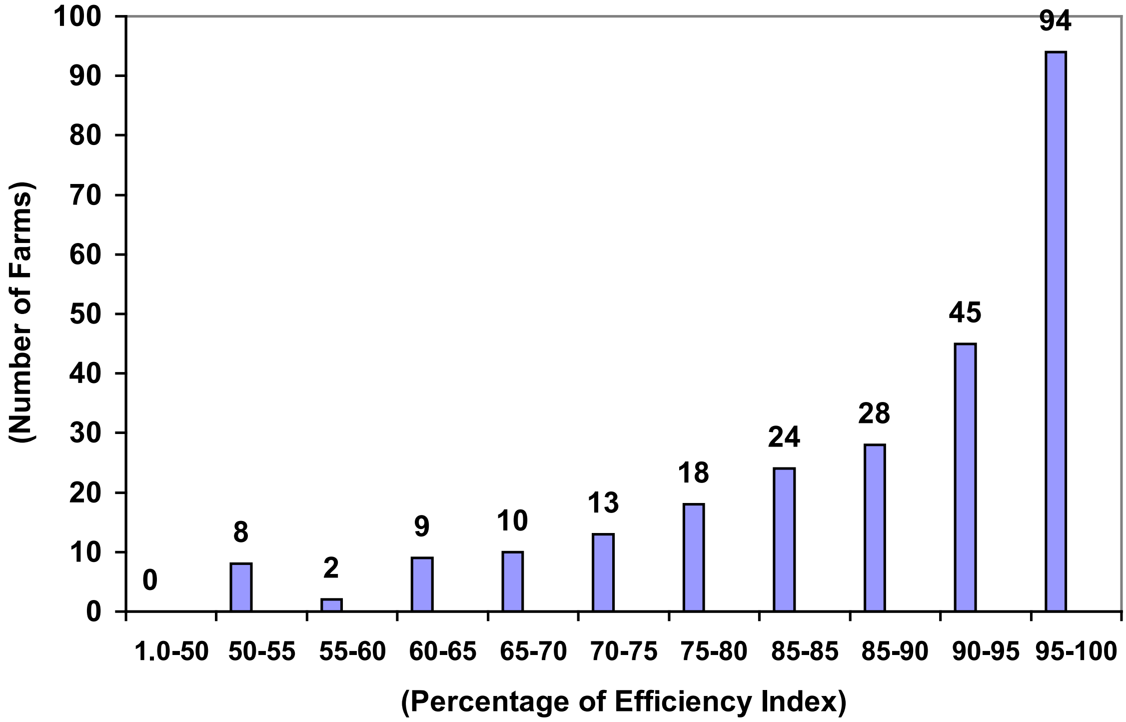


Figure 9.15: TE from Output-Oriented VRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together

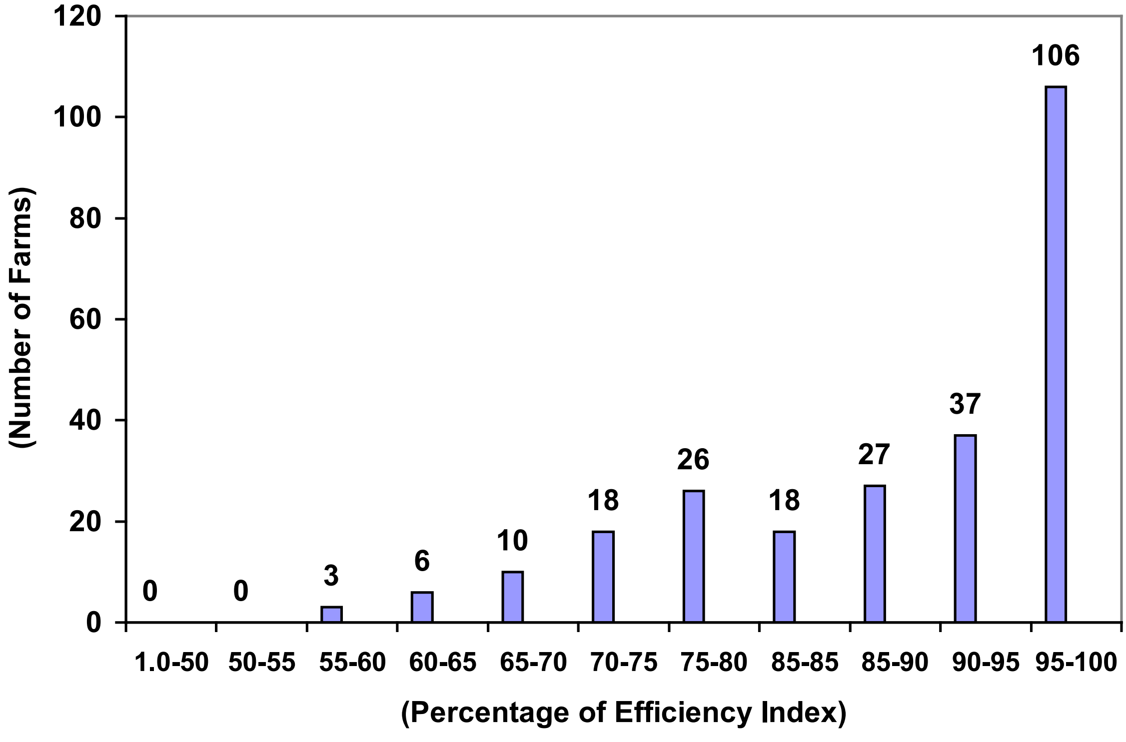


Figure 9.16: SE from Output-Oriented VRS DEA Frontier Method of Aman Season (S_1)

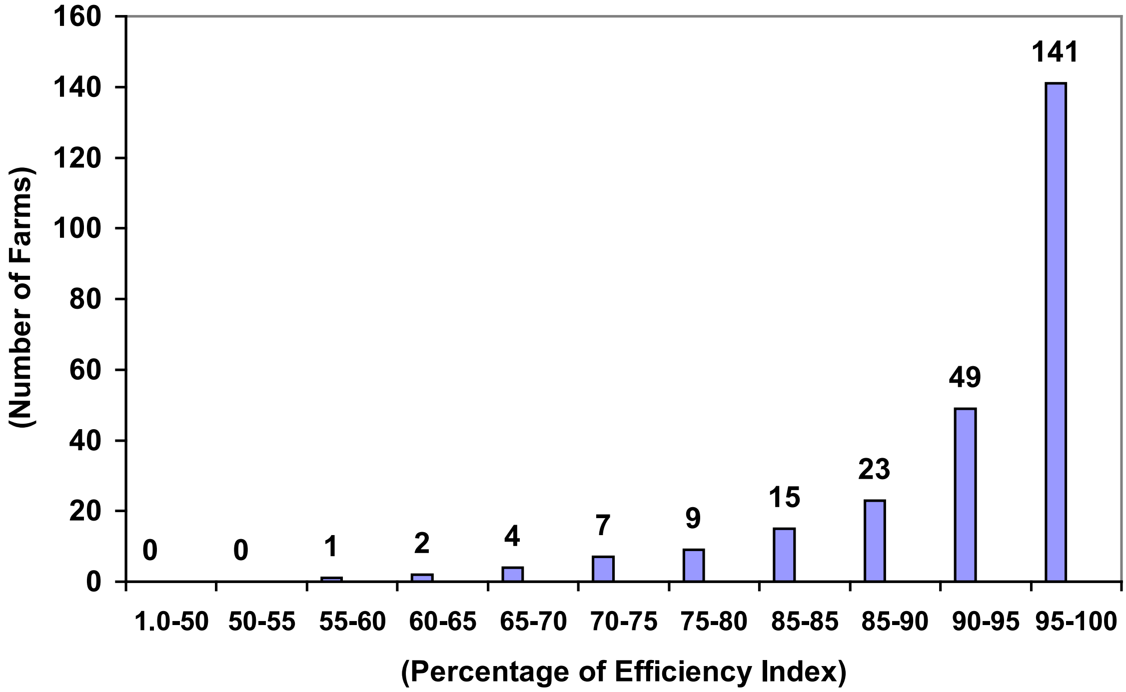


Figure 9.17: SE from Output-Oriented VRS DEA Frontier Method for Boro Season (S_2)

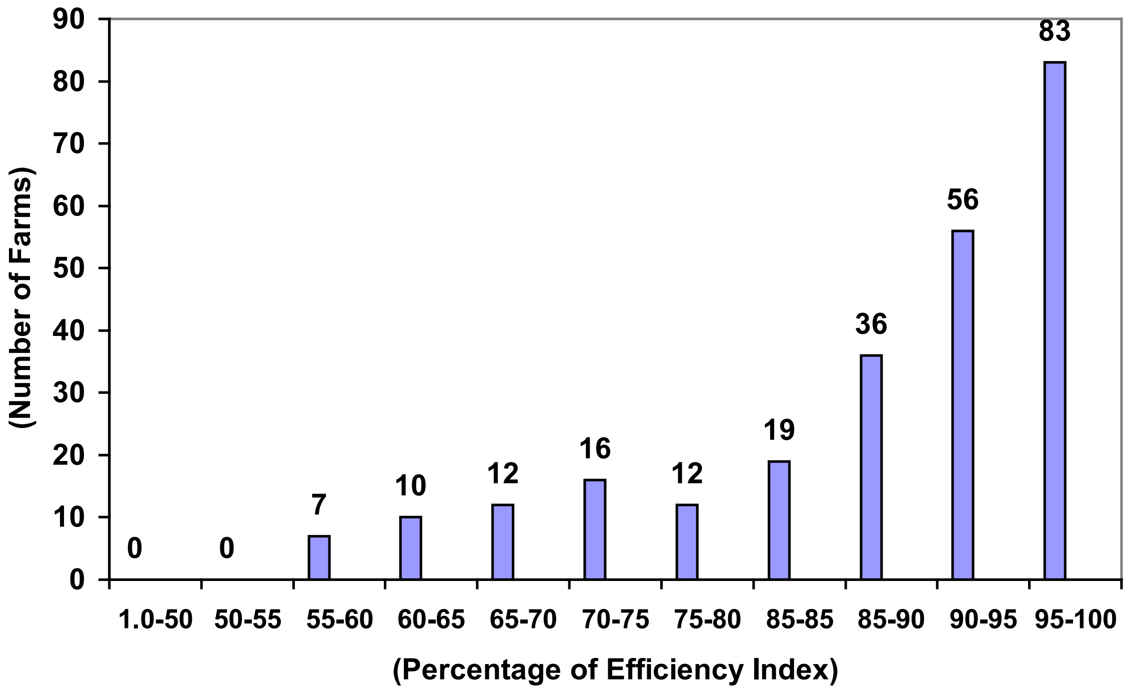
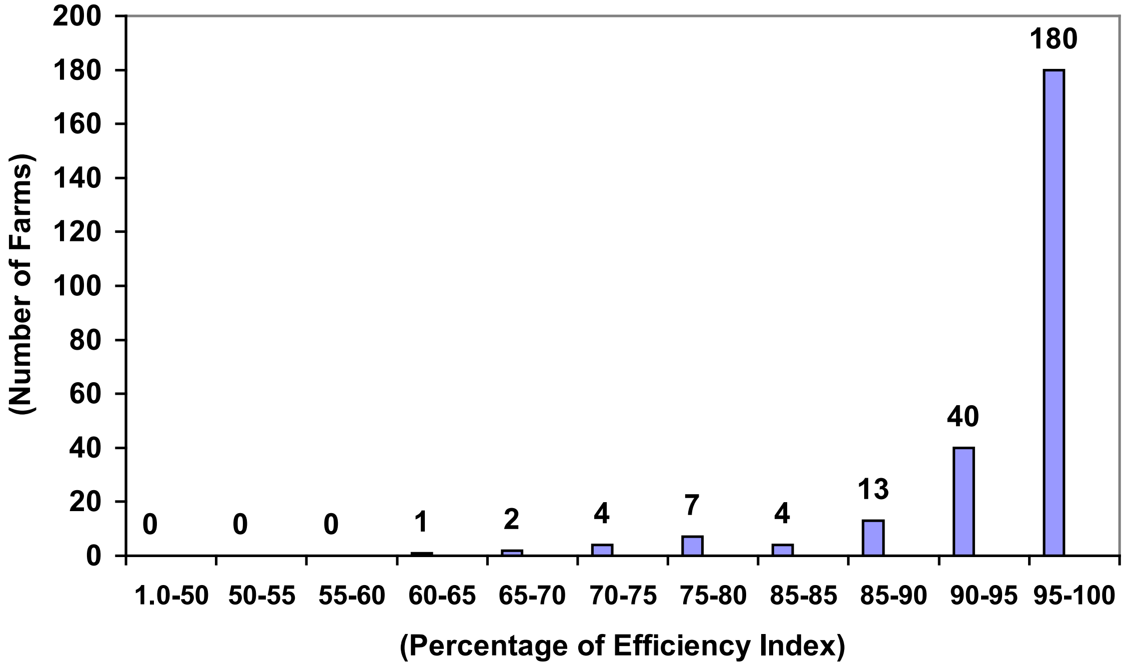


Figure 9.18: SE from Output-Oriented VRS DEA Frontier Method of both Aman and Boro Seasons (S_1+S_2) Together



9.3. Estimated Input-Oriented DEA Results for Technical Efficiency

We use input-oriented DEA model to estimate technical efficiency (TE) scores. These measures are estimated by using DEAP, version 2.1 (Coelli, 1996). The frequency distribution of technical efficiency (TE) measures under CRS and VRS frontier methods are reported in Table 9.10 and their summary statistics for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are separately presented in Table 9.11.

The average estimated technical efficiency for aman season (S_1) is 86 per cent, 88 per cent and 97 per cent respectively for CRS, VRS and SE DEA frontier and these are 83 per cent, 85 per cent and 97 per cent for CRS, VRS and SE DEA frontier for boro season (S_2) respectively. Further the average estimated technical efficiency of both aman and boro seasons (S_1+S_2) together are 86 per cent, 89 per cent and 97 per cent for CRS, VRS and SE DEA frontier respectively. Therefore, it is clear from results of CRS, VRS DEA analysis that there is a scope for comprehensive improvement of production as far as efficiency is concerned. In both seasons, we have got almost similar results, but more opportunity to improve efficiency in boro season (S_2) than in aman season (S_1). Therefore, these results clearly indicate that farmers can reduce production cost and hence can get more output gain through improving 14 per cent to 17 per cent efficiency without introducing new more improved technology in rice production process.

Table 9.10: Frequency Distribution of Efficiency Estimates from DEA Frontier for Aman (S_1), Boro (S_2) and both Aman and Boro Seasons (S_1+S_2) Together

Efficiency Index (%)	Input-Oriented DEA Frontier					
	Number of Farms					
	TE under CRS			TE under VRS		
	Aman season	Boro season	Both season	Aman season	Boro season	Both seasons
01-50	1	0	1	0	0	0
50-55	1	7	2	1	6	0
55-60	4	12	4	1	9	1
60-65	12	14	8	1	12	2
65-70	26	23	17	13	21	11
70-75	13	25	24	22	23	15
75-80	20	22	29	24	25	26
80-85	22	26	31	21	26	32
85-90	41	27	34	39	28	35
90-95	44	29	40	49	30	48
95-100	67	66	61	80	71	81
Total	251	251	251	251	251	251

Table 9.11: Summary Statistics of Efficiency Estimates from DEA Frontier for Aman (S_1), Boro (S_2) and both Aman and Boro Seasons (S_1+S_2) (in percentage)

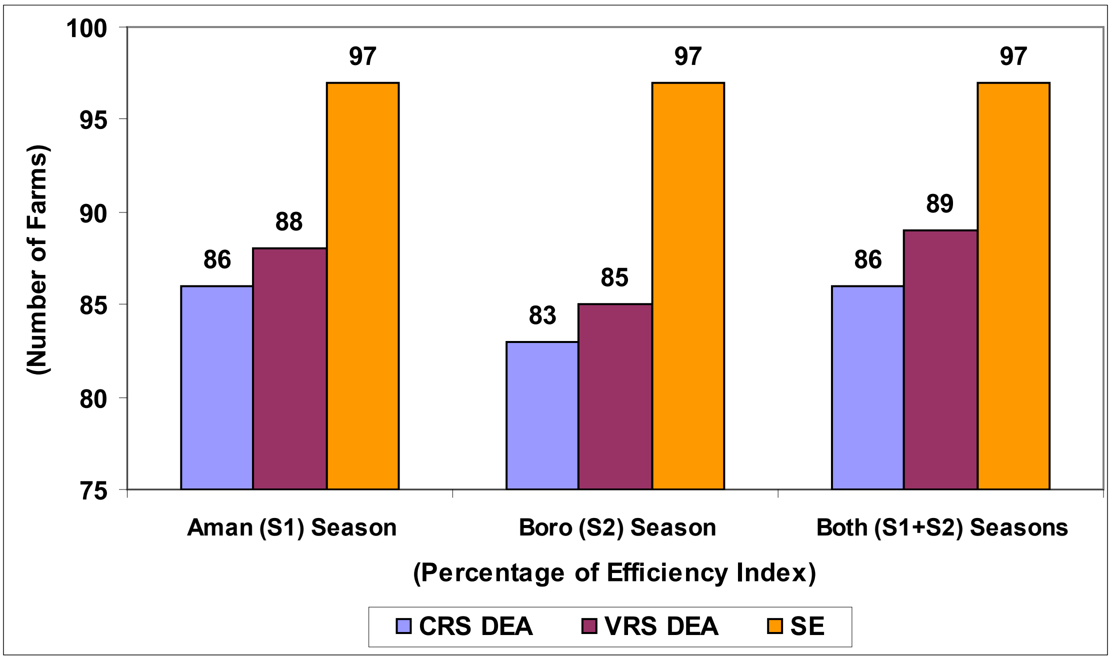
Statistics	CRS DEA Frontier			VRS DEA Frontier		
	Aman season	Boro season	Both seasons	Aman season	Boro season	Both seasons
Mean	86	83	86	88	85	89
Minimum	49	53	50	55	54	59
Maximum	100	100	100	100	100	100
Standard deviation	12	14	11	10	14	10

In terms of scale economies, 43 per cent farms are characterized by increasing returns to scale, 15 per cent farms having constant returns to scale and the rest 42 per cent farms are characterized by decreasing returns to scale technology of aman season (S_1). On the other hand, 39 per cent farms are characterized by increasing returns to scale, 17 per cent farms have constant returns to scale and the rest 44 per cent farms show decreasing returns to scale technology of boro season (S_2) production process.

If all farms are using same technology, then it would be expected that returns to scale to be increasing for farms with a relatively low output and decreasing returns to scale for farms with a relatively high output. Constant returns to scale would be expected for farms with an output level equal to mean output (Silberberg, 1990).

Graphical presentations of technical efficiency (TE) measures under input-output oriented of CRS, VRS DEA frontier and scale efficiency (SE) for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are given in Figure 9.19.

Figure 9.19: Average Estimated Technical Efficiency under the Input-Oriented CRS, VRS DEA and SE for Aman (S_1), Boro (S_2) and both Seasons (S_1+S_2) Together



9.4. Estimated Output-Oriented DEA Results for Technical Efficiency

We use output-oriented DEA model to estimate technical efficiency (TE) scores. The frequency distribution of technical efficiency (TE) measures under CRS and VRS frontier methods are reported in Table 9.12 and their summary statistics for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are separately presented in Table 9.13.

The average estimated technical efficiency for aman season (S_1) is 86 per cent, 89 per cent and 96 per cent respectively for CRS, VRS and SE DEA frontier and these are 83 per cent, 89 per cent and 93 per cent for CRS, VRS and SE DEA frontier for boro season (S_2) respectively. Further, the average estimated technical efficiency of both aman and boro seasons (S_1+S_2) together are 86 per cent, 89 per cent and 96 per cent for CRS, VRS and SE

DEA frontier respectively. Therefore, it is clear from results of output-oriented DEA analysis that there is a scope for comprehensive improvement of production as far as efficiency is concerned. In both seasons, we have got almost similar results, but more opportunity to improve efficiency of boro season (S_2) than in aman season (S_1). Therefore, these results clearly indicate that farmers can reduce production cost and hence can get more output gain through improving 14 per cent to 17 per cent efficiency without introducing new more improved technology in rice production process.

Table 9.12: Frequency Distribution of Efficiency Estimates from DEA Frontier for Aman (S_1), Boro (S_2) and both Aman and Boro Seasons (S_1+S_2) Together

Efficiency Index (%)	Output-Oriented DEA Frontier					
	Number of Farms					
	TE under CRS			TE under VRS		
	Aman season	Boro season	Both season	Aman season	Boro season	Both seasons
01-50	1	0	0	1	0	0
50-55	1	10	0	1	8	0
55-60	3	7	4	2	2	3
60-65	10	12	8	8	9	6
65-70	26	23	18	12	10	10
70-75	17	25	25	14	13	18
75-80	21	27	32	24	18	26
80-85	20	28	21	21	24	18
85-90	42	30	31	19	28	27
90-95	45	35	45	39	45	37
95-100	65	54	67	110	94	106
Total	251	251	251	251	251	251

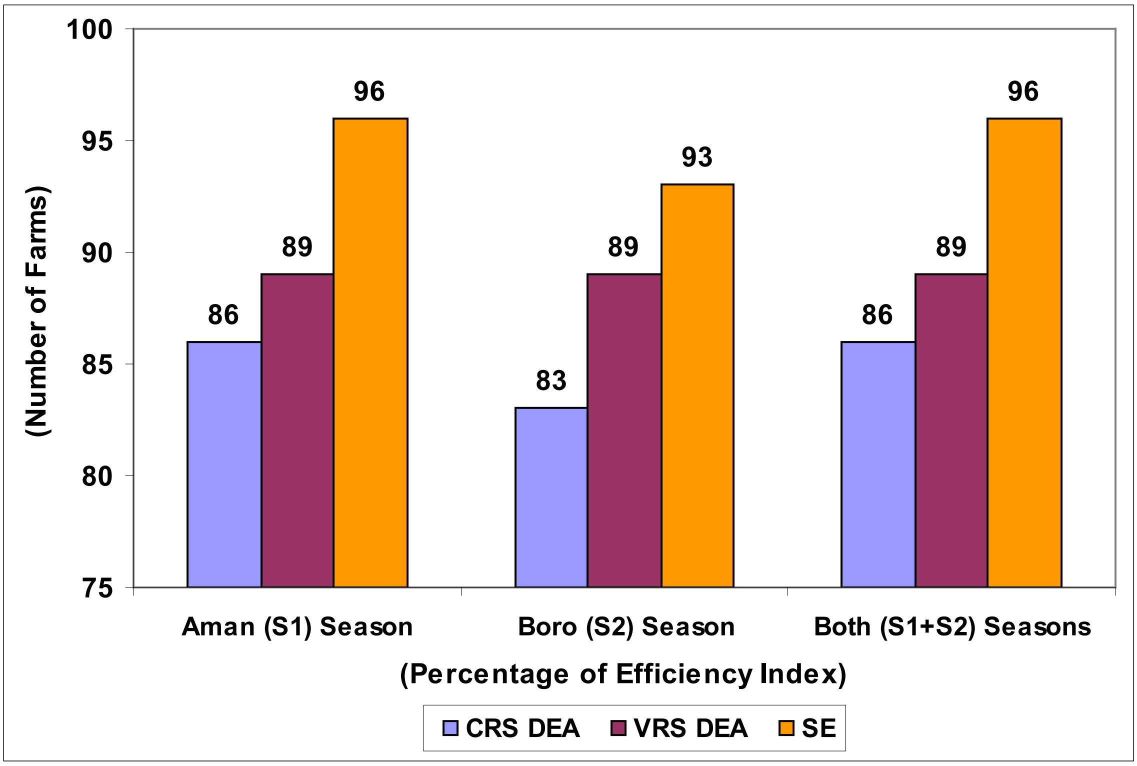
Table 9.13: Summary Statistics of Efficiency Estimates from DEA Frontier for Aman (S_1), Boro (S_2) and both Aman and Boro Seasons (S_1+S_2) (in percentage)

Statistics	CRS DEA Frontier			VRS DEA Frontier		
	Aman season	Boro season	Both seasons	Aman season	Boro season	Both seasons
Mean	86	83	86	89	89	89
Minimum	49	53	55	50	53	57
Maximum	100	100	100	100	100	100
Standard deviation	12	14	11	12	14	11

In terms of scale economies, 42 per cent farms are characterized by increasing returns to scale, 15 per cent farms having constant returns to scale and the rest 43 per cent farms are characterized by decreasing returns to scale technology in aman season (S_1). On the other hand, 40 per cent farms are characterized by increasing returns to scale, 17 per cent farms have constant returns to scale and the rest 43 per cent farms show decreasing returns to scale technology in boro season (S_2) production process.

Graphical presentations of technical efficiency (TE) measures under output-oriented from CRS, VRS DEA frontier and scale efficiency (SE) for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are given in Figure 9.20.

Figure 9.20: Average Estimated Technical Efficiency under Output-Oriented CRS, VRS DEA and SE for Aman (S_1), Boro (S_2) and both Seasons (S_1+S_2) Together



9.5. Factors Associated with Technical Inefficiency Effects

Tobit analysis is used to assess the role of human capital variables, land fragmentation, credit facilities, extension services, land degradation and environmental factors in technical efficiency. We specify the following inefficiency effects model to conduct the Tobit regression model:

$$IE_i = \delta_0 + \delta_1 z_{i1} + \delta_2 z_{i2} + \delta_3 z_{i3} + \delta_4 z_{i4} + \delta_5 z_{i5} + \delta_6 z_{i6} + \delta_7 z_{i7} + w_i$$

Where IE_i denotes farm inefficiency, z_i's are socio-economic and infrastructural variables which affect efficiency of farmers. The z_{i1} denotes age of the farmers, z_{i2} denotes year of education of the rice farmers, the variable z_{i3} represents years of experience on rice cultivation of farmers, the variable z_{i4} denotes land fragmentation, z_{i5} indicates credit facilities dummy which assumes the value one if farmer takes any kind of credit from government and non-government sources and zero otherwise, z_{i6} denotes extension services dummy which assumes the value one if the farmer takes extension services from related officials and zero otherwise; and z_{i7} denotes degradation dummy which takes the value one if land is un-degraded and zero otherwise. The values one for z_{i7} implies that most of land of an individual farm household are un-degraded.

The model includes a random error term, w_i which is normally and independently distributed with a zero mean and variance is σ_w^2. The Tobit model is used as inefficiency, IE_i, is a limited dependent variable with a positive (negative) coefficient will have a negative (positive) effect on the level of efficiency. We use Tobit model as the value of IE_i falls between zero and one, some of the values of IE_i are likely to be zero. We have obtained CRS technical inefficiency (CRS TI), VRS technical inefficiency (VRS TI) by subtracting corresponding efficiency from 100.

Results of the Tobit model for technical inefficiency δ_i coefficients for aman season (S_1) and boro season (S_2) are given in Table 9.14 and 9.15. The estimated coefficients of age and experience of rice producers for aman (S_1) and boro season (S_2) from CRS technical efficiency (TI) and VRS technical inefficiency (TI) are negative and insignificant as in the Cobb-Douglas stochastic frontier case in Table 7.4 and 7.5. This implies that the more aged and experienced rice producers are not more technically efficient than lower aged and less experienced producers in most cases. Again, this implies that the younger and less experienced rice producers utilize new innovated technologies to increase their production and capable in choosing input mixes at minimum cost. Some old and aged producers are conservative and less respective to newly introduced technology and practices; so they are less efficient.

The estimated coefficients years of schooling (education) for both aman (S_1) and boro season (S_2) from CRS and VRS TI are positive and insignificant which is unexpected but insignificant as in the Cobb-Douglas stochastic frontier case in Table 7.4 and 7.5 and those for VRS TI in boro season (S_2) are negative and significant as expected this indicates that more educated producers are responded readily in adjusting input combination with changing input prices and in using new technologies and produce closer to the frontier output than less educated producers.

Table 9.14 and 9.15 exhibit that the estimated coefficients of land fragmentations, i,e,. land plot size, in aman (S_1) and boro season (S_2) from CRS and VRS TI are negative and significant but estimated coefficient from VRS TI in boro season (S_2) are positive and insignificant which implies that, on average, farms with greater plot size, i,e,. less fragmentation, operate at higher levels of efficiency. Better performance among farms with larger plot size is attributed to better application of new technologies like power tillers, tractors and better application and management of irrigation (Wadud, 1990). This corresponds with the results from Cobb-Douglas stochastic frontier for technical efficiency. So the policy implementation is that producer should be encourage to keep their land with greater plot size and therefore, could utilize the benefits of the modern facilities for cultivations, harvesting and irrigation.

The coefficient of credit facilities dummy is positive and insignificant from CRS and VRS TI for aman season (S_1) and those for CRS TI in boro season (S_2) is negative and significant and VRS TI in boro season (S_2) is negative but insignificant. This indicates that it has a positive effect on efficiency of farms. Therefore, if we provide more credit in easiest way to the poor and marginal rice producers, they become more efficient in production process. Credit facilities do have great impact for reducing technical inefficiency in boro season (S_2). So, polices in relation to credit facilities should be improved and possibly make available to the producers of all sectors.

Table 9.14 and 9.15 also indicates that the coefficient for extension services dummy is negative and insignificant from CRS TI and VRS TI of aman (S_1) and boro seasons (S_2) as in the Cobb-Douglas frontier case in Table 7.4 and 7.5. This shows that as farmers are provided more quality extension services they can allocate inputs more efficiently as expected. So the policy implication is that the quality extension service could be encouraged more to reduce inefficiency.

Table 9.14: Results of Tobit Regression Model for CRS in Aman Season (S_1) and Boro Season (S_2)

Factors					
Constant Returns to Scale (CRS)	Para-meters	Aman season (S_1)		Boro season (S_2)	
		Co-efficients	t-ratios	Co-efficients	t-ratios
Constant	δ_0	0.0596	5.0826	0.0524	4.4478
Age (years)	δ_1	-0.0032	-1.0553	-0.0029	-1.0641
Years of Schooling	δ_2	0.0021	0.8538	0.0018	0.5653
Exp. of the farmers	δ_3	-0.0052	-2.4364	-0.0046	-1.3362
Land fragmentation	δ_4	-0.4828	-4.8267	-0.5009	-3.7458
Credit facilities dummy	δ_5	0.0043	1.8749	-0.0037	-2.5368
Extension service dummy	δ_6	-0.0014	-1.0472	0.0013	2.0835
Land degradation dummy	δ_7	-0.0605	-3.1615	-0.0712	-4.2704
Log Likelihood		123.26		114.42	

Table 9.15: Results of Tobit Regression Analysis for VRS in Aman Season (S_1) and Boro Season (S_2)

Factors					
Variable Returns to Scale (VRS)	Para-meters	Aman season (S_1)		Boro season (S_2)	
		Co-efficients	t-ratios	Co-efficients	t-ratios
Constant	δ_0	0.0348	4.0136	0.2543	3.4582
Age (years)	δ_1	-0.0028	-0.5942	0.0021	0.3738
Years of Schooling	δ_2	0.0083	1.3643	-0.0068	-2.9825
Exp. of the farmers	δ_3	-0.0046	-1.3164	-0.0038	-0.4593
Land fragmentation	δ_4	-0.7235	-3.3685	0.6342	2.2921
Credit facilities dummy	δ_5	0.0035	0.8967	-0.0029	-1.9446
Extension service dummy	δ_6	-0.0012	-0.3519	-0.0017	-1.2545
Land degradation dummy	δ_7	-0.0454	-2.0261	-0.0355	-3.4847
Log Likelihood		137.19		120.14	

The estimated coefficients of land degradation dummy for CRS TI and VRS TI for aman (S_1) and boro seasons (S_2) are negative and significant as expected. This implies that land degradation creates problems for applying new technology in cultivation and also restricts to use cost minimizing input combination in production process in northern Bangladesh. More and more degraded lands give more and more inefficiency in production. But in aman season (S_1) coefficients from VRS TI is negative but insignificant. This result conforms to the results obtained by Wadud and White (2000). Therefore, policies which aim to reduce the land degradation could be applied.

9.6. Comparison between Results from SFA and DEA Models

In Chapter 7 and early section of this Chapter, we have given all efficiency results for both SFA and DEA models. We now give some comparison between these results. For both models, we have got some mixed results. But it is interesting to see what kind of different results are found as far as technical efficiency (TE) concerned. In this purpose, we first present comparison of efficiency scores and then results of the inefficiency effects model.

9.6.1. Comparison of Efficiency Scores

The average efficiency measures based on CRS and VRS DEA frontier for technical efficiency scores and results from SFA model is less than both CRS and VRS DEA model. In both aman season (S_1) and boro season (S_2), we have almost similar results.

Few studies compared results obtained from two types of models. Ferrier and Lovell (1990), based on the US banking analysis, show higher technical efficiency for SFA model relative to DEA frontier. These results are consistent with our results. Based on a sample of swine industry in Hawaii, Sharma et. al., (1999) report higher levels of mean efficiencies than results of the stochastic frontier. In our study, we have higher efficiency results from DEA than from SFA model. So our results are similar to Sharma et. al., (1999).

Based on a sample data of Guatemalan farm, Kalaitzandonakes and Dunn (1995) find higher level of mean technical efficiency under CRS DEA frontier than under the SFA model. For the swine industry in Hawaii, Sharma et. al., (1997) report a higher mean technical efficiency obtained from the stochastic frontier (SF) less than those obtained from both CRS DEA and VRS DEA, which is similar to our results. Hjalmarson, Kumbhakar and Heshmati (1996) report both similar and dissimilar results obtained from the SFA model and DEA frontier model.

Percentage cumulative frequency distribution of technical efficiency from Cobb-Douglas stochastic frontier and CRS and VRS DEA from input-output orientation methods for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are presented in Figure 9.21 to Figure 9.26. Cumulative frequency distribution curve of technical efficiency for aman season (S_1) shows similar trends in SFA and CRS DEA methods, but more variability in case of VRS DEA method. In boro season (S_2), technical efficiency scores from CRS and VRS DEA from input-oriented methods give similar results, but more variability in case of the stochastic frontier analysis (SFA) method. Again, cumulative frequency distribution curve of technical efficiency for both aman and boro seasons (S_1+S_2) together show similar trends in SFA and VRS DEA methods, but more variability in case of CRS DEA method.

Figure 9.21: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Input-Oriented methods for Aman Season (S_1)

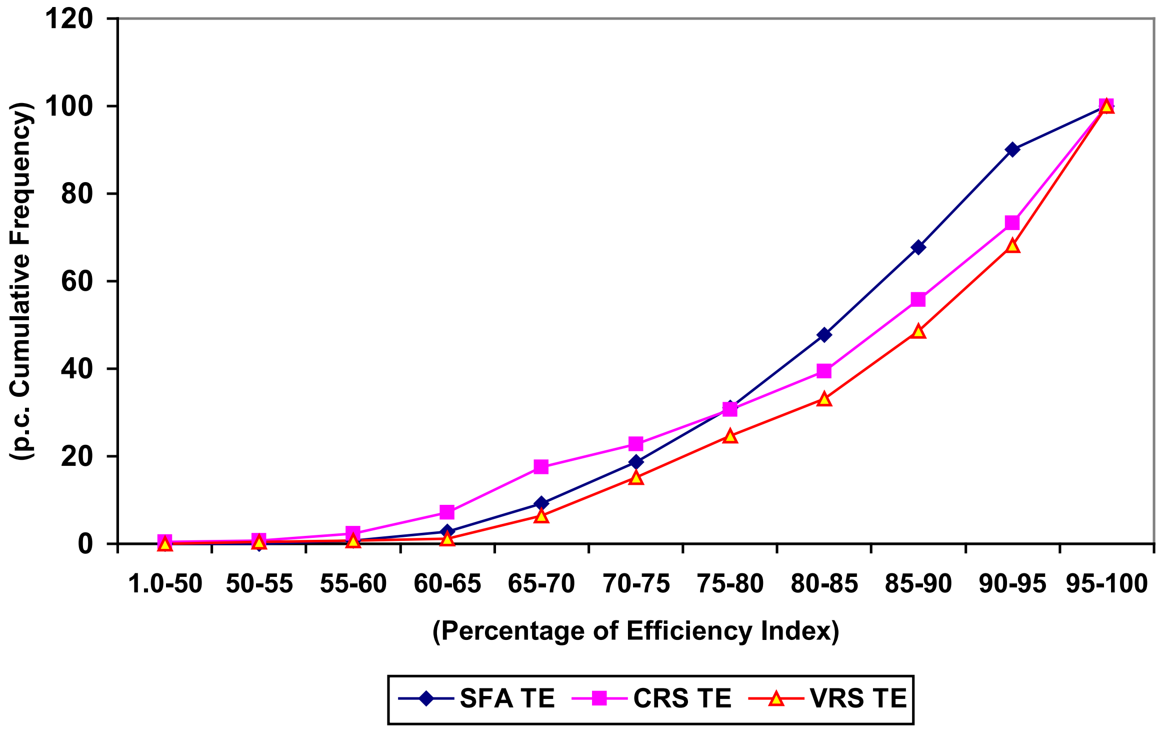


Figure 9.22: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Input-Oriented methods for Boro Season (S_2)

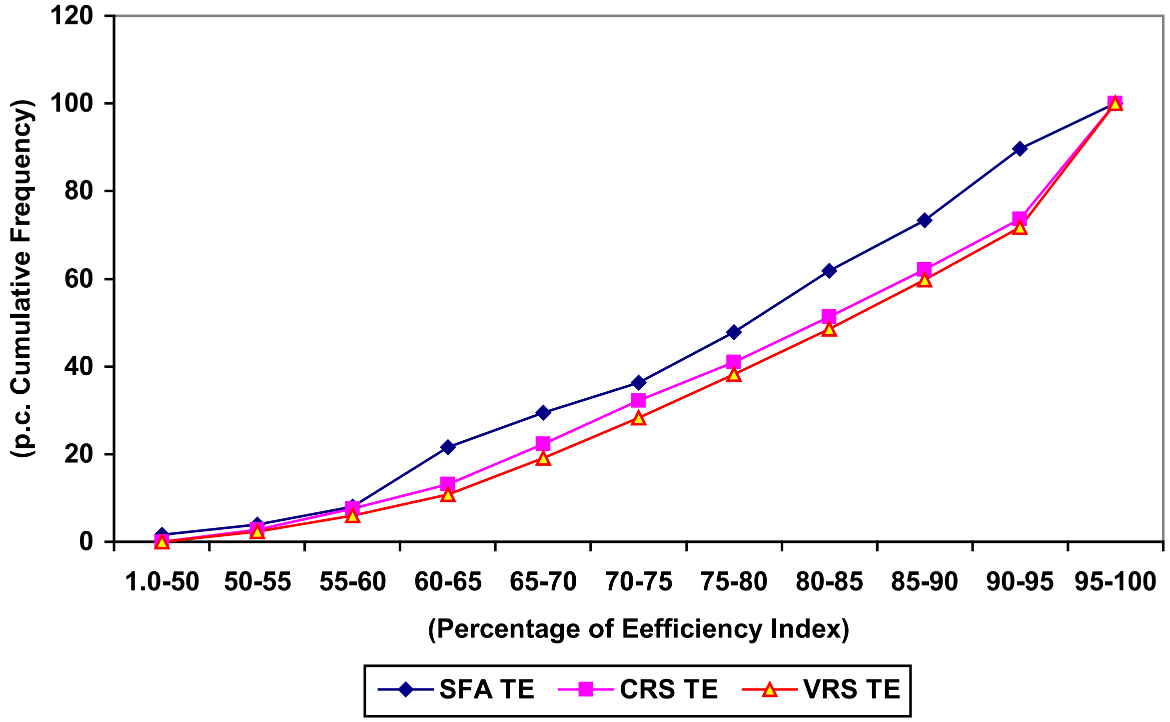


Figure 9.23: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Input-Oriented methods for both Aman and Boro Seasons (S_1+S_2) Together

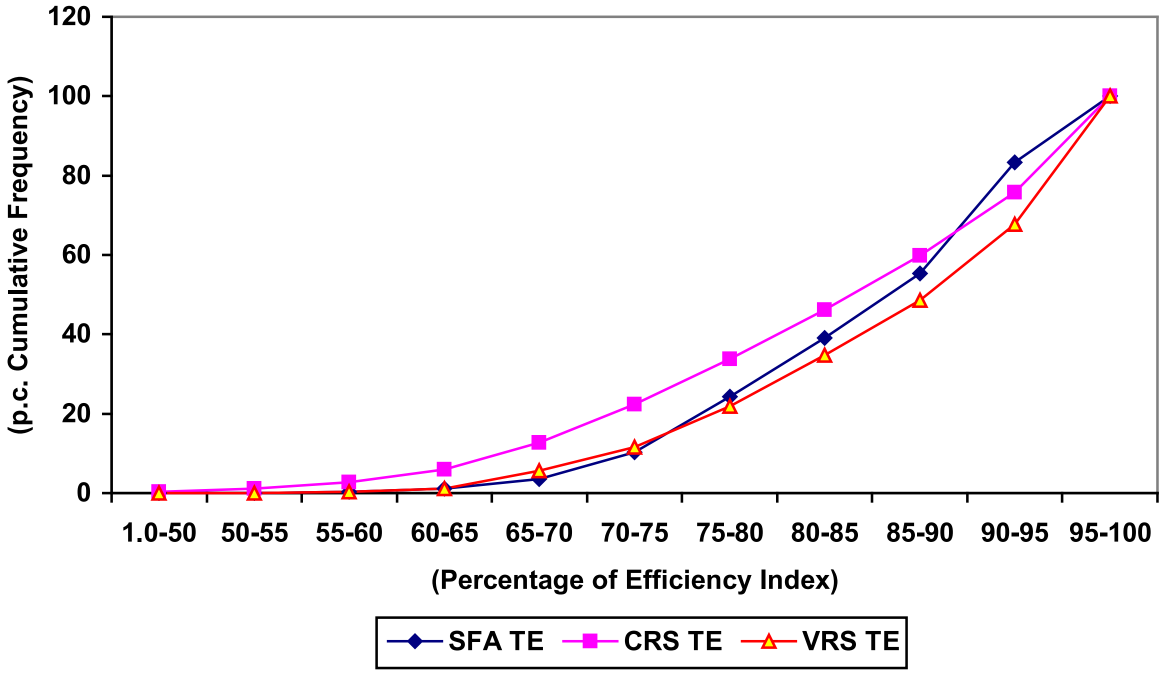


Figure 9.24: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Output-Oriented methods for Aman Season (S_1)

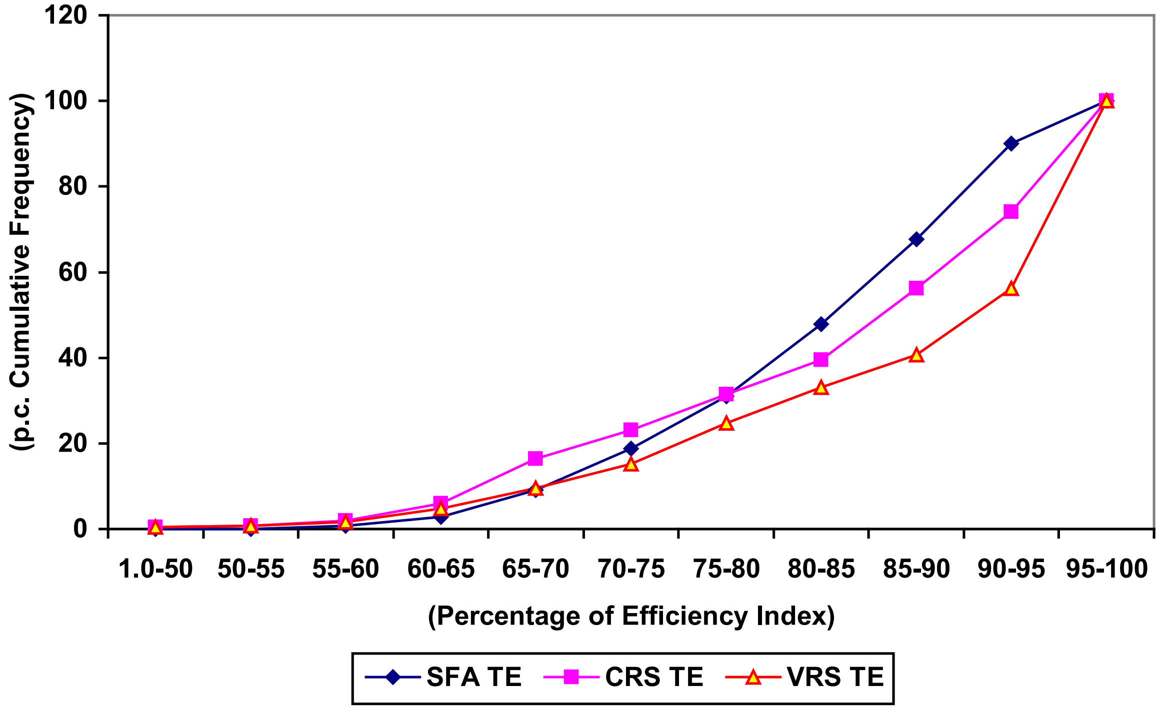


Figure 9.25: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Output-Oriented methods for Boro Season (S_2)

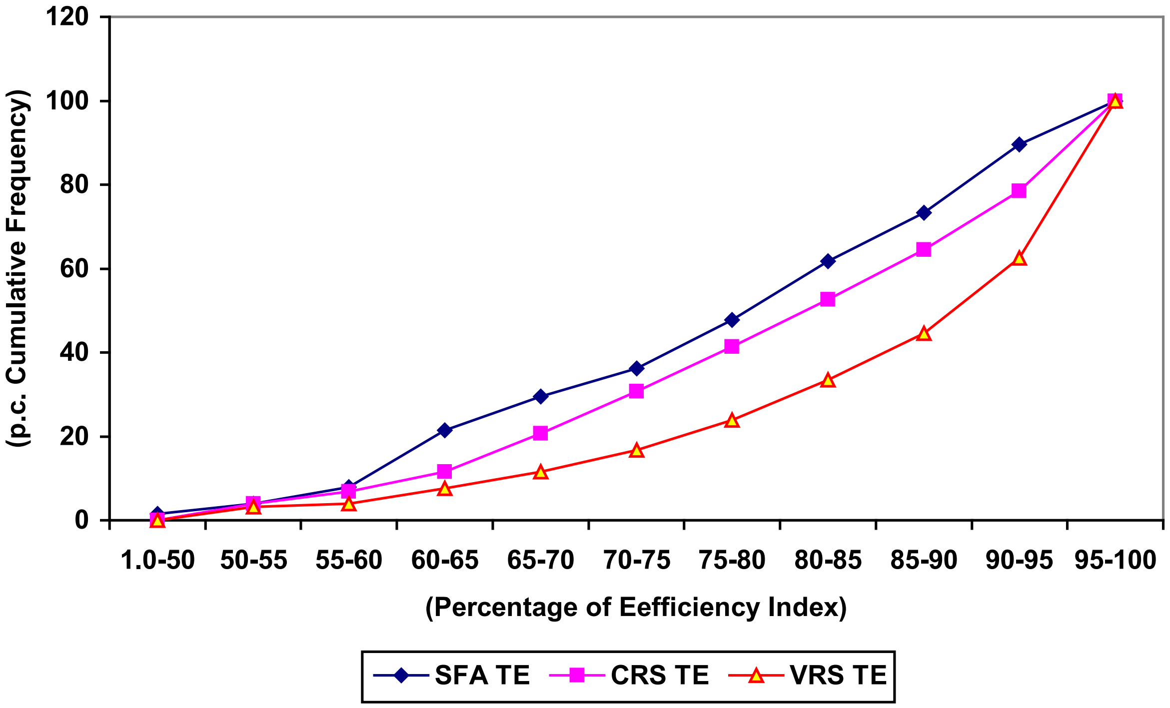
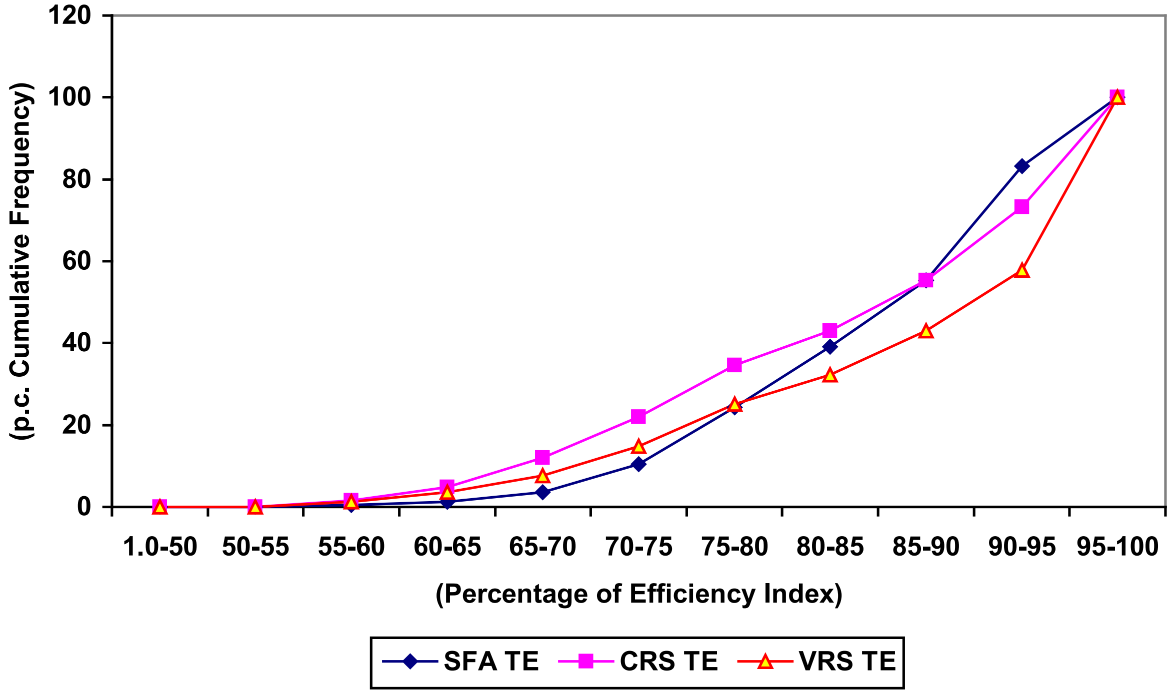


Figure 9.26: Percentage Cumulative Frequency Distribution of TE from SFA and CRS and VRS DEA under Output-Oriented methods for both Aman and Boro Seasons (S_1+S_2) Together



Cumulative frequency distribution curve of technical efficiency for aman season (S_1) and boro season (S_2) show similar trends in CRS and VRS DEA from output-oriented methods, but more variability in case of stochastic frontier analysis (SFA) method in both seasons. Further, again cumulative frequency distribution curve of technical efficiency for both aman and boro seasons (S_1+S_2) seasons together show similar trends in SFA and VRS DEA methods, but more variability in case of CRS DEA method.

In case of technical efficiency of aman season (S_1), cumulative frequency distribution curve shows different trends in case of VRS DEA method. But boro season (S_2) shows different trend in case of SFA method. About 31.07 per cent farmers lie up to 80 per cent efficiency group under SFA model in aman season (S_1), whereas CRS and VRS DEA from input-oriented methods show only 30.68 and 24.70 per cent farmers respectively are in this group. According to SFA model, 47.81 per cent farmers in boro season (S_2) are up to 80 per cent technical efficiency group; whereas according to CRS and VRS DEA methods, only 41.04 and 38.25 per cent farmers are in this group. Further, according to SFA model, 24.31 per cent farmers are up to 80 per cent technical efficient; whereas according to CRS and VRS DEA methods, only 33.86 and 21.92 per cent farmers are in this group in both aman and boro seasons (S_1+S_2) Together.

Again, in case of technical efficiency in aman (S_1) and boro season (S_2), cumulative frequency distribution curve shows different trend in case of SFA method. About 31.07 per cent farmers lie up to 80 per cent efficiency group under SFA model in aman season (S_1), whereas CRS and VRS DEA from output-oriented methods show only 8.37 and 9.56 per cent farmers respectively are in this group. According to SFA model, 47.81 per cent farmers in boro season (S_2) are up to 80 per cent technical efficiency group; whereas according to CRS and VRS DEA methods, only 10.76 and 7.17 per cent farmers are in this group. Further, according to SFA model, 24.31 per cent farmers are up to 80 per cent technical efficient; whereas according to CRS and VRS DEA methods, only 34.65 and 25.10 per cent farmers are in this group in both aman and boro seasons (S_1+S_2) together.

Thus we may conclude from these results that SFA model implies more room for production gain through improvement of technical efficiency than DEA method. But there are similar opportunities to get production gain by improving technical efficiency for both SFA model and DEA methods.

9.6.2. Comparison of Result of Inefficiency Effect (IE) Model

The inefficiency effect models are estimated using Tobit regression analysis. We have discussed these results of inefficiency effect model for SFA model in Table 7.4 and 7.5 for aman season (S_1) and boro season (S_2) respectively in chapter 7. On the other hand, inefficiency effect model for DEA frontier are presented in early section of Table 9.14 and 9.15 in this Chapter. These show that estimated coefficient of years of education for technical inefficiency (TI) are positive for both SFA and DEA model in aman (S_1) and boro seasons (S_2). This result conforms to results obtained for Kanzara village by Coelli and Battese (1996). This is expected and implies that less educated farmers allocate the inputs less efficiently and more educated farmers allocate the inputs more efficiently with changing input prices.

The estimated coefficients for age and experience of farmers for technical inefficiency (TI) from both models give negative coefficient. Which suggest that relatively new farmers are more technically efficient than their old counterparts. This result is similar to results obtained by Coelli and Battese (1996), Ajibefun et. al., (1996) and Seyoum et. al., (1998). The older farmers are more experienced in terms of length of cultivation period, although they are conservative in nature. So they are less interested to introduce new technologies in cultivation. Therefore, perhaps they are more technically inefficient in production.

The estimated coefficient of land fragmentation, i,e., plot size is negative, as is expected for both frontiers. This results show that farmers on average with greater plot size, i,e., less land fragmentation, operate at high level of technical efficiency.

The estimated coefficients on credit facilities dummy are positive in aman season (S_1) from CRS and VRS for technical inefficiency (TI). But for boro season (S_2), all estimated coefficients on credit facilities are negatively related.

The estimated coefficient on extension services dummy in aman season (S_1) and boro season (S_2) for technical inefficiency from both SFA and DEA frontier is found to be negatively related.

The estimated coefficients on land degradation dummy for both aman season (S_1) and boro season (S_2) from both frontiers give negative results. So, land degradation situation has a huge impact on all kinds of efficiency scores.

9.7. Summary and Conclusions

In this Chapter, we have described results obtained from DEA frontier model by using the program DEAP, version 2.1 (Coelli, 1996). Input and output oriented DEA methods are estimated for the same number of farmers. Scale efficiency is obtained by the ratio of CRS and VRS DEA efficiency estimates. We have got almost similar results from both orientations. Summary results of input and output oriented DEA show that there are small differences between VRS input and output oriented DEA method. The average estimated technical efficiency in aman season (S_1) are 86 per cent and 88 per cent respectively for CRS and VRS DEA frontier and those are 83 per cent and 85 per cent for CRS and VRS DEA frontier in boro season (S_2) respectively. Efficiency scores in boro season (S_2) is little less than in aman season (S_1). These results imply that there are rooms to improve efficiency level of farmers by 12 per cent to 17 per cent without any change in production process or without introducing any technology. Therefore, farmers can get more output gain without applying new improved technology.

Like the stochastic frontier analysis (SFA) model, the DEA frontier model results show that there is a room to improve efficiency levels of farms without improving technologies for both aman (S_1) and boro seasons (S_2). More specifically, CRS and VRS DEA frontier results show that 14 per cent and 12 per cent technical efficiency (TE) in aman season (S_1) and 17 per cent and 15 per cent technical efficiency (TE) respectively in boro season (S_2) could be improved if the farmers would operate at full efficiency level.

We have discussed human capital and other factors as the sources of inefficiency in production process. Some of the inefficiency factors are discussed with their effects. Age and education of farmers, experience for cultivation, land fragmentation, credit facilities and environmental degradation are most important in determining the sources of inefficiency. Quality extension services can also have played a vital role to improve the efficiency of farmers.

Comparison of results from stochastic frontier analysis (SFA) and data envelopment analysis (DEA) frontier for aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) is produced in this Chapter. Cumulative frequency distribution curve of technical efficiency (TE) for aman season shows similar trends in case of input-output CRS and VRS DEA method, but small variability in case of VRS DEA method in boro season (S_2), technical efficiency (TE) scores from SFA and DEA methods give different results.

Thus we may conclude from these results that stochastic frontier analysis (SFA) model implies more room for production gain through improvement of technical efficiency (TE) than data envelopment analysis (DEA) model.

Chapter 10

Conclusion and Recommendations

10.1. Introduction

This study examines the pattern and sources of technical efficiency of rice farms in Northern Bangladesh. We apply the stochastic frontier analysis (SFA) and data envelopment analysis (DEA) approach to obtain estimates of technical efficiency. We make some comparison of efficiency estimates obtained from two approaches. We estimate technical efficiency by specifying a Cobb-Douglas stochastic production model. The farm households appear to be decreasing returns to scale under the set up of stochastic frontier approach in general, but they are dominantly decreasing returns to scale under the DEA methodology.

The inefficiency effects model are examined as a function of various farm specific socioeconomic variables, environmental factors, irrigation infrastructure. We explain how these factors affect the efficiency performance.

We give in the next section summary of pervious chapters. Conclusion and some recommendations are discussed in the final section.

10.2. Summary of Results

Bangladesh is a small country in south Asia with a population of almost 160.80 million, increasing at a rate of 1.3 per cent, adding about 2 million labour forces with the existing 72 million every year. Agriculture is the principal economic activity and still the single largest contributor to GDP. It provides 43.60 per cent of total national employment. If we only consider the rural economy, then agriculture alone provides employment for more than 65.41 per cent of the rural labour forces. Among the various agricultural crops, rice is the main crop as well as the staple food of the country and the demand for rice is constantly rising in Bangladesh with nearly 2.3 million people being added each year to its population. Bangladesh is still dependent on food import and the pressure on import is on a rise in recent years. To feed the growing number of population is one of the big challenges this country. So, the policy makers should take immediate measures to enhance rice production of the country. They may consider two measures for rice productivity gains: (1) technological improvement and (2) efficiency improvement. Technological changes in agricultural system is not so easy, it is much complex and time being and will need huge amount of investment in agriculture sector.

Efficiency improvement depends on the farmer's experience, level of education, land size and fragmentation, credit facilities, extension services, use of modern technology, use of improved seeds, chemical fertilizers, pesticides and other inputs. Efficiency improvement process is easy, it takes small time and will need small amount of investment. So, the policy makers might have given more emphasis to the improvement of efficiency rather than technological change. This study tries to find out how these factors could affect the efficiency performance of the rice producers in our study area of Northern Bangladesh.

In second chapter, we have reviewed in detail the literature related to productivity, performance and efficiency of rice farms of northern Bangladesh. Since objectives of this study is to measure technical efficiency of the farms of Bangladesh. We review both stochastic frontier analysis (SFA) and data envelopment analysis (DEA) which have been popular since Aigner, Lovell and Schmidt (1977) and Charnes, Coopers and Rhodes (1978). In an influential article, Farrell (1957) proposes two ways to estimate efficiency of farms in production. Farrell's presentation is outstanding and pioneering in finding two distinct and methodologically different ways to obtain measures of efficiency. Among these, stochastic frontier is parametric or econometric approach and DEA is nonparametric or mathematical approach. Both approaches are popular in recent time. The general stochastic frontier production function model decomposes the composed error term into two components: a stochastic random error component and an asymptotic non-negative random term which reflects inefficiency. DEA is a nonparametric mathematical approach which has been developed independently of the stochastic frontier approach over the last three decades. The DEA frontier gives either the maximum output for a given input level or uses the minimum input for a given output level. Thus this analysis of efficiency has an input-saving or output-augmenting interpretation.

In chapter three, we have given a brief review of the study area and its socio-economic, climatic, weather and physiographical conditions. The study area is located in the northern part of Bangladesh. Rice is the main crop in this area. Around 47 per cent of the region is classified as highland and about 41 per cent medium highland and the rest is lowland. The overall weather condition of the study area is hotter, and less rainfall is observed than the rest of the country. The surface water is not sufficient for agricultural use in this area. The average rainfall is about 1628.23 mm per year. The major constraints to agriculture in this area, specially to cultivation of dry land are unstable silky top soils and strongly developed plough pans which make the soil quickly wet and dry. In Tanore upazila 15.14 per cent farmers are marginal and small, whereas in Manda and Nachole 24.31 per cent and 10.75 per cent farmers are marginal and small. About 10.76 per cent, 18.72 per cent and 11.16 per cent farmers are medium in Tanore, Manda and Nachole upazilas respectively. Only 2.39 per cent, 4.78 per cent and 1.99 per cent large farmers exist in Tanore, Manda and Nachole upazilas. Land used under different rice cultivations during the survey period 2009-10 in aman season are 231.68 acres in Tanore upazila, 374.75 acres in Manda and 292.94 acres in Nachole upazila. On the contrary, in boro season land used in survey areas are 234.82 acres in Tanore upazila, 533.44 acres and 295.94 acres of Manda and Nachole upazilas. Most of land of the study area fragmented. About 86.46 per cent farmers have an average plot size is less than half an acre.

In chapter four, we have discussed field level survey methodology of collecting data and survey results. We conduct a survey of 251 rice producers from ten villages of three upazilas from three different districts. About 28.29 per cent rice farmers are selected in Tanore upazila at Rajshahi district, 47.81 per cent and 23.90 per cent rice farmers are sampled in Manda and Nachole upazilas from Naogaon and Chapai Nawabganj districts. List of farmers are collected from upazila agricultural offices. We have used a structural questionnaire to collect primary data, both closed and open-ended types of questionnaires are used. The data, used in this study, are collected from two consecutive rice seasons, aman and boro. In aman season (S_1) data are collected from December to February 2009-10 and boro season (S_2) data from June to August 2010.

Before collecting data from rice producers, we have done a pilot survey among respondents. About 72.51 per cent farmers among respondents are between ages of 20 years to 50 years, 17.13 per cent farmers have never attended the school and others have no professional training about rice cultivation. About 33.07 per cent rice farmers in the survey area are included in the education group of 1-4 years and 50.99 per cent farmers have an experience of 5-25 years of rice cultivation. Most of farmers are small and medium. In aman and boro rice 66.93 per cent and 58.56 per cent farmers have cultivated land are less than 5 acres during survey period in 2009-10. About 70.91 per cent farmers' have average cost of production in aman season (S_1) is between 18-21 thousand taka. About 35.45 per cent farmers' have average cost in boro season (S_2) is between 20-22 thousand taka. About 69.33 per cent and 32.67 per cent farmers' rice production in aman season (S_1) and boro season (S_2) are between 30 to 50 mounds (1 mound = 37.32 Kg) respectively.

In chapter five, we have conducted different issues relating to production function and some related issues of efficiency of rice farms in northern Bangladesh. Farrell's (1957) article on efficiency measurement based on production function provide the concept of technical efficiency. Technical efficiency reveals the ability of a farm to obtain maximum output from a given set of input or ability to minimize input use in the production of a given vector. Since technical efficiency is the core of Farrell's (1957) productive efficiency, the focus of the study is centered on the fundamental of the technical efficiency. According to Farrell (1957), technical efficiency can be obtained for input orientations and output orientations. Accordingly this chapter discusses the notion of production function, marginal productivity, output elasticity, marginal rate of technical substitution and returns to scale. The output elasticity is a unit free measure of marginal productivity and estimates the degree of substitution between inputs. The efficiency implies that a farm produces maximum output by utilizing its available inputs with minimum cost. If the farm fails to achieve optimal output by using minimum quantities of inputs under existing technical support then the farm is inefficient (Koopman,1951). Thus the concept of technical efficiency arises as the ability to produce maximum output by minimum input mix with existing technology.

Stochastic frontier analysis (SFA) is discussed theoretically in chapter six. We discussed the evolution of the concept stochastic production frontier analysis (SFA). The analytical foundation for the definition of efficiency goes to Farrell (1957). The major econometric approach to estimation of frontier efficiency involves deterministic frontier model and stochastic econometric frontier model. Econometric SFA approach needs to impose an explicit functional form for the underlying technology and distributional assumptions for the inefficiency term. The great merit of stochastic production frontier model is that impact on output due to internal or external shocks can be separated. Exogenous shocks on output can be separated from the contribution of variation in technical efficiency by incorporating an additional random error term. Therefore, in stochastic frontier approach the error term is segmented into two components. Since the error term has two components, the stochastic production frontier model is often called as composed error model. Stochastic frontier analysis is introduced by Meeusen and vanden Broeck (1977). At the same time, Aigner, Lovell and Schmidt (1977) have introduced independently and separately the stochastic production frontier model. The stochastic production frontier model permits the estimation of standard errors and tests of hypothesis by using maximum likelihood (ML) method, which has been impossible under deterministic production function. It has been discussed that we need a specific functional form of a production function to fit stochastic model. In our study, stochastic frontier production model is specified by the Cobb-Douglas production model.

In seventh chapter, we describe the technical efficiency results obtained by using the stochastic Cobb-Douglas production function model. We obtain technical efficiency (TE) estimates scores for 251 rice farms of northern Bangladesh in a single output and multiple input framework for the period in aman season (S_1) in December-February 2009-10 and boro season (S_2) in June-August 2010. According to objectives of our study we obtain overall technical efficiency (TE) scores as average of all 251 rice farms. We then compare the results of the technical efficiency scores achieved in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together. Comparative efficiency performance is shown in Table 7.10 and Figure 7.4.

The stochastic frontier results show that sign of the β_i parameters of the Cobb-Douglas stochastic frontier are all positive, as expected. Some unusual characteristics are observed in case of labour and seeds. This perhaps because of existence of disguised unemployment of labour and excessive use of seeds or misuse of seed in the production process.

Mean score of technical efficiency in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 85.17 per cent, 80.42 per cent and 86.85 per cent respectively. So there is an opportunity to increase technical efficiency of farmers by 14.83 per cent, 19.58 per cent and 13.15 per cent in aman season (S_1), boro season (S_2) and both aman and boro (S_1+S_2) seasons together without any change or improvement on cultivation technologies if farmers operate at full efficiency levels.

In chapter eight, we have discussed methodology of data envelopment analysis (DEA). Application of DEA as an empirical methodology is conducted under several sections. DEA is a non-parametric mathematical programming approach to estimate efficiency of production unit. DEA can handle multiple outputs and multiple inputs at the same time. Measures of efficiency obtained from DEA are considered as Pareto optimal. This approach is formulated for two types of orientations, input orientation and output orientation. Method of estimating of productive efficiency of the farms with nonparametric methods is obtained. Empirical investigations have been discussed on the efficiency scores that varies over time. Technical efficiency is divided into two types of efficiency under data envelopment analysis (DEA). Constant returns to scale (CRS) and the variable returns to scale (VRS) frontiers produce overall technical efficiency. Scale efficiency (SE) is calculated as a ratio of CRS technical efficiency and VRS technical efficiency. Comparing efficiency estimates from CRS and VRS technical efficiency and non-increasing returns to scale (NIRS) technologies, economies of operation level is found for individual farm. These measures are found for both input-oriented DEA and output-oriented DEA for individual farm. Empirical result shows that there is not much difference as far as orientation is concerned.

In chapter nine, we have discussed the results obtained for 251 rice farms in northern Bangladesh with the application of data envelopment analysis (DEA) under input orientation first and then under output orientation. We compare the results of DEA with those obtained from stochastic frontier model. We find under input-oriented DEA mean efficiency scores. Results of CRS and VRS DEA show technical efficiency (TE) and scale efficiency (SE) in aman season (S_1), boro season (S_2) and both aman and boro seasons (S_1+S_2) together are 86 per cent, 88 per cent and 97 per cent, 83 per cent, 85 per cent and 97 per cent, and 86 per cent, 89 per cent and 97 per cent respectively. At the same season, under output-orientation, CRS and VRS DEA methodology gives technical efficiency (TE)) and scale efficiency (SE) scores are 86 per cent, 89 per cent and 96 per cent, and 83 per cent, 89 per cent and 93 per cent, and 86 per cent, 89 per cent and 96 per cent respectively. These results imply that there are rooms to improve efficiency level of farmers by 14 to 17 per cent without any change in production process or without introducing any new technology. Therefore, farmers can get more output gain without applying new improved technology.

10.3. Conclusion and Recommendations

This study assesses different efficiencies of rice farms on the basis of production frontier and mathematical programming frontier. One of the contributions of this research is that stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are applied to analyze technical efficiency of farms in northern Bangladesh. We have measured overall technical efficiency and scale efficiency of farms. We have compared farm efficiency under stochastic econometric frontier and data envelopment analysis. Each method has its strength and weaknesses. The stochastic frontier model imposes a functional form on technology and a distributional assumption on inefficiency effects. It distinguishes the effects of noise from the effects of inefficiency.

Results of inefficiency effects model from both the stochastic frontier and DEA frontier approach imply that inefficiency effects in production are influenced by many factors. Results suggest that education, experience, plot size and land fragmentations, credit facilities, extension services, land degradation and irrigation infrastructure are statistically significantly associated with technical inefficiency.

One of the major inefficiency effect factors in production is land fragmentation, that is, smaller plot size. So policies should be targeted in such way that the existing land tenure and land management system can reduce land fragmentation.

Credit facility is one of the important factors which is related to efficiency of farmers. Credit particularly agriculture credit facility in this study area as well as in Bangladesh is not so organized. Results from both methodologies suggest that credit is directly related to inefficiency. At the same time during the field level survey we observe that there are lots of difficulties faced by the farmers to get agricultural credit. For an example, government financial institution like Rajshahi Krishi Unnayan Bank (Agriculture Development Bank in Northern part of Bangladesh) and other institutions have lots of formalities and processes which discourage rural and low educated farmers to go there for credit. Agricultural credit systems through government banks are lengthy and complicated process. So, poor and uneducated farmers feel helpless. With this context, some corrupted local leaders and peoples help them by taking money. On the other hand, non-government organizations and other institutions, which have credit programs especially micro-credit program, are generally not interested to agriculture. Even they have some credit program for agriculture; the interest rate is so high that farmers are not benefited by taking that kind of credits. Another serious problem should be noted here that the marginal farmers sell their products or crops in advance to get credit from local Mahajans (village micro credit providers). Therefore, they do not get appropriate price for their crops. So, policies should be targeted to improve the credit facilities for farmers. Credit system should be made simple and disciplined and formalities should be minimized so that people can get credit as easier way as possible.

Results show that extension services are directly related to efficiency of the farmers. Both SFA and DEA approaches give similar results. Field survey also indicates that in this region there are very poor extension services facilities to the grass-root level. So, if the proper authority gives appropriate effect to improve the extension services, it would be expected that farmers' efficiency in rice cultivation will improve. Therefore, policies should be targeted to increase quality extension services for the grass-roots and marginal farmers.

Irrigation infrastructure is another prime factor to influence efficiency of the farmers in Bangladesh. Irrigation infrastructure has developed sufficiently in the northern Bangladesh by the help of Barind Multipurpose Development Authority (BMDA). Moreover, Rural Electrification Board (REB) supplies power to the deep tube-wells. So, policies should be to keep this irrigation infrastructure as well as improve and should supply electricity to the deep tube-wells timely and efficiently.

Land degradation is considered as an environmental factor. Results show that it decreases technical efficiency. So it implies that land degradation decreases farmer's ability to utilize the existing technology in full capacity and hinders the allocation of inputs in a cost minimizing way. On the other hand, results from both frontiers for aman season (S_1) and boro season (S_2) indicate that human factors such as, age and duration of formal education i.e., years of schooling and cultivation experience of farmers are more or less affect the efficiency of the farmers. So, policies which aim to reduce land degradation and also policies related to agricultural education and training could be taken to improve practical knowledge and experience of farmers, which in turn improve the efficiency of farmers.

Government of Bangladesh, in recent time, is giving more emphasis on agriculture sector. For these purpose, government has increased agriculture subsidy, particularly to fertilizer and irrigation from Tk 120 million to Tk 650 million during 2011-12. The government should strictly supervise whether benefits of subsidized money are going to the targeted marginal and small farmers of the country. This study suggests that if the policy makers give more attention to the inefficiency factors which are identified in this study, then it will be easier to help the rural level farmers as far as efficiency is concerned. The electrification program in rural area is most useful and time demanding task for irrigation. Production and new technology related to education and training programs should be extended by the Thana/Upazila extension agriculture offices. Learning by doing workshop for land degradation and use of new methods of production could be arranged. Therefore, the target people could be educated and properly trained so that they become capable to operate the existing technology more efficiently and can easily adapt the new technology to come. So, policies to reduce land degradation and to use more environment friendly fertilizer and pesticides will decrease technical inefficiency and hence eventually increase rice production and welfare of the farm households.

From the statistics of efficiency estimates, it is obvious that a considerable amount of technical inefficiency among the sample farm household in this study is found. Therefore, there is a substantial potential for increasing rice production through the improvement of technical efficiency without any remarkable change in production process or existing technology. More specifically, the sample farmers, on average, could increase their production by 14 to 20 per cent depending on frontier methodology, seasonal variation and scale assumption if they could operate at full technical efficiency levels, given the existing technology. If efficiency of farmers' are increased, resulting cost of production will be decreased. In other words, farmers have not to pay extra-expenditure for their improvement in production. Therefore, it is helpful for them for further production which increase welfare for their own and family members. In some sense, it helps for the development of agriculture sector, as well as, the rural economy of the country.

We summarize recommendations and policy implications based on this research which are as follows:

From our own observation during this study, we found that people in rural area do not get the appropriate price for their agricultural product. Lion part of benefits goes to the middle-man and businessman who are not directly involved with production process. Thus, farmers do not cover total cost of production and face losses day by day. This creates direct effects on efficiency performance of farmers. So government should take initiative to buy the agricultural products from farmers directly or introduce systems where farmers can get appropriate prices for their product.

Land fragmentation or small size of land is one of the prime problems in our agriculture sector. So, the government should revise the existing land tenure and management system in a fashion that could help to introduce modern technology in this sector.

Agricultural credit is one of the major factors which influence directly the efficiency level of farmers. But credit facilities in rural agricultural sector are not so organized. Recently a study, organized by the World Bank and Bangladesh Government, shows that 55 per cent rural money goes to the urban area for investment. To protect this money flow from rural to urban sector, government should motivate small investors to invest in agriculture-based small industries in rural area. So, the environment in favour of investment could be increased by increasing banking, electrification, marketing facilities and rural infrastructure. The securities for the marginal and small investors in the rural area could be increased.

Extension services for the farmers can contribute to improve the efficiency level of the farmers. Government should give attention to increase the quality of extension services for the rural area, so that they can be able to use inputs in appropriate proportion and minimize the misuse of input use.

Agriculture subsidy can contribute a lot to improve the efficiency of the farmers in third world country, like Bangladesh. Government of Bangladesh already has taken initiatives to improve subsidies of Tk 120 million in 2005-06 to Tk 650 million in 2011-12. But government should be ensured that this allocated money for subsidy goes to benefits of the targeted people, so that they can buy agricultural inputs at subsidized rate which will improve their efficiency performance.

Irrigation mainly depends in this area on ground water. If farmers use surface water easily that will reduce the cost of irrigation. So, policies should be introduced to reduce dependency on ground water. Therefore, the facilities to use surface water should be improved by reconstructing canals, Khals, ponds and semi-dead rivers.

Formal education, particularly agriculture related education can help the farmers to increase their knowledge about rice cultivation and cost minimizing input use. So, government should take initiative to provide this kind of formal and informal education facilities to the poor marginal and small farmers.

To avoid the excessive use or misuse of seeds, farmers can use dram seeder, a new technique of seeding, in their cultivation process. This will reduce the cost of seeds and will improve efficiency performance of farmers.

10.4. Further Research

We have examined technical efficiency only but one can further investigate allocative efficiency and economic efficiency. There is no scientific method introduced in Bangladesh to measure environmental degradation. Scientific techniques like Geographical Information System, remote sensing and soil surveys can be applied to measure land degradation. The inclusion of the resulting measure of land degradation can improve the prediction power of our efficiency models.

To find answers all of these questions, further research and investigation are required.

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Appendix

Appendix 4.1: Questionnaire

Here we show the full set of the questionnaire adopted in the field survey. For our study we have not used all the information in tabular form. Those not so used were however not unimportant. They were helpful for a good understanding of the behaviour of our sample farm households and aided much in the analysis of the qualitative data.

01. Area Base Information

Name of the district		Name of the upazila	
Union		Village	

02. Personal Information (use tick sign)

S/I.	Name of the Household				
(i)	Age	Years	Experience	Years	
(ii)	Sex	(1) Male ☐	(2) Female ☐		
(iii)	Marital status	**(1) Unmarried □**	**(2) Married □**	**(3) Widow □**	**(4) Divorced □**

03. Household Characteristics

Number of people living in the household		Number of children of the household	

04. Information of Total Members of the Household (children and others)

Serial no.	Name	Age	Sex	Education	Income	Relationship
(i)						
(ii)						
(iii)						
(iv)						
(v)						
(vi)						

05. Occupational Information of the Household

Serial no.	Name of occupation	Duration	Per year spent time	T. Income
a) Main Occupation				
b) Others Occupation				
(i)				
(ii)				

06. Information of Formal Education

Serial no.	Type of education	use tick sign	Years of schooling
(i)	Never attended school	□	
(ii)	Below class six	□	
(iii)	Above class five but below SSC	□	
(iv)	SSC	□	
(v)	HSC	□	
(vi)	Bachelor degree	□	
(vii)	Masters degree	□	
(viii)	Technical education	□	

07. Special Status of the Household (use tick sign on serial no.)

Serial no.	Status	Serial no.	Status	Serial no.	Status
(i)	Teacher	(iii)	Official (non-Govt.)	(v)	Ordinary member
(ii)	Official (Govt.)	(iv)	Ward member	(vi)	Business man

08. Information of Land Ownership of the Household

Serial no.	Type of land	Quantity in acres	Serial no.	Type of land	Quantity in acres
(i)	Total cultivable land		(iv)	Forest area	
(ii)	Homestead area		(v)	Fallow area	
(iii)	Garden		(vi)	Total area owned	

09. Description of Cultivable Land of the Household (in acre)

Serial no.	Type of land	Quantity in acre	Serial no.	Type of land	Quantity in acre
(i)	Own cultivated land		(vi)	Total cultivated land	
(ii)	Rented in land		(vii)	No. of plots	
(iii)	Rented out land		(viii)	Plot size (average)	
(iv)	Share cropping in land		(ix)	Plot distance(average)	
(v)	Share cropping out land		(x)		

10. Own Land Utilization (in acre)

Rice and Seasons	Cultivated land area	Market price per acre	Cultivated land price	1% cultivated land value	
				T.Culti.land	Per acre
Aman season (S_1)					
Boro season (S_2)					
Aus season (S_3)					
Total					

11. Land Utilization (Rented-in/Sharecropping-in Land)/(Rented-out/Sharing-out Land)

Rice and Seasons	Cultivated land area	Market price per acre	Cultivated land price	1% cultivated land value	
				Per acre	Rent value
Aman season (S_1)					
Boro season (S_2)					
Aus season (S_3)					
Total					

12. Do you think the following points cause land degradation?

(i) Use cow-dung for domestic fuel (1) Yes □, (2) No.□

(ii) Use crop residues for domestic fuel (1) Yes □, (2) No.□

(iii) Use leaves and twigs for domestic fuel (1) Yes □, (2) No.□

(iv) Grazing domestic animal in the open field (1) Yes □, (2) No.□

(v) Excess use of chemical fertilizers (1) Yes □, (2) No.□

(vi) Please specify any other reasons (If any)

....

13. Family Labour Utilization (per acre)

Serial no.	Seasons	Male	**Female**	**Child**	Hours of work (Per day)	Days of work	Wage rate (Per day)	Total labour cost
(i)	Aman (S_1)							
(ii)	Boro (S_2)							
(iii)	Aus (S_3)							
Total								

14. Hired Labour Utilization (per acre)

Serial no.	Seasons	Male	**Female**	**Child**	Hours of work (Per day)	Days of work	Wage rate (Per day)	Total labour cost
(i)	Aman (S_1)							
(ii)	Boro (S_2)							
(iii)	Aus (S_3)							
Total								

15. Some questions about the labour market

(i) Any socio-economic problem exist in labour market? (1) Yes □ , (2) No. □

(ii) Do you have any comment about the labour market? (1) Yes □ , (2) No. □

If yes, please specify ....

(iii) Any suggestions for improvement of the labour market? ....

16. Plough Cost (per acre)

S/I.	**Seasons**	Home plough	Buy plough	Wooden plough	Power-tiler	Tractor used	How much time used	Per time cost	Total cost
(i)	Aman								
(i)	Boro								
(iii)	Aus								
Total									

17. Seed Utilization in Kg. (per acre)

S/I.	Seasons	Home seed	Buy seed	Amount (Kg)	Price per Kg (Taka)	Total market price (Taka)	Trans. cost	Total seed cost
(i)	Aman							
(ii)	Boro							
(iii)	Aus							
Total								

18. Fertilizers Utilization in Kg. and Pesticides (per acre)

S/I.	Seasons	Cow-dung (mound)	Urea (Kg)	TSP (Kg)	MOP (Kg)	DAP (kg)	Others (Kg)	Total used Fertilizer	Pesticides used (kg/ml)
(i)	Aman								
(ii)	Boro								
(iii)	Aus								
Total									

19. Cost of per Kg. Used Fertilizers and Pesticides (per acre)

S/I.	**Seasons**	Cow-dung (Taka)	Urea (Taka)	TSP Per Kg (Taka)	MOP Per Kg (Taka)	DAP Per Kg (Taka)	Others Per Kg (Taka)	Total Cost of Fertilizers	T. cost of Pesticides (Taka)
(i)	Aman								
(ii)	Boro								
(iii)	Aus								
Total									

20. Some questions about sources of inputs

(i) What are the sources of (seed, fertilizers, pesticides) inputs?

(1) Home (2) Office (3) Local Market

(ii) Do you think that the price of inputs is reasonable? (1) Yes □, (2) No. □

(iii)If no, how much it should be.

....

21. Irrigation Cost (per acre)

Seasons	Cultivated area	Irrigation area			Price per acre (Taka)			Total cost of Irrigation
		DTW	STW	Others	DTW	STW	Others	
Aman								
Boro								
Aus								
Total								

22. Some questions about irrigation

a. Which sources of water pump do you take? i) Diesel oriented □, ii) Electricity oriented □

b. Which sources of water is reasonable price? i) Diesel oriented □, ii) Electricity oriented □

c. Which sources always supplied sufficient water ?i) Diesel oriented □,ii) Electricity oriented □

d. Which sources of water give more production? i) Diesel oriented □, ii) Electricity oriented □

e. Do you think that the water extraction capacity of the diesel-oriented pumps is lower? (1) Yes □, (2) No. □

f. Do you think that this affects rice production? (1) Yes □, (2) No. □

g. Are there any environmental problems creating due to used irrigation, fertilizer and pesticides ? (1) Yes □, (2) No. □

If yes, please specify

....

h. To reduce these problems what is your suggestions?

....

23. Output and Revenue (per acre)

Seasons	Output per acre (Mounds)	Total output (Mound)			Market price (Per Mound)	Total revenue (Taka)
		Own output	Sharing output	Total output		
Aman (S_1)						
Boro (S_2)						
Aus (S_3)						
Total						

24. Do you think that market price of your products are reasonable? (1) Yes □, (2) No. □

25. Which sources do you have arranged finance? (use tick sign)

(1) Self-fund □ , (2) Credit □ , (3) None □

26. Do you think that lack of finance affects your rice production? (1) Yes □, (2) No. □

27. Information about Credit Contact of Farm Households

S/I.	Bank	NGOs	Others	Total amount of credit contact	Years of credit contact	Amount used of credit in rice cultivation
(i)						
(ii)						
(iii)						

28. Some questions about credit market

(i) Do you have sufficient access to agricultural credit market? (1) Yes □, (2) No. □

(ii) Which source does credit gives easily? (1) Bank □, (2) NGOs □, (3) Others□

(iii) What are the main problems to get credit?

....

(iv) Do you think that credit brings happiness and comfort of your family?

(1) Yes □ , (2) No.□

29. Others Yearly Income from Non-Farm Activities

Serial no.	Activities	Hours of work (per day)	Days of work (per week)	Cost in this period	Income per year
(a)	Business				
(b)	Services				
(c)	Fishing				
(d)	Poultry				
(e)	Labourer				
(f)	Others				
Total					

30. Do you think that non-farm income is reasonable? (1) Yes □, (2) No. □

31. Capital Assets (Machineries) Utilization (use tick sign)

Seasons	Intensive-1	Semi-intensive-2	Traditional-3	Traditional-semi-intensive-4
Aman (S_1)				
Boro (S_2)				
Aus (S_3)				

32. Do you think that intensive methods are more beneficial than the traditional system? (1) Yes □, (2) No. □

33. Information of Livestock

Type of Livestock	No. of Livestock	Each pres. value	Total value	Purchase this year	Sale this year	Present position	Yearly income
Bullock							
Cow							
Buffalo							
Goat/Sheep							
Chicken/Ducks							
Total							

34. Participatory rural appraisal (PRA) questions

(i) Any extension officials come to help you for giving ideas about different aspects of crop production system? (1) Yes □, (2) No. □

(ii) If yes, how many time is an official comes in a season? ....

(iii) Did you take any training on crop production? (1) Yes □, (2) No. □

(iv) Do you regularly read any news paper or watch television? (1) Yes □, (2) No. □

(v) Do you have electricity advantage to your house? (1) Yes □, (2) No. □

Date of interview: Thanks

Appendix 4.2: Total Cost, Total Output, Total Revenue and Total Profit of Aman and Boro both Seasons Together

Appendix 4.1: Total Cost of both Aman and Boro Seasons Together

Total cost (TC) (Thousand Tk.)	No. of farmers	Percentage	Total cost (TC) (Thousand Tk.)	No. of Farmers	Percentage
20-50	29	11.55	170-200	23	9.16
50-80	71	28.29	200-230	7	2.79
80-110	56	22.32	230-260	4	1.59
110-140	41	16.33	260-290	2	0.80
140-170	18	7.17	Total	251	100.00

Appendix 4.2: Total Output of both Aman and Boro Seasons Together

Total production (In mound)	No. of farmers	Percentage	Total production (In mound)	No. of Farmers	Percentage
40-100	28	11.16	340-400	18	7.17
100-160	46	18.33	400-460	9	3.58
160-220	57	22.71	460-520	4	1.59
220-280	44	17.53	520-580	2	0.80
280-340	43	17.13	Total	251	100.00

Appendix 4.3: Total Revenue of both Aman and Boro Seasons Together

Total revenue (Thousand Tk)	No. of farmers	Percentage	Total revenue (Thousand Tk)	No. of Farmers	Percentage
20-55	36	14.34	195-230	12	4.78
55-90	50	19.92	230-265	6	2.39
90-125	70	27.89	265-300	2	0.80
125-160	46	18.33	300-335	1	0.40
160-195	28	11.16	Total	251	100.00

Appendix 4.4: Total Profit of both Aman and Boro Seasons Together

Total profit (Thousand Taka)	No. of farmers	Percentage	Total profit (In Taka)	No. of Farmers	Percentage
8-20	121	48.21	68-80	2.79	7
20-32	49	19.52	80-92	1.99	5
32-44	34	13.55	92-104	1.59	4
44-56	19	7.57	104-116	1.20	3
56-68	9	3.59	Total	251	100.00

Appendix 6.1: Derivation of the Mean of the Truncated Normal Distribution

Probability density function of a truncated normal variable: If ζ is a continuous random variable with pdf $f(\zeta)$, then the truncated probability density function (pdf) takes the following form:

$$f(\zeta/\zeta \geq 0) = \frac{f(\zeta)}{pr\{\zeta \geq 0\}}$$

If the continuous random variable ζ has a normal distribution with mean μ and variance $\sigma_\zeta{}^2$, then

$$pr\{\zeta \geq 0\} = [1 - pr\{\zeta \leq 0\}] = 1 - \int_{-\infty}^{0} \frac{1}{\sigma_\zeta \sqrt{2\pi}} e^{-\frac{1}{2}(-\mu/\sigma_\zeta)2} d\zeta = 1 - \Phi(-\mu/\sigma_\zeta)$$

Where, $\Phi(\cdot)$ is the standard normal cumulative density function (pdf). Therefore, the probability density function of the truncated normal distribution is:

$$f(\zeta/\zeta \geq 0) = \frac{\frac{1}{\sigma_\zeta\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{\zeta-\mu}{\sigma_\zeta})^2}}{1-\Phi(-\mu/\sigma_\zeta)} = \frac{\frac{1}{\sigma_\zeta}\Phi(\frac{\zeta-\mu}{\sigma_\zeta})}{1-\Phi(-\mu/\sigma_\zeta)} = \frac{\Phi(\frac{\zeta-\mu}{\sigma_\zeta})}{\sigma_\zeta[1-\Phi(-\mu/\sigma_\zeta)]}$$

Therefore, the mean of the truncated variable is written as:

$$E(\zeta_i/\zeta_i \geq 0) = \int_0^\infty \zeta f(\zeta/\zeta \geq 0) d\zeta$$

$$= \int_0^\infty \zeta \frac{1}{\sqrt{2\pi\sigma_\zeta[1-\Phi(-\mu/\sigma_\zeta)]}} e^{-\frac{1}{2}(\frac{\zeta-\mu}{\sigma})^2} d\zeta$$

Appendix 6.2: Log-Likelihood Function

The log-likelihood function for the sample observations, $y = (y_1, y_2, \ldots, y_n)$ can be obtain from the probability density function for y_1 for the *ith* farm. The probability density function for y_1 is derived by substituting $\{y_i \; f(x_i;\beta)\}$ for μ_i. Where x_i is the $(1\times q)$ vector for the *ith* farm and q is the dimension of the vector β, as :

$$f(y_i) = \frac{[1-\Phi(-\mu^* / \sigma_\zeta{}^*)]e^{\frac{1}{2}[\{(y_i - f(x_i;\beta)\}'\{y_i - f(x_i;\beta)\}/\sigma_\zeta{}^2{}_i) + (\mu/\sigma_\zeta)^2 - (\mu^*/\sigma_\zeta{}^*)]}}{\sqrt{2\pi[\sigma_\zeta{}^2 + \sigma_\zeta{}^2]^{\frac{1}{2}}}[1-\Phi(-\mu/\sigma_\zeta)]}$$

Therefore, the log likelihood function is:

$$L(\Omega^*, y) = \sum_{i=1}^{n} In[1-\Phi(-\mu_i^* / \sigma_{i\zeta}{}^*)] - \frac{1}{2}\sum_{i=1}^{n}[\{y_i - f(x_i;\beta)\}'\{y_i - f(x_i;\beta)\}/\sigma_\xi{}^2] - \frac{1}{2}n(\mu/\sigma_\zeta)^2$$

$$+\frac{1}{2}\sum_{i=1}^{n}(\mu_i^* / \sigma_{i\zeta}{}^*)^2 - \frac{1}{2}nIn(2\pi) - \frac{1}{2}nIn(\sigma_\zeta^2 + \xi_\xi^2) - nIn[1-\Phi(-\mu/\sigma_\zeta)]$$

Where, $\Omega^* = (\beta', \sigma_\xi^2, \sigma_\zeta^2, \mu)'$. Using the reparameterization $\sigma_s^2 = \sigma_\xi^2 + \sigma_\zeta^2$ and $\gamma = \sigma_\zeta^2 / \sigma_s^2$, suggested by Battese and Corra (1997), the log-likelihood function is written as:

$$L(\Omega, y) = \sum_{i=1}^{n} In[1-\Phi(-z_i^*)] - \frac{1}{2}\sum_{i=1}^{n}\{y_i - f(x_i;\beta)\}'\{y_i - f(x_i;\beta)\}/(1-\gamma)\sigma_s^2 - \frac{1}{2}nz^2$$

$$+\frac{1}{2}\sum_{i=1}^{n} z_i^{*2} - \frac{1}{2}n\{In(2\pi) + In(\sigma_s^2)\} - nIn[1-\Phi(-z)],$$

Where, $\Omega = (\beta', \sigma_s^2, \gamma, \mu)'$, $z = \mu/(\gamma\sigma_s^2)^{\frac{1}{2}}$ and $z_i^* = \dfrac{\mu(1-\gamma) - \gamma\{y_i - f(x_i;\beta)\}}{\{\gamma(1-\gamma)\sigma_s^2\}^{1/2}}$.

The partial derivatives of the log-likelihood function with respect to the parameters, $\beta, \sigma_s^2, \gamma and \mu$ are derived by:

$$\frac{\partial L}{\partial \beta} = \sum_{i=1}^{n} x_i'\{y_i - f(x_i;\beta)\}/(1-\gamma)\sigma_s^2 + \sum_{i=1}^{n}[\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*].\frac{\gamma x_i'}{\{\gamma(1-\gamma)\sigma_s^2)^{1/2}},$$

$$\frac{\partial L}{\partial \sigma_s^2} = +\frac{1}{2\sigma_s^2}\sum_{i=1}^{n}\{y - f(x_x;\beta)\}'\{y_i - f(x_x;\beta)\}/(1-\gamma)\sigma_s^2$$

$$-\frac{1}{2\sigma_s^2}\sum_{i=1}^{n}\{\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*\}z_i^* - \frac{1}{\sigma_s^2}n + n\{\frac{\phi(-z)}{1-\Phi(-z)} + z\}z$$

$$= -\frac{1}{2\sigma_s^2}[\sum_{i=1}^{n}\{\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*\}z_i^* - \sum_{i=1}^{n}\{y_i - f(x_x;\beta)\}'\{y_i - f(x_x;\beta)\}/(1-\gamma)\sigma_s^2$$
$$+\frac{1}{\sigma_s^2}n - n\{\frac{\phi(-z)}{1-\Phi(-z)} + z\}z]$$

$$\frac{\partial L}{\partial \gamma} = \sum_{i=1}^{n}[\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*]z_i^* - \frac{1}{2}\sum_{i=1}^{n}\{y_i - f(x_i;\beta)\}'\{y_i - f(x_i;\beta)\}/\{(1-\gamma)\sigma_s^2\}^2$$
$$+\frac{1}{2}n[\frac{\phi(-z)}{1-\Phi(-z)} + z]z\gamma^{-1} + \sum_{i=1}^{n}[\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*]\frac{\partial z_i^*}{\partial \gamma}$$

where $\frac{\partial z_i^*}{\partial \gamma} = -\frac{\mu - \{y_i - f(x_i;\beta)\}}{\{\gamma(1-\gamma)\sigma_s^2\}^{1/2}} - \frac{1}{2}\frac{[\mu(1-\gamma) - \gamma\{y_i - f(x_i;\beta)\}](1-2\gamma)}{\sigma_s\{\gamma(1-\gamma)\}^{3/2}}$

$$\frac{\partial L}{\partial \mu} = \sum_{i=1}^{n}[\frac{\phi(-z_i^*)}{1-\Phi(-z_i^*)} + z_i^*] \times \frac{(1-\gamma)}{\{\gamma(1-\gamma)\sigma_s^2\}^{1/2}} - n[\frac{\phi(-z)}{1-\Phi(-z)} + z] \times \frac{1}{(\gamma\sigma_s^2)^{1/2}}.$$

Appendix 6.3: Maximum Likelihood Estimators

The principle of maximum likelihood estimation is illustrated in the context of the linear regression which is defined by:

$$y_i = X\beta + u \quad \text{(A6.4.1)}$$

where X is a fixed nonstochastic matrix. This model then defines a transformation from u to y. The assumption of a multivariate density function for u implies a multivariate density function for y, which may be written as:

$$f(y) = f(u)\left|\frac{\partial u}{\partial y}\right|$$

where $|\partial u / \partial y|$ denotes the absolute value of the determinant formed from the matrix of partial derivatives:

$$\begin{bmatrix} \partial u_1 / \partial y_1 & \partial u_1 / \partial y_2 & \cdots & \partial u_1 / \partial y_n \\ \partial u_2 / \partial y_1 & \partial u_2 / \partial y_2 & \cdots & \partial u_2 / \partial y_n \\ \ldots & \ldots & \cdots & \ldots \\ \partial u_n / \partial y_1 & \partial u_n / \partial y_2 & \cdots & \partial u_n / \partial y_n \end{bmatrix}$$

This matrix appears to be the identity matrix whose determinant is unity in case of (A5.4.1). Thus:

$$f(y) = f(u)$$

If we assume that u is multivariate normal with mean zero and variance $\sigma^2 I$, all the u's are pairwise uncorrelated, then we obtain:

$$f(u) = \frac{1}{(\sigma\sqrt{2\pi})^n} e^{\frac{1}{2\sigma^2}u'u}$$

and so:

$$f(y)=\frac{1}{(\sigma\sqrt{2\pi})^{n}}e^{-\frac{1}{2\sigma^2}(y-x\beta)'(y-X\beta)} \qquad \text{(A5.4.2)}$$

Equation (A6.4.2) includes both the observations on *y* and the unknown parameters β and σ^2. As the observations on *y* are known and β and σ^2 are not known, the function in (A5.4.2) is termed the likelihood function denoted by *L*. Taking natural log of the likelihood function in (A6.4.2) yields:

$$InL=-\frac{n}{2}In(2\pi)-\frac{n}{2}In(\sigma^2)-\frac{1}{2\sigma^2}(y-X\beta)'(y-X\beta) \qquad \text{(A5.4.3)}$$

The maximum likelihood (ML) principal consists in estimating the unknown parameters with the values which maximize the likelihood function, given the sample data *y*. Differentiating (A5.4.3) partially with respect to β and σ^2 and setting equal to zero gives:

$$\frac{\partial(InL)}{\partial\beta}=-\frac{1}{2\hat{\sigma}^2}(-2X'y+2X'X\hat{\beta})=0$$

or:

$$\frac{1}{\hat{\sigma}^2}(X'y-X'X\hat{\beta})=0$$

and:

$$\frac{\partial(InL)}{\partial\sigma^2}=-\frac{1}{2\hat{\sigma}^2}+\frac{1}{2\hat{\sigma}^4}(y-X\hat{\beta})'(y-X\hat{\beta})=0$$

where $\hat{\beta}$ and $\hat{\sigma}^2$ are maximum likelihood estimators. The solution of these equations simultaneously gives:

$$\hat{\beta}=(X'X)^{-1}X'y$$

and

$$\hat{\sigma}^2=\frac{e'e}{n}$$

where $e=y-X\hat{\beta}$. The ML $\hat{\beta}$ is identical with OLS estimator and the estimates of σ^2 is asymptotically unbiased.

Appendix 7.1: Result of the Cobb-Douglas Stochastic Frontier Model for Aman Season, Boro Season and both Seasons Together

Appendix 7.1 : Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Model for Aman Season

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	0.6482	6.5509
Land	β_1	0.1442	5.1194
Labour	β_2	0.9302	2.5429
Plough	β_3	0.5116	3.9143
Seeds	β_4	0.3708	1.1885
Irrigation	β_5	0.1956	4.4394
Fertilizer	β_6	0.1528	3.3884
Pesticides	β_7	0.9438	3.3369
Inefficiency Model			
Constant	δ_0	0.1797	6.2303
Age	δ_1	-0.9364	-1.4588
Years of schooling	δ_2	0.1478	0.3971
Experience	δ_3	-0.2102	-2.6601
Land fragmentation	δ_4	0.3379	3.2512
Credit facilities dummy	δ_5	0.1032	0.2514
Extension services dummy	δ_6	-0.2409	-0.2352
Land degradation dummy	δ_7	-0.6134	-3.2496
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1873	2.1872
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.9037	4.2342
	σ_ξ^2	0.0180	
	σ_ζ^2	0.1693	
Log-Likelihood value		46.2647	

Appendix 7.2: Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Model for Boro Season

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	0.1408	5.6164
Land	β_1	0.1281	6.4592
Labour	β_2	0.1853	2.4491
Plough	β_3	0.4805	3.5038
Seeds	β_4	0.3633	1.5698
Irrigation	β_5	0.2379	5.3153
Fertilizer	β_6	0.1586	4.3808
Pesticides	β_7	0.2639	3.3257
Inefficiency Model			
Constant	δ_0	0.2684	4.4806
Age	δ_1	-0.4713	-1.1937
Years of schooling	δ_2	0.3613	0.1095
Experience	δ_3	-0.5435	-2.1264
Land fragmentation	δ_4	-0.7995	-3.8641
Credit facilities dummy	δ_5	0.3778	2.8193
Extension services dummy	δ_6	-0.3489	-0.8198
Land degradation dummy	δ_7	-0.1471	-4.8623
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.5944	3.5943
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.7377	5.8752
	σ_ξ^2	0.1559	
	σ_ζ^2	0.4385	
Log-likelihood value		18.2835	

Appendix 7.3 : Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Model for both Aman and Boro Seasons Together

Name of variables	Parameters	Coefficients	t-ratios
Constant	β_0	0.2782	4.8651
Land	β_1	0.1675	5.8135
Labour	β_2	0.1332	2.4586
Plough	β_3	0.5381	3.6968
Seeds	β_4	0.4004	1.1050
Irrigation	β_5	0.2137	5.3632
Fertilizer	β_6	0.9673	4.2119
Pesticides	β_7	0.1082	3.2127
Inefficiency Model			
Constant	δ_0	0.1113	5.7947
Age	δ_1	-0.6356	-1.1688
Years of schooling	δ_2	0.3853	0.1391
Experience	δ_3	-0.7825	-2.1189
Land fragmentation	δ_4	-0.4161	-4.1017
Credit facilities dummy	δ_5	0.2136	2.9266
Extension services dummy	δ_6	-0.1468	-2.8918
Land degradation dummy	δ_7	-0.4005	-4.1017
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1173	5.1173
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma^2)$	0.7960	4.1390
	σ_ξ^2	0.0240	
	σ_ζ^2	0.0933	
Log-likelihood value		31.29	

Appendix 7.3: Technical Efficiency of Farms in Aman Season, Boro Season and both Seasons Together

Appendix 7.4: Frequency Distribution of Farm-specific Efficiency Estimates from the Stochastic Cobb-Douglas Frontier Model for Aman Season

Efficiency Index (percentage)	Number of farms	Percentage of farms
01 – 50	0	0
50 – 55	0	0
55 – 60	3	1.20
60 – 65	10	3.98
65 – 70	18	7.17
70 – 75	22	8.76
75 – 80	25	9.96
80 – 85	48	19.12
85 – 90	51	20.32
90 – 95	53	21.12
95 – 100	21	8.37
Total	251	100.00

Summary Statistics of Technical Efficiency for Aman Season

Statistics	Technical Efficiency of Stochastic Frontier
Mean	83.97
Minimum	56.82
Maximum	99.41
Standard deviation	9.79

Appendix 7.5: Frequency Distribution of Farm-specific Efficiency Estimates from the Cobb-Douglas Stochastic Frontier Model for Boro Season

Efficiency Index (percentage)	Number of farms	Percentage of farms
01 – 50	0	0
50 – 55	1	0.40
55 – 60	9	3.59
60 – 65	15	5.98
65 – 70	30	11.95
70 – 75	36	14.34
75 – 80	38	15.14
80 – 85	41	16.33
85 – 90	45	17.93
90 – 95	22	8.76
95 – 100	14	5.58
Total	251	100.00

Summary statistics of technical efficiency for Boro season

Statistics	Technical Efficiency of Stochastic Frontier
Mean	79.55
Minimum	52.70
Maximum	98.72
Standard deviation	10.16

Appendix 7.6: Frequency Distribution of Farm-specific Efficiency Estimates from the Cobb-Douglas Stochastic Frontier Model of both Seasons Together

Efficiency Index (percentage)	Number of farms	Percentage of farms
01 – 50	0	0
50 – 55	0	0
55 - 60	0	0
60 – 65	7	2.79
65 – 70	9	3.59
70 – 75	22	8.76
75 – 80	45	17.93
80 – 85	58	23.11
85 – 90	52	20.72
90 – 95	35	13.94
95 – 100	23	9.16
Total	251	100.00

Summary statistics of technical efficiency of both seasons together

Statistics	Technical Efficiency of Stochastic Frontier
Mean	84.08
Minimum	64.14
Maximum	99.05
Standard deviation	8.33

Appendix 9.1: Frequency Distribution of Input-Oriented TE and SE from DEA Frontier for Aman Season, Boro Season and both Seasons

Appendix 9.1: Frequency Distribution of TE and SE from DEA Frontier for Aman Season

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of Farms
01-50	2	0.80	0	0	0	0
50-55	0	0	1	0.40	0	0
55-60	9	3.59	5	1.99	0	0
60-65	13	5.18	10	3.98	1	0.40
65-70	28	11.16	16	6.37	4	1.59
70-75	21	8.37	17	6.77	5	1.99
75-80	17	6.77	18	7.17	6	2.39
80-85	14	5.58	19	7.57	16	6.37
85-90	38	15.14	22	8.76	35	13.94
90-95	46	18.33	45	17.93	57	22.71
95-100	63	25.10	98	39.04	127	50.60
Total	251	100.00	251	100.00	251	100.00

Appendix 9.2: Frequency Distribution of TE and SE from DEA Frontier for Boro Season

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of Farms
01-50	0	0	0	0	0	0
50-55	14	5.58	9	3.59	0	0
55-60	19	7.57	6	2.39	0	0
60-65	12	4.78	13	5.18	1	0.40
65-70	23	9.16	15	5.98	2	0.80
70-75	25	9.96	18	7.17	3	1.20
75-80	22	8.76	20	7.97	4	1.59
80-85	26	10.36	24	9.56	8	3.19
85-90	27	10.76	28	11.16	17	6.77
90-95	29	11.55	30	11.95	22	8.76
95-100	54	21.51	88	35.06	194	77.29
Total	251	100.00	251	100.00	251	100.00

Appendix 9.3: Frequency Distribution of TE and SE from DEA Frontier for both Aman and Boro Seasons Together

Efficiency Index (%)	Input-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of Farms
01-50	0	0	1	0.40	0	0
50-55	2	0.80	2	0.80	0	0
55-60	6	2.39	5	1.99	0	0
60-65	13	5.18	9	3.59	1	0.40
65-70	18	7.17	11	4.38	4	1.59
70-75	25	9.96	17	6.77	1	0.40
75-80	26	10.36	19	7.57	5	1.99
80-85	28	11.16	24	9.56	6	2.39
85-90	34	13.55	25	9.96	12	4.78
90-95	46	18.33	41	16.33	58	23.11
95-100	53	21.12	97	38.65	164	65.34
Total	251	100.00	251	100.00	251	100.00

Appendix 9.2: Frequency Distribution of Output-Oriented TE and SE from DEA Frontier for Aman Season, Boro Season and both Seasons

Appendix 9.4: Frequency Distribution of TE and SE from DEA Frontier Aman Season

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of farms
01-50	2	0.80	0	0	1	0.40
50-55	3	1.20	0	0	1	0.40
55-60	9	3.59	2	0.80	5	1.99
60-65	14	5.58	3	1.20	12	4.78
65-70	26	10.36	5	1.99	21	8.37
70-75	23	9.16	7	2.79	15	5.98
75-80	18	7.17	10	3.98	17	6.77
80-85	16	6.37	17	6.77	22	8.76
85-90	35	13.94	22	8.76	21	8.37
90-95	44	17.53	36	14.34	39	15.54
95-100	61	24.30	149	59.36	97	38.65
Total	251	100.00	251	100.00	251	100.00

Appendix 9.5: Frequency Distribution of TE and SE from DEA Frontier Aman Season

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of farms
01-50	0	0	0	0	0	0
50-55	14	5.58	0	0	13	5.18
55-60	7	2.79	0	0	7	2.79
60-65	12	4.78	2	0.80	10	3.98
65-70	24	9.56	7	2.79	19	7.57
70-75	24	9.56	13	5.18	17	6.77
75-80	5	1.98	18	7.17	21	8.37
80-85	26	10.36	26	10.36	25	9.96
85-90	27	10.76	32	12.75	30	11.95
90-95	29	11.55	45	17.93	25	9.96
95-100	83	33.07	110	43.82	84	33.47
Total	251	100.00	251	100.00	251	100.00

Appendix 9.6: Frequency Distribution of TE and SE from DEA Frontier of Aman and Boro both Seasons Together

Efficiency Index (%)	Output-Orientation					
	CRS		VRS		SE	
	No. of farms	% of farms	No. of farms	% of farms	No. of farms	% of farms
01-50	0	0	0	0	0	0
50-55	3	1.20	0	0	3	1.20
55-60	6	2.39	0	0	4	1.59
60-65	13	5.18	1	0.40	5	1.99
65-70	18	7.17	4	1.59	19	7.57
70-75	27	10.76	5	1.99	22	8.76
75-80	25	9.96	12	4.78	28	11.16
80-85	26	10.36	40	15.94	20	7.97
85-90	34	13.55	47	18.73	17	6.77
90-95	46	18.33	55	21.91	39	15.54
95-100	53	21.12	87	34.66	94	37.45
Total	251	100.00	251	100.00	251	100.00

Appendix 9.3: Summary Statistics of Efficiency Estimates from DEA Method for Aman Season, Boro Season and both Seasons Together

Appendix 9.7: Summary Statistics of Efficiency Estimates from DEA Method for Aman Season

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	85	88	96	85	87	97
Minimum	50	51	70	50	50	59
Maximum	100	100	100	100	100	100
Standard deviation	13	12	6	13	13	5

Appendix 9.8: Summary Statistics of Efficiency Estimates from DEA Method for Boro Season

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	83	86	96	83	85	97
Minimum	53	53	65	53	53	65
Maximum	100	100	100	100	100	100
Standard deviation	14	14	6	14	14	5

Appendix 9.9: Summary Statistics of Efficiency Estimates from DEA Method of both Aman and Boro Seasons Together

Statistics	Input-Orientation			Output-Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	84	88	95	84	87	97
Minimum	54	55	63	54	55	63
Maximum	100	100	100	100	100	100
Standard deviation	12	12	6	12	13	5

Appendix 9.4: Frequency Distribution of Efficiency Estimates from DEA Frontier for Aman Season, Boro Season and both Seasons Together

Appendix 9.10: Frequency Distribution of Efficiency Estimates from DEA Frontier for Aman, Boro and both Seasons Together

Efficiency Index (%)	DEA Frontier					
	Number of farms					
	TE under CRS			TE under VRS		
	Aman season	Boro season	Both seasons	Aman season	Boro season	Both seasons
01-50	2	0	0	0	0	1
50-55	0	14	2	1	9	2
55-60	9	19	6	5	6	5
60-65	13	12	13	10	13	9
65-70	28	23	18	16	15	11
70-75	21	25	25	17	18	17
75-80	17	22	26	18	20	19
80-85	14	26	28	19	24	24
85-90	38	27	34	22	28	25
90-95	46	29	46	45	30	41
95-100	63	54	53	98	88	97
Total	251	251	251	251	251	251

Appendix 9.11: Summary Statistics of Efficiency Estimates from DEA Frontier for Aman, Boro and both Seasons in percentage

Statistics	CRS DEA Frontier			VRS DEA Frontier		
	Aman season	Boro season	Both seasons	Aman season	Boro season	Both seasons
Mean	85	83	84	88	86	88
Minimum	50	53	54	51	53	55
Maximum	100	100	100	100	100	100
Standard deviation	13	14	12	12	14	12