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Technical, Allocative and Economic Efficiency of Rice Farms in Bangladesh

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TO

MY PARENTS

AND

OUR BELOVED SON (NEPHEW)

WHO PASSED AWAY

SORROWFULLY

DURING

THE COURSE OF MY STUDY

Certificate

I have the pleasure to certify that the dissertation entitled "Technical, Allocative and Economic Efficiency of Rice Farms in Bangladesh" is the original work of Mir Khaled Iqbal Chowdhury. So far as I know that this is researcher's own work and achievement and not a conjoint work. The researcher has completed this dissertation under my direct guidance and supervision.

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

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Declaration

I do hereby declare that this dissertation entitled "Technical, Allocative and Economic Efficiency of Rice Farms in Bangladesh" submitted to the University of Rajshahi for the degree of Doctor of Philosophy in Economics is exclusively my own and original work. No part of it, in any form, has been submitted to any university or any other institutions for any degree, diploma or any other similar purposes.

25.06.2007.

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ABSTRACT

This study estimates the efficiency of rice farms in Bangladesh by applying stochastic production frontier and data envelopment analysis (DEA) methods. Technical, allocative and economic efficiency of 205 individual farms are measured by using cross-section data for consecutive two rice seasons. The stochastic Cobb-Douglas production frontier is first applied to estimate technical efficiency of farms. Then we apply stochastic cost decomposition method to estimate allocative and economic efficiency.

Constant Return to Scale (CRS) and Variable Return to Scale (VRS) input-oriented and output-oriented DEA frontiers are estimated. The CRS frontier produces measures of overall technical efficiency and the VRS frontier produces measures of pure technical efficiency. Scale efficiency is obtained as the ratio of the two. Technical, allocative and economic efficiencies, obtained from both stochastic and DEA frontiers for aman and boro seasons, are compared. Tobit Inefficiency Effects Model is applied to identify factors which affect inefficiency.

The average scores of technical, allocative and economic efficiencies obtained from stochastic frontier method are 84, 71 and 58 per cent respectively for aman season and the corresponding values are 87, 75 and 64 per cent respectively for boro season. Both input- and output oriented methods give same results for aman season. The mean TE scores of CRS, VRS and SE for aman season from both orientations are 77, 83 and 92 per cent respectively. The corresponding values from input oriented method are 75, 81 and 93 per cent and from output oriented method are 75, 81 and 92 per cent respectively for boro season. The average technical, allocative and economic efficiencies obtained from CRS DEA are 77, 90 and 69 per cent respectively and

corresponding VRS DEA technical, allocative and economic efficiencies are 83, 90 and 75 per cent respectively for aman season. On the other hand, the average CRS DEA technical, allocative and economic efficiencies are 75, 84 and 63 per cent respectively and the corresponding VRS DEA values are 81, 89 and 72 per cent respectively for boro season. The efficiency estimates from both stochastic frontier and DEA approach for boro season are slightly higher than those from aman season, as expected. According to stochastic frontier results 16 per cent technical efficiency (TE), 29 per cent allocative efficiency (AE) and 42 per cent economic efficiency (EE) could be improved in aman season and 13 per cent TE, 25 per cent AE and 36 per cent EE could be improved in boro season if the farmers could operate at full efficiency levels. CRS DEA frontier shows that 23 per cent TE, 10 per cent AE and 31 per cent EE could be increased in aman season and 25 per cent TE, 16 per cent AE and 37 per cent EE could be increased boro season by the same way. Similarly, VRS DEA results indicate that 17 per cent TE, 10 per cent AE and 25 per cent EE could be improved in aman season and 19 per cent TE, 11 per cent AE and 28 per cent EE could be enhanced in boro season if the farmers could operate at full efficiency levels.

Inefficiency effects model shows that land size, credit facilities, quality extension services are inversely related to inefficiency of farms in both seasons. Environmental factor, such as land degradation, is directly related with inefficiency. 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, technical, allocative and economic efficiencies could be improved which leads to reduction of cost of production. This enhances the income and welfare of the farmers.

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CHAPTER 1	INTRODUCTION

1.1 Present Situation of the Rice Production in Bangladesh

Bangladesh is an agro-based developing country. Agriculture is the single largest sector in Bangladesh economy. Contribution of agricultural products (raw jute, jute products, frozen foods, tea and vegetable) to total export of the country is 7.04 per cent in 2003-2004 (July-March). This is one of the largest export sectors after Knitwear and Readymade Garments (Bangladesh Economic Survey, 2004). The contribution of agriculture (including fisheries) to Gross Domestic Product (GDP) is around 23 per cent in 2003-2004. Though the contribution of agriculture to GDP is decreasing comparatively as it is 50.48 per cent in 1985 and is around 75 per cent in 1971, but still agriculture has a great impact on its national economy. The growth rate of agriculture sector is 5.5 per cent in 2000-2001 (base year 1995-96 =100). Over the last couple of years after 2000-01, the growth is declining sharply. Even it is negative in 2001-02. This is because of flood and other natural disaster all over the country. But the growth rate is improving over next years. It is 2.41 per cent in 2003-04. Annual growth rate of crop sub-sector of the same year is 1.67 per cent, and livestock and fishery sub-sectors are 4.48 per cent and 3.6 per cent respectively (Bangladesh Economic Survey, 2004).

More than 62 per cent of total labour forces are engaged in agriculture (BBS Labour Forces Survey, 1999-2000). Agriculture in Bangladesh accounts for about 59.56

per cent of its land area and employs about 66 per cent of the labour force and provides the main sources of income for 80 per cent of the population. The rice crop accounts for 74 per cent of the cultivated area, 83 per cent of the irrigated area, 88 per cent of fertilizer consumption. The rice crop is one of the main sources of caloric intake of people of Bangladesh (about 68 per cent). The growth rate of GDP is 6.27 per cent in 2003-2004 and at the same period growth rate of agriculture is 4.23 per cent.

In the 1960s Bangladesh agriculture started to adopt the prescriptions of the Green Revolution. There has been a widespread adoption of new varieties and modern inputs. The government of Bangladesh has liberalized the markets of agricultural 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 rise to 73 per cent by 1989-90, and further to about 80 per cent by 1998-99. Over the last 25 years, Bangladesh has greatly increased its food-grains production from 11.81 million metric tons in 1974 to 24.9 million metric tons in 1999-2000 and 26.9 million metric tons in 2000-2001. The total food-grains production in 2003-04 is 27.44 million metric tons (Bangladesh Economic Survey, 2005). The contribution of rice (Aman, Aus, and Boro) in total food-grains is 94 per cent in 1993-94, and almost same in recent years. Actually it is 93.8 per cent in 2003-04 (Yearbook of Agricultural Statistics of Bangladesh, 2000).

1.2 Discussion: The Statement of the Problem

The government of Bangladesh has accelerated the structural change of agricultural sector during the 1990s. An important point is that the agriculture is now much more diversified than before. We have achieved a huge growth in crop sector production. In 1980-81, total crop production is 14.97 million metric tons, but in 2003-04, it is increased to 27.44 million metric tons (Bangladesh Economic Survey, 2005). The area of cultivated land for rice crops is almost the same or slightly increased than before. For example, in 1997-98 total cultivated area of land is 25.36 million acres; in 1999-2000 it is 26.46 million acres. But at that period crop production is almost doubled (Yearbook of Agricultural Statistics of Bangladesh, 2000). So, an improvement is made in this sector. We have achieved this growth, perhaps because of technological change which is supported by a rapid development of irrigation infrastructure. Bangladesh has a little scope to increase agricultural production through expansion of land as the cultivated land has remained constant at around 21 to 25 million acres since the 1960s (Hossain, 1990). But it can be said that this improvement in crop production is not sufficient, because population of Bangladesh is increasing.

The economy of Bangladesh primarily depends on agriculture. The scope of modern agriculture has been widened significantly. Not only cultivation of land for producing crops, now-a-days, any sorts of applied activities using natural resources related to production, development, preservation, processing, marketing are considered as agricultural activities. Therefore, apart from crop production, animal husbandry, fisheries, forestry etc. are integral components of agriculture. For this reason, government has introduced a new national agricultural policy in 1999.

Some of the main objectives of the policy are:

To ensure profitable and sustainable production in agriculture, and thus creating purchasing power of the farmers by increasing real income;

To preserve and develop the productivity of land;

To increase production and supply of food security in the country;

To introduce biotechnology and take some steps to use it effectively;

To establish agro-processing and agro-based industries;

To protect interests of small, marginal and tenant farmers.

(Bangladesh National Agriculture Policy, 1999).

All of these objectives are clearly good for the agriculture of Bangladesh and particularly helpful for the farmers of crop section of the country if implemented. But to observe carefully about the objectives of the policy, it can be said that it takes a long time to get full benefit from it. So, the policy makers should take immediate action to enhance crop production of the country. They may consider two issues to enhance agricultural productivity gains: (1) technological change or improvement and (2) efficiency improvement. Technological change in agricultural system is not a small issue. It is a huge task and it takes obviously a long time and needs a big amount of investment in this sector.

For attaining food self-sufficiency through increased crop production – chemical fertilizers, modern varieties of inputs, irrigation and pesticides have been introduced in agriculture since the late 1970s. The introduction of modern varieties of rice, wheat, potato, oil seeds and other crops has increased cropping intensities and yields (Farouk and Hossain, 1996). In 1980-81 cropping intensity was 159.69, but it has increased to 177 in 2000-01 (Bangladesh Economic Survey, 2004). Almost everywhere, agricultural sector is being developed through the adoption of improved technology but this advancement has provided little benefit to the resource poor small farmers because most of them are unable to purchase or facilitate the required inputs. In addition, they can hardly apply inputs timely and as a result, receive low yield and production. For whatever reason, developments of new technologies sometimes make small farmers worse off than before (Shaner *et al.*, 1982). This happens when large farmers adopt new technologies and small farmers do not. The policy makers might have given more emphasis to the improvement of efficiency rather than technological change.

Efficiency of farmers depends on their experience, level of education, land size and fragmentation, use of modern technology, use of seeds, fertilizer and other inputs. This study tries to find out how these factors could affect the efficiency level of the farmers at the study area of Barind region in Bangladesh.

1.3 Aims and Objectives of the Study

This study is concerned with the efficient utilization of resources allocation in rice production. The general objective of the study is to examine the productivity and productive efficiency of rice producers in Bangladesh and to suggest ways for improving rice farmer's performance. Therefore, this study has some specific aims and objectives.

These are as follows:

i) to assess the technical, allocative and economic efficiency performance of rice farmers in Bangladesh,

ii) to identify and quantify factors which affect efficiency of farmers,

iii) to make a comparison of efficiency of farmers during aman and boro season,

iv) to make a comparison of results obtained from applying stochastic frontier (SF) and data envelopment analysis (DEA) approach,

v) to prescribe some policy conclusions on how efficiency of farmers can be improved, so that they can increase their farm revenue and welfare.

1.4 Contribution of the Study

Productivity and productive efficiency may be very useful tools for rice farmers in Bangladesh for expansion and sustainability of rice production. Unfortunately, there is a little or possibly no information on productive efficiency specially technical, allocative and economic efficiency in agriculture sector in Bangladesh. Few works has been done in this sector previously. This study attempts to estimate the farm-level technical, allocative and economic efficiency of agriculture sector. We also attempt to identify sources of inefficiency where improvements can be made. Therefore, this study could provide vital information to the farm-level cultivators to assist themselves in becoming more competitive and to maintain long-term sustainability in the agriculture sector.

A farmer 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 farmers and factors affecting efficiency of the farmers are the key to promoting efficient utilization of resources.

Determination of frontier technology and DEA method and the knowledge of various types of efficiency may provide important insights for the rice farmers 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 farmers, and profit gain.

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

DEA method is generally used to assess the performance of non-agricultural sector, such as banks, hospitals and nursing homes, education institutions, and 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 good 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 only and few study have looked at allocative efficiency (Bravo-Ureta, and Evenson, 1994). Few study (Wadud and White, 2000; and Wadud, 1999, 2003) have used stochastic frontier and DEA frontier for estimating technical, allocative and economic efficiency in Bangladesh agriculture sector. To our knowledge, no research has been done on comparison of one season data to another season data using both stochastic frontier and DEA frontier for the same number of farmers and the same place. This study attempts to fill this gap by doing a comparison between aman season and boro season data using both stochastic frontier and DEA frontier at the same place and same size of farmers.

1.5 Organization/ Outline of the Study

Chapter 2 reviews the literature related to stochastic frontier and DEA methods. In this chapter we have tried to see some of the related literatures in critical ways and make understand that there is a comprehensive opportunity to do such kind of research in Bangladesh.

Chapter 3 gives a short description about the study area. We also give here some *physiographic* statement about the Barind Area. Then we discuss weather condition, rainfall situation, soil condition and other related conditions of the area. We describe groundwater condition and its impact on the environment of this area as well.

Chapter 4 states the survey methods which are followed in this study and primary survey results about socio-economic, educational condition of the people in the study area and production related information. Techniques of sampling are stated in some details in this chapter. Then we describe the method of designing a standard questionnaire. We also define the variables which are used in the next chapters. Variables associated with inefficiency are discussed in this chapter. Primary survey results which include age of the farmers, experience of rice cultivation, duration of schooling of the farmers, total land own by the farmers, total land cultivated by the farmers etc. are shown in this chapter.

Chapter 5 provides a short description of some theoretical issues about production function and efficiencies. The simple concepts of total, average and marginal product and elasticity are stated. Choice of optimal combination of factors of production is discussed. Technical, allocative and economic efficiencies are defined in this chapter. Input- and output oriented measures of calculating efficiency are also discussed.

Chapter 6 produces a detail description about the stochastic frontier model. It includes a short statement about the origin of the frontier model. Developments of the stochastic frontier model since 1977 are discussed. The stochastic frontier model and efficiency measurement are discussed theoretically. The relevant properties of Cobb-Douglas production frontier are stated in this chapter.

Chapter 7 details the empirical results of the stochastic frontier model. The statement about estimated model is given first in this chapter. Then we report the results of Cobb-Douglas stochastic frontier based on Maximum-Likelihood estimates. Estimated production, cost and input-demand functions (derived by using cost decomposition methods) are produced. Results of Tobit inefficiency effects model are discussed in this chapter.

Chapter 8 provides a detailed theoretical description of Data Envelopment Analysis (DEA). Firstly, we describe the concept of DEA. The description of measuring efficiency using DEA is detailed in this chapter. Then we have discussed input-oriented and output-oriented DEA models. Both input-oriented and output-oriented DEA model include Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) model. Then we describe the process of calculating the Scale Efficiency. Slacks in the process of efficiency measurement are also discussed.

Chapter 9 gives the results of DEA methods. A detailed description of results obtained from the DEA model is given in tabulated form. A comparison between stochastic frontier analysis and DEA results for aman and boro seasons is presented in this chapter. Firstly, we have given a comparison of efficiency scores. Then the comparison between the results for aman and boro seasons of inefficiency effects model are given.

Chapter 10 finally presents the concluding remarks including some implications and recommendations.

Chapter 2

Review of Literatures Related to Stochastic Frontier and DEA Method

CHAPTER 2

REVIEW OF LITERATURES RELATED TO STOCHASTIC FRONTIER AND DEA METHOD

2.1 Introduction

Farrell (1957) presents a very outstanding and pioneering article on efficiency measurement which is based on production frontiers. This article has led the foundation for the development of several approaches to efficiency analysis. These approaches are summarized in Figure 2.1 (Sharma, 1996). Among these, stochastic frontiers or econometric frontiers (parametric) and data envelopment analysis (DEA) or deterministic nonparametric (mathematical programming) are most popular in recent time.

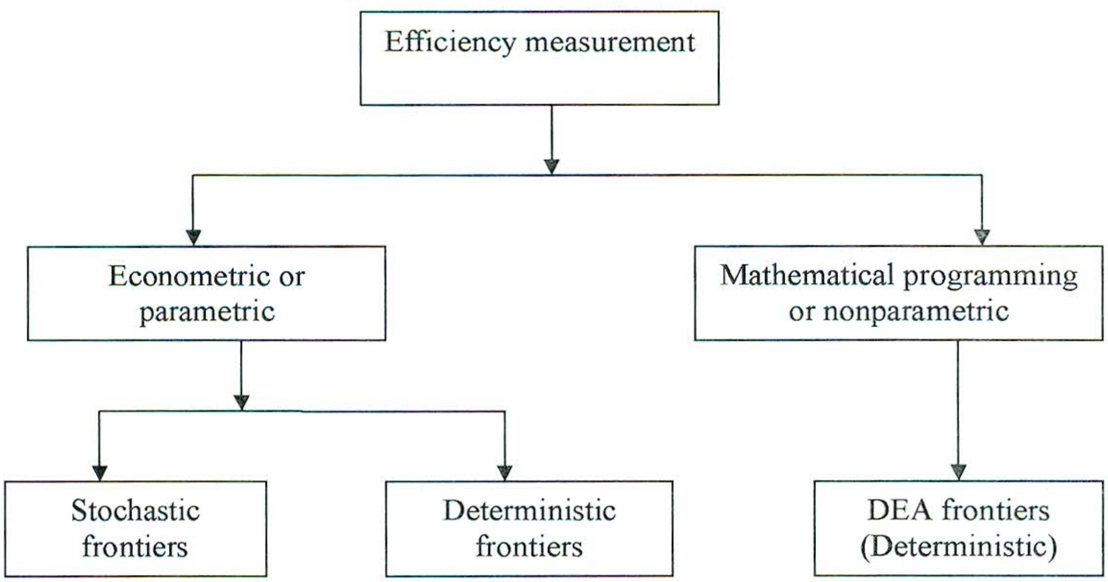


Figure 2.1: Approaches to Efficiency Measurement.

2.2 Critical Review

2.2.1 Stochastic Frontier

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% while the best farm is 85.87% 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 not be separated from technical inefficiency using cross sectional data.

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-climatic regions of the semi-arid tropics of India. The production frontiers involve inputs of land, labour, bullock 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 farm 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 of inefficiency of farms if the data and information of these omitted variables are available.

Kumbhakar and Heshmati (1995) consider a generalization in modeling technical inefficiency in a panel data setup by decomposing it into a persistent farm-specific component and a residual farm and time component. Instead of using a single-stage maximum likelihood method, they apply a multi-step procedure, which minimizes distributional assumptions on the error components. The main focus of the paper is to estimate technical inefficiency of dairy farms and examine whether inefficiency is distributed randomly across farms, or whether there is also a persistent component of inefficiency, which varies across farms but is invariant over time.

The model is used to examine technical efficiency in Swedish dairy farms during the period 1976 to 1988. Empirical results from a rotating panel of 1,425 dairy farms during 1976-88 show that the mean persistent technical inefficiency is 10.27% and the mean residual inefficiency is 3.90%. Results show that the persistent component of inefficiency is much larger than the residual components for all farms.

As they do not want to provide an exhaustive study of the Swedish dairy industry but to develop a framework that can easily be adapted to address similar issues for other industries and/ or the same industry in a different country. Therefore, there is a scope for further study using the same technology in our country.

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 functions for the Pastoral Zone of Eastern Australia indicate that the variance of asymmetric error in the model is a highly significant component. Data from 146 sample farms were used in the empirical analysis, 57 being from New South Wales, 60 from Queensland, and 29 from South Australia. The coefficients of determination for the ordinary least-squares regressions for the N.S.W., Queensland, S.A. and the whole zone were 0.59, 0.31, 0.86 and 0.44 respectively.

In this paper, they estimate a production frontier model, but do not estimate the efficiencies (technical, allocative or economic) separately.

Bravo-Ureta and Rieger (1991) extend Kopp and Diewert's efficiency decomposition methodology from a deterministic to a stochastic framework. They use the stochastic framework to analyze efficiency in Dairy production. This stochastic formulation yields technical, allocative and economic efficiency measures that are free from distortions, stemming from statistical noise, inherent in deterministic models. Cross-sectional data for a sample of 511 New England Dairy farms are used to estimate a Cobb-Douglas stochastic production frontier. This study shows that efficiency levels are not markedly affected by the socio-economic variables like, farm size, education, extension service and experience.

It is a conflicting remark, particular for the developing country contexts. So, we think that there is a scope to re-examine the fact that efficiency level is not much affected by the socio-economic factors.

Abdulai and Huffman (1998) employ a stochastic frontier model to examine profit inefficiency of rice farmers 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 farmers in four districts in Northern Ghana conducted in 1992-93.

The efficiency index, based on a half-normal distribution of the stochastic error is related to farm and household characteristics. The average measure of inefficiency is 27.4%, which suggests that on average, about 27% 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 farmers in Bangladesh in order to identify the inefficiency factors.

Kalirajan (1981) illustrates the advantage of using a stochastic frontier model for the analysis of yield variability in paddy production. To estimate the efficiency, a sample of 70 farmers in Coimbatore district of Tamil Nadu State in India was selected. The period of analysis relates to the rabi (winter) season of 1978. Assuming a Cobb-Douglas production relationship, the model is estimated by the maximum likelihood method.

In this paper, the results of the empirical study demonstrate the workability and potential usefulness of the methodology, and show that individual farm variability (technical inefficiency) was the major cause for yield variation, and the major contributing factors to the difference between the actual and maximum yields among participants are extension workers' limited contact with the farmers and the farmers' misunderstandings of the technology.

But the major weakness of the paper is that allocative efficiency of sample farmers is not examined directly, as the frontier is estimated with observations on output and inputs only.

So, there is a scope for extending the approach to estimate both technical and allocative efficiency in paddy production.

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 by randomly. For the analysis in this study, they have used 1889 observations. Two output prices of crops and livestock, two variable input prices of chemical fertilizer and other purchased materials, and three fixed inputs of labour, land, and capital are constructed from the survey data set. The survey contains no price variables. All price variables for individual commodities and input factors imputed using quantity, revenue, and expenditure variables.

This study examines Chinese farm household's production efficiency. Given a mixed government-controlled and free market economy, the observed prices used in the analysis are an average of government-controlled prices, semi controlled prices, and free market 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 use rights to transfer more freely, enhancing the farmers' accessibility to education, and providing a social- economic environment that helps farmers to increase their net income.

So, there is a lot of scope to use the shadow-price model for the individual level farmers 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.

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 1991-94 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 prices' of the nitrogen surplus. This estimate gives the guidelines 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.

Kopp and Diewert (1982) present a method by which a frontier cost function can be used in lieu of frontier production function to generate Farrell indexes of productive efficiency. They show that their method is applicable to a broad class of cost functions, including flexible functions such as the translog, which do not have analytically derivable underlying production functions.

The method, discussed in this paper, has several possible extensions and generalizations. For example, Kopp (1981) extends the Farrell measures of technical and allocative efficiency to consider the individual efficiency of a single factor's employment. The resulting indexes of single factor technical efficiency, single factor technical cost efficiency, single factor allocative efficiency and partially adjusted allocative efficiency are originally intended to be measured with the cost function method. A richer generalization would involve the adoption of frontier profit functions in which both input demanded and output supplied are allowed to vary.

So, one can generally use the cost frontier function in place of production frontier function to measure the technical and allocative efficiencies.

Schmidt and Lovell (1979) have investigated the relationship among stochastic production, factor demand and cost frontiers. They demonstrate how a (technically and/ or allocatively) 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 frontiers under three different assumptions concerning the magnitude and the nature of allocative inefficiency.

They have used the empirical data from a previously collected sample of 150 new privately-owned steam-electric generating plants constructed in the US between 1947 and 1965. The mean of the one-sided disturbances in the production function is -0.09889, indicating that output on average 9.9% 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% above the cost frontier.

Their 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 their model can estimate allocative inefficiency by plant and so a search for its sources is feasible. The authors pointed out that much works can be done with this topic. For example, they assume that the two types of inefficiency are uncorrelated. This assumption can be relaxed. Secondly, homogeneous Cobb-Douglas assumption can also be relaxed. Thirdly, one can consider alternatives to the cost minimization hypothesis. Finally, it is be desirable to obtain estimates of the extent and cost of technical inefficiency by plant.

So, there is 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 (600 farm groups) of the National Agricultural Data Net (total: 8773 farms per year) under the German Federal Ministry of Agriculture. They show that after half a decade of transition in East Germany, eastern farms still have lower overall efficiencies than those in the West Germany. On 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.

Bravo-Ureta and Evenson (1994) contribute to the productivity literature in developing country agriculture by quantifying the level of efficiency for a sample of peasant farmers from Eastern Paraguay. A stochastic efficiency decomposition methodology is used to derive technical, allocative and economic efficiency measures separately for cotton and cassava.

The data, used in this paper, come from a random sample of small-scale Paraguayan producers for the 1986-87 agriculture year collected in July, 1987. The sample is comprised of 148 peasant farms producing traditional food crops and cotton in Eastern Paraguay. Empirical results of this study suggest that this sample of peasant farmers could increase output, and thereby, household income through better use of available resources given the scale of technology. The relationship between efficiency and various socioeconomic variables do not reveal a clear strategy in this study that may be recommendation to improve performance.

Therefore, this model can be extended by establishing a consistent relationship between efficiency and socioeconomic variables in developing countries like Paraguay as well as in Bangladesh and also doing emphasis to improve education and agricultural extension services. So further investigation may be required in human capital and related factors.

Tadesse and Krishnamoorthy (1997) examine the level of technical efficiency across the ecological zones and farm size groups in paddy farms of the southern Indian State of Tamil Nadu. The study shows that 90% of the variation in output among paddy farms in the state 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 climatic zones of the state, collected from 60 clusters taken on an appropriate random sampling basis. Data for this study refer to 129 high yielding variety rice (IR-20) cultivators distributed over the four zones during the major production season of October- December for the year 1992-93.

The overall mean technical efficiency of 83% is achieved by paddy farms in the state which means that there is a scope for increasing paddy production by 17% with the present state of technology.

A significant variation is observed in the mean level of technical efficiency among the four major rice growing zones of the state and farmers operating on small and medium sized farms achieved a high level of technical efficiency than those with large holdings. This study suggests that special attention should be given to improve the efficiency of paddy farms with 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 climatic condition and farm condition in southern state of Tamil Nadu in India and Bangladesh is almost similar.

2.2.2 Data Envelopment Analysis (DEA) Frontier

Coelli (1995) examines recent developments in the estimation of the frontier functions and DEA frontier. The measurements of efficiency from the 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 investigation.

Yu (1998) conducts a Monte Carlo Study to compare the stochastic frontier method and the data envelopment analysis (DEA) method in measuring efficiency in situations where firms 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 firm-specific efficiency.

He reports, 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 functions.

Therefore in our country, there is a scope for estimating efficiency of farms by using the stochastic frontier method.

Sharma, Leung and Zeleski (1999) analyze technical, allocative and economic efficiency for a sample of 53 commercial swine producers in Hawaii during the fall of 1994. Both the parametric and nonparametric frontier approaches are used for estimating the efficiencies and make a comparison between the two approaches. The effect of the various factors on efficiency levels is examined by estimating a regression model where various production inefficiencies are expressed as a function of various farm-specific factors. The empirical results reveal substantial production inefficiencies for a sample swine producer in Hawaii and hence considerable potential for enhancing profitability by reducing costs through improved efficiency.

In our study we will estimate the technical, allocative and economic efficiencies of rice farmers in Bangladesh. The socio-economic conditions of Bangladesh and Hawaii are almost different. So, within the existing conditions of Bangladesh agriculture, taking appropriate variables, it is justified to investigate and estimate rice farmer's efficiencies.

On the other hand, it is expected that the DEA approach is more sensitive to outliners and other noise in the data, but this paper shows that the DEA results are more robust than those obtained from the parametric approach.

These interesting findings as well as the disagreements in existing studies in comparing two frontier approaches demonstrate the need for more empirical work to further examine the performance of the two approaches using the same data sets.

Bayarsaihan and Coelli (2003) discuss causes of dramatic collapse in many centrally-planned economies. In their paper, the researchers use detailed farm-level data to measure total factor productivity (TFP) changes in Mongolian grain and potato farming during the 14 years period immediately preceding the 1990 economic reforms.

They measure TFP growth using stochastic frontier analysis (SFA) and data envelopment analysis (DEA) methods. Results show an average annual TFP change of -1.7% in grain and 0.8% in potatoes over the 14 years of period of the country. Empirical results from this research show that TFP growth exceeding 7% per year in the later half of 1990s. Reasons for the improvement of the performance of Mongolian crop farming are that they have introduced policies of improved education, greater management autonomy and improved incentives.

Therefore, a researcher in our country may check the performance of crop farming using SFA and DEA methods and then produce some suggestions for improving that performance significantly.

Henderson and Kingwell (2005) examine rain-fed broad-acre agriculture farms. Researchers are applying data envelopment analysis (DEA) to measure technical efficiency for a sample of broad-acre farms. They specify rainfall as a non-discretionary production input in an input-oriented DEA model.

They have gathered data from Western Australia region mixed enterprises of crops and livestock. The numbers of farms are 100 and data is 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% efficient farms in 1997 where rainfall-adjusted DEA model gives 45% efficient farms in the same year. Therefore, their suggestion is that measuring technical efficiency, where possible, should include environmental effects, such as rainfall.

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

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 modelled as a function of farm-specific socioeconomic factors, environmental factors and irrigation infrastructure. Results from both econometric 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) estimates 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 technique and DEA for estimating efficiencies. SF model shows results for technical, allocative and economic efficiency scores are 86, 91 and 78 per cent respectively. On the other hand, DEA model shows the corresponding efficiency scores are 86, 91 and 78 per cent respectively for CRS DEA and 91, 87 and 79 per cent 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, such as, credit facilities, quality extension services, experience of cultivation for the farmers etc.

2.3 Conclusion

We have reviewed both stochastic frontier and DEA frontiers 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 which might be important for modeling output and inefficiency effects, such as, rainfall data, extension services, access to credit etc. Bravo-Ureta and Rieger (1991) study shows that efficiency levels are not markedly affected by the socioeconomic variables like, farm size, education, extension services and experience. So, this statement can be reexamined by doing further study. Kalirajan (1981) do 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. Thiele and Brodersen (1999) produce a comparison of the efficiency of East and West German farms in 1995-97. 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 Indian State of Tamil Nadu. This study shows that a special attention should be given to improve the efficiency of paddy farms with holdings 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 assumptions 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 outputs 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 developments in the estimation of frontier functions and DEA frontier. Sharma, Leung and Zeleski (1999) use both parametric and nonparametric frontier 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 rainfall 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 (SF) analysis and data envelopment analysis (DEA) are not much familiar in Bangladesh. Few researchers have done the efficiency measurement using these two modern and sophisticated techniques of mathematical and econometrical methods particularly in agricultural sector. So far as we know that simultaneous estimation of technical, allocative and economic efficiency and comparison of results of these efficiencies using data from two different seasons, viz., aman and boro season, particularly in the northern part of Bangladesh, is not done.

This is first of its kind.

Chapter 3

Socioeconomic Conditions of the Study Area: The Barind

3.1 Introduction

3.2 Physiographic Description

3.3 Climate of the Region

3.4 Clay and Other Mineral Resources of the Region

3.5 Environment and Water Condition of the Region

3.6 Soils and Major Substitutes of the Region

3.7 Constraints for Using the Soils in the Region

3.8 Role of BMDA for Developing the Region

3.9 The Study Area: Selected Area from Three Different Districts

3.10 Conclusion

CHAPTER 3	SOCIOECONOMIC CONDITIONS OF THE STUDY AREA: THE BARIND

3.1 Introduction

The study is concerned about the rice production of Bangladesh. More specifically this study is related to the estimation of efficiency of rice farmers of High Barind area in Bangladesh. We have chosen this area where rice is the main crop of production. The surface water is not sufficient in this area. 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 are cultivated here other than main crop rice recently. Despite the fact described earlier, rice is the main crop in this region.

3.2 Physiographic Description

The Barind Tract is the largest *Pleistocene Physiographic* unit of the Bengal Basin covering an area of about 7,770 sq. km. It has been recognized as a unit of *Old Alluvium* which differs from the surrounding Floodplains. Geographically this unit lies roughly between latitudes $24^{\circ}20'$ N and $25^{\circ}35'$ N and longitudes $88^{\circ}20'$ E and $89^{\circ}30'$ E. This physiographic unit is bounded by the *Karatoya* River to the east, *Mahananda* River to the west, and northern bank of the *Ganges* to the south (Banglapedia, 2003).

A lower fault scarp marks the eastern edge of the Barind Tract, and the little *Jamuna*, *Atrai* and lower *Punarbhaba* Rivers occupy fault troughs. The western part of this unit has been tilted up; parts of the western edge are 15 m higher than the rest of the tract and the adjoining *Mahananda* floodplain. The southern part of the main eastern block of the Barind Tract tilted down toward the southwest and passes under lower Atrai basin Sediments in the south. The Barind Tract covers most part of the greater Dinajpur, Rangpur, Pabna, Rajshahi, Jaypurhat, Naogaon and Chapai Nawabganj districts of Rajshahi division (Banglapedia, 2003).

Physiographically this region is divided into three units. These are *Recent Alluvial Fan*, *Barind Pleistocene*, and *Recent Floodplain* (Brammer, 1996). These morphologic units are separated by long, narrow bands of Recent Alluvium. The floodplain of the Mahananda flanks the west side while the Karatoya delineates the eastern margin. The Punarbhava, Atrai and Old Jamuna with headwaters in the foothills of the Himalayas have cut across the Pleistocene and their floodplains separate the units. This and numerous other streams are responsible for the development of a broad Piedmont Alluvial plain which delineates the northern flank of the Tract. The Tista alluvial fan is located to the north of the area. This fan surface of the Himalayan foothills has a slope of approximately 0.43 m/km and it overlaps the Barind, which has essentially a flat or somewhat domed surface. South of the Barind Tract are Recent Floodplains, with a southerly slope about 0.06 m/km.

In the Barind region, three distinct Channel patterns are observed. In the north there is a great number of small Braided Streams, which have built broad piedmont alluvial plains along the foothills of the Himalayas. The major rivers of the alluvial plains are the Atrai, and the Punarbhaba, with entrenched valleys. On the Pleistocene unit, there are numerous small entrenched, tightly meandering streams, which have developed an overall dendritic pattern and flow into the major north-south rivers of the Barind unit. There are some major valleys that separate the Pleistocene unit into some north-south elongated units. These valleys are followed by some major rivers, such as the Mahananda in the west, the Karatoya in the east, the Atrai and the Punarbhaba in-between. The largest unit is bounded by the river Punarbhaba and the Atrai. Another large unit is bounded by the Karatoya and the little Jamuna. Many small channels, mostly of dendritic pattern, flow through the individual units.

The Barind Tract, which is the largest Pleistocene Terrace of the country, is made up of the Pleistocene alluvium, also known as older alluvium. Tectonically, this region is situated in the Precambrian Indian Platform, mostly in the saddle and shelf area of the shield. This platform area is covered mostly by Tertiary and Quaternary sediments and Recent Alluvium.

The Barind unit is comparatively at a higher elevation than the adjoining floodplains. The contours of the tract suggest that there are two terrace levels - one at 40 m and the other between 19.8 m and 22.9 m. 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% of the Barind region is classified as highland; about 41% as medium highland and the rest are lowland. Agricultural land commonly occupies about 80% of the hill slopes of the Barind unit most of 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 converted 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 and their distributaries 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 Climate of the Region

The Barind Tract lies in the Monsoon region of the summer dominant hemisphere. The tropic of cancer lies south of this region. The climate of the area is generally warm and humid. Based on rainfall, humidity, temperature and wind pressure, the weather condition is classified into four types, such as, (a) pre-monsoon, (b) monsoon, (c) post-monsoon and (d) winter.

Rainfall is comparatively little in this region, the average being about 1,971 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 798 mm only. This region has already been designated as *Drought* prone. Its average temperature ranges from 25^{o} c to 35^{o} c in the hottest season and 9^{o} c to 15^{o} c in the coolest season. Generally this region is rather hot and is considered as semi-arid. In summer, some of the hottest days experience a temperature of about 45^{o} c or even more in Rajshahi area. In winter it falls to about 5^{o} c in some places of Dinajur, Rangpur and Rajshahi districts. So this older alluvium region experiences extremes that are clearly in contrast to the climatic condition of the rest of the country.

3.4 Clay and Other Mineral Resources of the Region

The Barind is floored by the characteristics Pleistocene sediments known as Madhupur (Barind) Clay. The Madhupur Clay is reddish brown in colour, oxidized, sticky and rather compact. This tract is characterized by its comparatively high elevation, radish and yellowish clay soils, entrenched dendritic stream pattern and a relative paucity of vegetation.

The Barind Tract is rich in Mineral Resources as it rest upon the Pre-Cambrian Indian Shield of the Bengal Basin. Of the mineral resources, Coal, Peat, Hard Rock, Limestone, White Clay and Glass Sand are important (Rashid, 1991). Actually these mineral deposits are found within the platform area below the Pleistocene rock units of the Barind Tract. High-grade Bituminous Coal deposits have been discovered in Bogra, Rajshahi, Rangpur and Dinajpur districts. These are found in small isolated basins, known as Grabens, located within the Pre-Cambrian basement below Pleistocene sediments of the Barind Tract. Limestone is also found in the Shelf area of the platform located in the southern part of the Barind Tract beneath the Pleistocene units. This Limestone belongs to the Eocene period and is an important raw material for the manufacture of cement. Hard Rock is another precious resource of the Barind region. Actually the whole platform area is composed of Pre-Cambrian igneous and metamorphic rocks. This Hard Rock is an essential building material commonly used for constructing roads, bridges, and other structures. White Clay and Glass Sand are generally found in the upper part of the basement rocks right below the Barind rock units. These minerals are widely used for the manufacture of ceramic wares, electric goods and many other industrial items.

3.5 Environment and Water Condition of the Region

Rapid population growth along with modifications of the land forms of Barind Tract has been degrading the biophysical environment of this region. The climatic 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 source of the groundwater recharge in this area, 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 Barind region. This phenomena have eventually been greatly affected the environment parameters and if it persists the environment of the Barind Tract 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% are of this Tract was covered by forests in early 19th century. Statistical reports of the land survey since 1849 showed that forest covered about 55% of the Barind lands. But by 1974, about 70% land of the region had been changed into cultivable land (Banglapedia, 2003).

The Barind almost become an arid region 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 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 only one crop and the Tract 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.

3.6 Soil and Major Substitutes of the Region

The age of the Barind Tract is difficult to establish with certainty. The Barind Tract has a level surface underlain by little-altered Madhupur Clay. Other areas have been dissected by valleys, but the interfluves between them are either level rise to a uniform level.

The Barind Tract comprises a number of uplifted blocks in the north-west which are underlain by Madhupur Clay. Relief and soil patterns are much less complex than those occur on the Madhupur Tract (Brammer, 1996).

There are three major substitutes-

(1) The level Barind Tract comprises level, poorly-drained areas which occupy most of the Tract. The Madhupur Clay substratum underlying the prevalent Grey Terrace Soils is more variably weathered, ranging from impervious, little-altered, heavy clay through all gradations to pervious, red-molted, highly-weathered, friable-clay, sometimes within distances of only a few metres. Seasonal flooding is mainly shallow and rainwater, which is retained between field bunds on the relatively higher parts of the relief, but flooding becomes deeper in the south towards the margin with the Lower Atrai Basin.

(2) The Barind Tract reaches a high point of >40 m MSL on the western edge of the tract overlooking the Lower Punarbhaba Floodplain. It is deeply dissented by valleys, the sides which have mainly been terraced for paddy cultivation. The ridge tops between valleys are usually flat or gently sloping towards the east, and are also bended for paddy cultivation. Most of the valleys are stream less.

(3) The North-eastern Barind Tract occupies some small nearly-level areas along the northern and southern margins of the tract where the underlying Madhupur Clay has been deeply weathered to permeable, friable, red-molted clay. The soils are red and well drained along the highest edges, becoming progressively more poorly drained and greyer towards interior sites which are shallowly flooded by rainwater or the raised groundwater-table in the monsoon season.

Soils on Madhupur and Barind Tracts are more clayey than those in hill areas and come under the influence of a seasonally fluctuating water-table. They generally are less acid in reaction than the hill soils, usually with p^H values in the range 5.0-5.5, or occasionally higher.

On the Madhupur and Barind Tracts, weathering of the parent Madhupur Clay started many thousand years ago, probably under different climate and geo-morphological conditions from the present. For instance, the large amount of lime nodules and the presence of slickenside found in some shallowly weathered soils are thought to have been inherited from drier and possibly hotter climatic conditions from several thousand years ago.

Mineralogical studies show that the Deep Red-Brown Terrace Soils on the Barind Tract are not completely weathered. About 40% of the clay fraction is made up by illite and vermiculite, relatively un-weathered alkali and plagioclase feldspars remain in the sand fraction.

Deep Red-Brown and Deep Grey Terrace Soils are found on the Barind Tract. These soils are similar to those on level terrace areas of the Madhupur Tract, but occur in significantly different proportions. On the well-drained red soils, fields are bordered by jack fruit trees and aus followed by rabi crops is the main practice; potatoes, vegetables and wheat are grown with irrigation from dug wells; sugarcane and mesta are also important. On less well-drained soils, aus-transplanted aman is the main practice; with irrigation, HYV boro paddy or potatoes are grown, followed by rainfed aus or transplanted aman in the monsoon season.

3.7 Constraints for Using the Soil in the Region

The main constraints on agricultural use and potential are:

- low moisture-holding capacity;
- uncertain depth and duration of seasonal flooding on the brown-mottled and grey soils; and
- low natural soil fertility.

On the other hand, Deep and Shallow Gray Terrace Soils occupies the greater part of the Barind Tract. The deep soils occupy over half of the area and the shallow soils about one quarter. The two soils often occur closely intermixed in the landscape, but the deep soils are relatively more extensive in the west, especially on the High Barind in Rajshahi region.

On the High Barind, more than 90% of the land lies about normal flood levels, but rainwater is held on terraced fields within high field bunds in order to grow transplanted rice. On the level Barind, Highland occupies 30%, medium Highland 55%. Both 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 Barind Tract (Brammer, 1996).

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

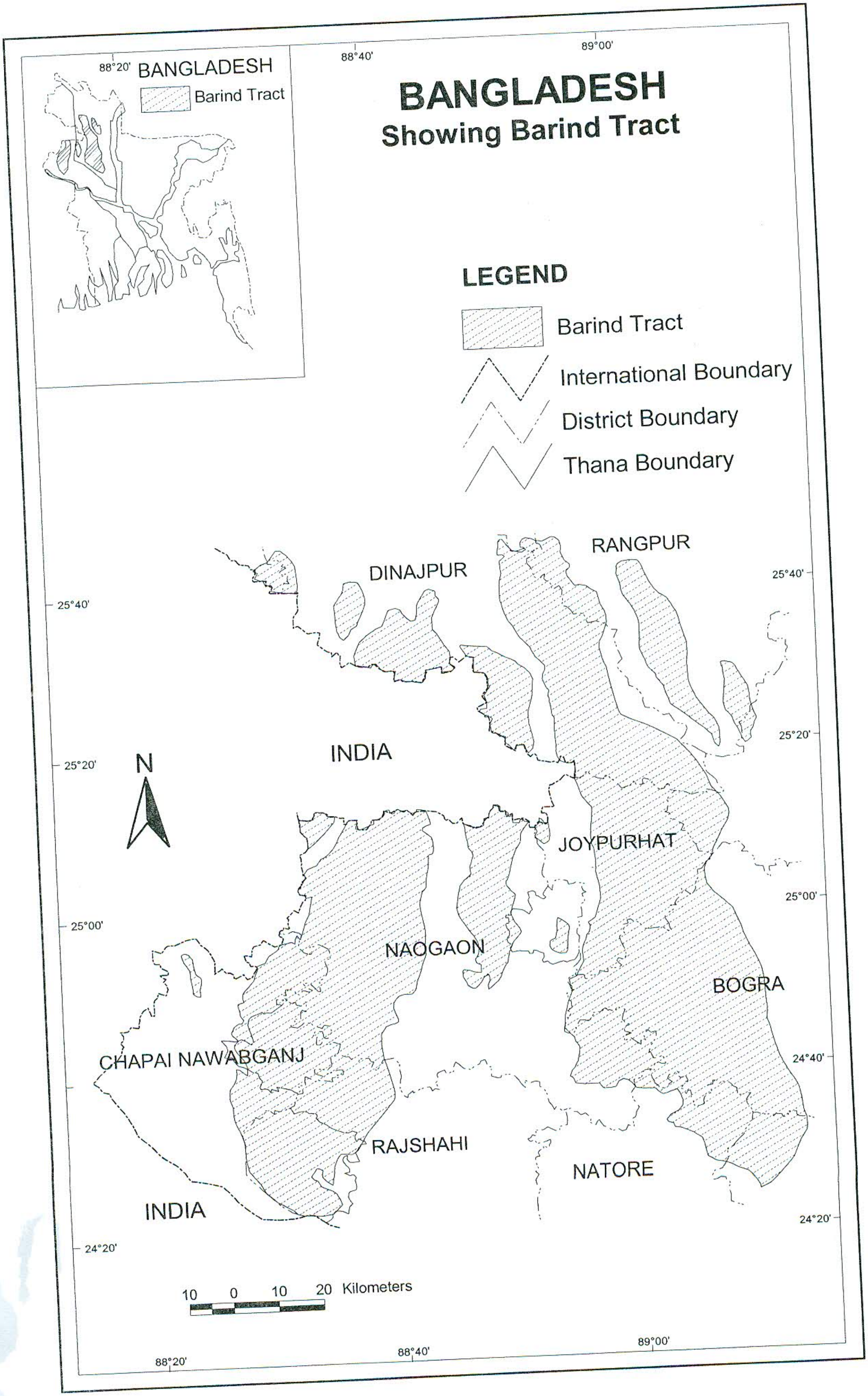
The major constraints for agriculture especially for the cultivation of dry land crops are provided by the unstable silty topsoils and strongly developed ploughpans which make the soils quickly wet and dry. Variable pre-monsoon and monsoon rainfall, especially uncertain in the west, aggravate the poor 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 Barind Tract are subject to moderately deep flooding in years with exceptionally high rainfall, for example, such as, occurred in 1987.

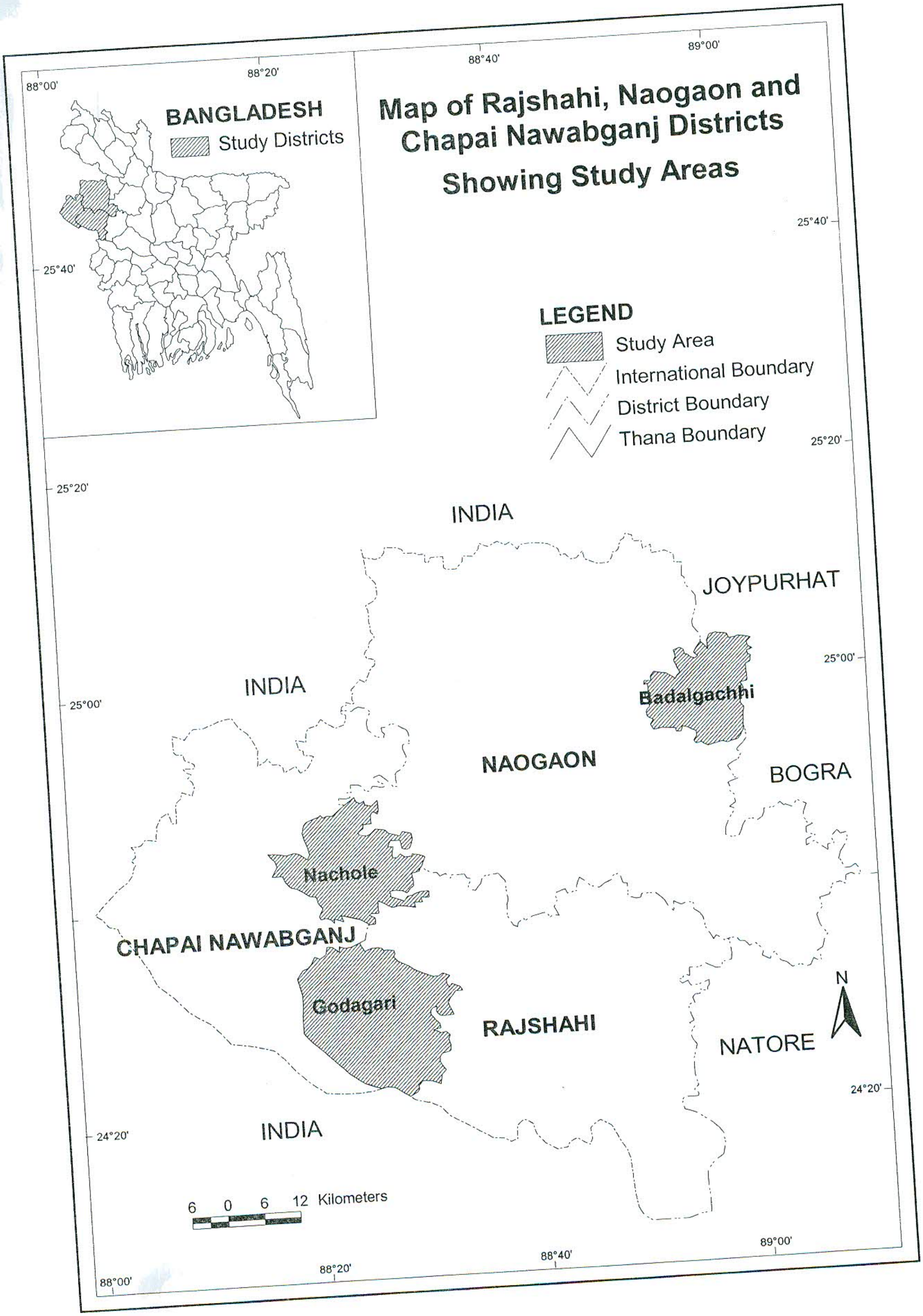
3.8 Role of BMDA for Developing the Region

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 connected development schemes such as road development, have had a positive impact on the socio-economic conditions of the area. Thus the project has proved it a success. The project has been renamed as the Barind Multipurpose Development Authority (BMDA) since the early 1990s and now covers a large part of the Barind Tract.

3.9 The Study Area: Selected Area from Three Different Districts

The High Barind Tract is our study area. More specifically we have selected three upazella from three different districts in the High Barind Tract. The upazellas are Godagari from Rajshahi district, Nachole from Chapai Nawabganj district and Badalgachhi from Naogaon district. A geographical diagram is depicted here to show the Barind Tract and also the selected three upazellas from three different districts.


BANGLADESH
Showing Barind Tract
BANGLADESH
Barind Tract
LEGEND
Barind Tract
International Boundary
District Boundary
Thana Boundary
RANGPUR
DINAJPUR
INDIA
N
JOYPURHAT
NAOGAON
BOGRA
CHAPAI NAWABGANJ
RAJSHAHI
NATORE
INDIA
10 0 10 20 Kilometers
88°20'
88°40'
89°00'
25°40'
25°20'
25°00'
24°40'
24°20'


Map of Rajshahi, Naogaon and Chapai Nawabganj Districts Showing Study Areas
BANGLADESH
Study Districts
LEGEND
Study Area
International Boundary
District Boundary
Thana Boundary
INDIA
JOYPURHAT
INDIA
Badalgachhi
NAOGAON
BOGRA
Nachole
CHAPAI NAWABGANJ
Godagari
RAJSHAHI
NATORE
INDIA
N
6 0 6 12 Kilometers
88°00'
88°20'
88°40'
89°00'
25°40'
25°20'
25°00'
24°20'

We have shown two different maps for the Barind Tract and the study in particular. In the first map the total Barind Tract is shown with the country map of Bangladesh. This Barind Tract comprises three major subunits, such as: (1) The Level Barind Tract, (2) The High Barind Tract, and (3) The North-eastern Baind Tract. The Level Barind Tract comprises level, poorly-drained areas which occupy most of the tract. The High Barind Tract reaches a high point of >40 m MSL on the western edge of the tract overlooking the Lower Punarbhaba Floodplain. This subunit has no equivalent on the Madhupur Tract. The ridge tops between valleys are usually flat or gently sloping towards the east, and also bunded for paddy cultivation. The North-eastern Tract occupies some small, nearly level areas along the northern and eastern margins of the tract. The soils are red and well drained along the highest edges. On the other hand, the second map shows three selected upazellas (sub district) from three different districts of the Barind Tract.

3.10 Conclusion

In this study, we have selected three different districts for collecting data. Though all the selected areas are under the high Barind region, but there are little differences as far as educational, social and soil conditions are concerned.

The climate of the Barind region is generally warm and humid. Rainfall is comparatively little in this region, the average being about 1971 mm. The region has already been designated as Draught prone. The average temperature ranges from 25^0c to 35^0c in the hottest season and 9^0c to 15^0c in the coolest season.

The clay of this region is reddish brown in colour, oxidized, sticky and rather compact. The biophysical environment of this region is degrading. The climatic condition of this region has changed rapidly. There is very little rainfall and weather remains hot by 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 of the Barind region.

The Barind area almost becomes an arid region due to massive deforestation and also due to its extreme dry nature and relatively low rainfall, the vegetation cover decreased remarkably. So, the area is already picked up as a hot and dry land. Soils on the Barind tracts are more clayey than those in hill areas and come under the influence of a seasonally fluctuating water-table. The soils are generally less acidic than the hill soils, usually with p^H values in the ranges 5.0 to 5.5 or occasionally higher.

Main constraints on agriculture use of soils are (1) low moisture-holding capacity, (2) uncertain depth and duration of seasonal flooding on the brown-mottled and grey soils and (3) low nature soil fertility. So, the prime constraints for agriculture especially for cultivation of dry land crops are unstable silty topsoils and strongly developed ploughpans which make soils quickly wet and dry.

Barind Multipurpose Development Authority (BMDA) has done a remarkable change in this area. BMDA has taken initiative to develop groundwater irrigation in this area since mid- 1980s. 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 production intensity has improved than before.

All of these factors may affect the efficiency performance of rice farmers and hence decrease farm income of the households.

Chapter 4

The Survey Method and Survey Results

CHAPTER 4	THE SURVEY METHOD AND SURVEY RESULTS

4.1 The Survey Method

4.1.1 Introduction

Survey techniques generally are thought of more as an art than a science, but perhaps both should be involved. Perhaps one should bring to bear on survey research procedures whatever scientific knowledge he has about human behavour (Phillips, 1976). In our study, we have focused the following characteristics of the survey method:

1) The purpose of the survey is to produce ***statistics***- that is, quantitative or numerical descriptions of some aspects of the study populations.
2) The main way of collecting information is by asking people ***questions***. Their ***answers*** constitute the data to be analyzed.
3) Generally, information is collected about only ***a fraction of the people***- that is, ***a sample***- rather than from every member of the population.

The main reason of the survey is to collect information that is not available from any other sources. The strengths of survey methods, however, that result in their wide use are the value of statistical sampling, consistent measurement, and the ability to obtain information not systematically available elsewhere in the form of needed analyses (Fowler, 1985).

A sample survey brings together three different methodological areas: ***sampling, designing questions, and interviewing.*** Each of these techniques has many applications outside of sample surveys, but their combination is essential to a good survey design.

4.1.2 Sampling

Sampling is the most basic component of survey methods. A major development in the process of making surveys useful was learning how to sample, to select a small sub-set of a population representative of the whole population. The key to good sample is finding a way to give all (or nearly all) population members the same chance of being sampled, and to use probability methods for choosing the sample. (Fowler, 1985).

In simple words sampling consists of obtaining information of a portion of a large group or universe. Often a social researcher has to collect information about a universe that consists of vast, differentiated population spread over a large territory; and within limited amount of time and money. Measuring or collecting information from each and every of such a vast population is, therefore, always not possible. It is known that part of a whole can give sufficient dependable information if the procedures followed in selection of the part are scientific. It is this part of a whole which is called as a sample. It is a portion or sub-part of the total population. To collect information about a population one can follow any of the two methods, (i) Census or (ii) Sampling. In our study we are not interested for census because it not possible to collect information from every person of the population due to time and money constraint. So, we do sampling of the population.

Elements are selected in a manner that they yield all-most all information about the whole universe, if and when selected according to some scientific principles and procedures. We do prefer sampling because it helps to collect vital information more quickly. Even small samples, when properly selected helps to make estimates of the characteristics of the total population in a shorter time. Sampling also cuts costs. So far as accuracy is concerned, sampling techniques often increase the accuracy of the data, and finally from administrative point of view, sampling becomes easier. Study through census method would involve the hiring of a large staff, the task of training and supervising them, and the problem of dealing with a huge data. Sampling provides short-cut ways to solve these problems (Thakur, 1998).

The different sampling techniques can be broadly divided into two groups: (a) probability sampling techniques, and (b) non-probability sampling techniques. The probability sampling technique is one in which one can specify for each element of population the probability of its being included in the sample. An essential quality of a probability sample is that it makes possible representative sampling plans. Major types of probability sampling methods are: (i) simple random sampling method, (ii) systematic sampling method, (iii) stratified random sampling method, (iv) cluster sampling method, and (v) multistage sampling.

In non-probability sampling techniques, one cannot estimate beforehand the probability of each element being included in the sample. It also does not assure that every element has a chance of being included. In probability sampling one does to prepare or know a list of all the elements of the total population from which the sample is to be drawn. This makes the sampling procedure costlier and more time consuming, which can be saved in non-probability sampling. The major forms of non-probability samples are: (i) accidental samples, (ii) quota samples, and (ii) purposive samples. In our study we have used both probability and non-probability techniques stated earlier when doing sampling.

For doing the job of sampling from the total Barind area we, first of all, have used purposive sampling. In case of purposive sampling one picks up the cases that are considered to be typical of the population in which one is interested. The cases are judged as typical on the basis of the needs of the researcher. By using the purposive techniques we have selected three upazella, one from Rajshahi district, and one from Chapai Nawabganj district and the third one from Naogaon district. Then we select three villages from each upazella. These villages are considered as strata. In the second stage we have used the technique of stratified random sampling.

When the population is divided into different strata or groups, then the samples are selected from each stratum by simple random sampling procedure or by regular interval method which we call it as stratified random sampling method. We use simple random sampling technique. The same result can be achieved without increasing the size of the sample through the application of stratified random sampling method. The stratified random sampling method can be applied only when the population characteristics are known. In Barind area, the nature, attitude, characteristics, and behavour of rice farmers are well known by the researcher. So, the way, in which we have done the sampling under the procedure of stratified random sampling method, is justified.

We have selected three villages from Godagari upazella of Rajshahi district under the procedure of purposive sampling. The names of the villages are Rishikul, Baipur, and Alok Chhatra. Then we have categorized the rice farmers into three groups, such as large farmers, medium farmers, and marginal farmers. Finally we have sampled eighty rice farmers from the selected three villages under the procedure of simple random sampling.

Similarly, we have selected three villages from Nachole upazella of Chapai Nawabganj district under the procedure of purposive sampling. The names of the villages are Nizampur, Fatepur, and Kasba. With the same procedure, discussed earlier, fifty rice farmers are selected.

Finally, we have selected four villages from Badalgachhi upazella of Naogaon district under the procedure of purposive sampling. The names of the villages are Khokshabari, Hakimpur, Mithapur, and Parora. In the same way, we have categorized the rice farmers into three major groups, namely large farmers, medium farmers, and marginal farmers. Then seventy five farmers are selected by the procedure of simple random sampling for collecting data. The numbers of the farms in sample are depending on the size of the population.

4.1.3 Designing Questionnaire

Next important task for a survey is to design questionnaire. Questionnaire is a set of questions developed in an organized and ordered manner for gaining information from the people in relation to the given problems. Questionnaire can be divided into different types on the basis of the type of response required. Response may be (a) fixed or closed type, (b) open-ended type, and (c) mixed of both closed and open-ended type. In our study we have used mixed of both closed and open-ended type questions.

The questionnaire aims to achieve two goals. Firstly to gather data relevant to objectives of the survey and secondly to gather data which are reliable and valid. These goals can be called relevance and accuracy (Warwick and Lininger, 1975). To achieve these goals we have conducted a plot survey to check whether the questionnaire is capable of gathering required data, the respondents grasp of the survey and how many times is taken to complete the survey. After completing the plot survey an integrated questionnaire has been prepared which consists of four major sections. The first section contains a number of personal questions discussing name, age, marital status, educational status, demographic characteristics, and social status of farm household. The second section covers production and it includes questions on total land owned, total land cultivated, homestead area, forest area, fallow land, total cultivated area, net cultivated area, total irrigated area, number of plots, average plot size, average plot distance, share cropping area, homestead utilization, land and labour utilization, irrigation information, fertilizer utilization, pesticides utilization, water seller's information, yield, and output and input prices. The third section concerns non-farm incomes and activities, and fourth section includes livestock information. A sample questionnaire is given in Annexure-1.

When questionnaire has been printed finally and is ready for collection of data the researcher needs to make preparations for its application, depending upon the methods of administering the questionnaire. From different methods of administering the questionnaire, we have used the Interview Method.

4.1.4 The Interview Method

Although all surveys do not involve interviewing, as some surveys have respondents who answer self-administered questions. It is common to use this technique to ask questions and record answers. It is important not to influence the respondent in process of answering questions and at the same time to ensure the accuracy with which questions are answered. In interview method the researcher tries to penetrate deeply in his imagination into the circumstances presented by the subject. Interview has two basic objectives, discovery and measurement. Discovery indicates gaining new knowledge, new consciousness or new insight of certain unexplored qualitative/ quantitative aspects of the problem. There are mainly two types of interview: (i) structured, and (ii) unstructured. Types of interview method to be used depend on the nature of the problem being investigated and the type of the information wanted. We have used both structured and unstructured types of questions in conducting interviews.

4.1.5 The Survey Data

The data used in this research are collected from ten villages of three different upazell of three different districts in the High Barind area of Bangladesh. The survey data are collected for two consecutive rice seasons. One aman season from June to September in 2002 and another Boro season from November to February in 2003-2004.

We have discussed our theoretical and empirical models in next chapters in detail. But here we give some definition and description of collected data. We have used one output and six inputs in this study. We have also used six socio-economic and infrastructural variables which affect production and inefficiency of the farmers.

Output is defined as the observed rice production and is measured in kilograms (km). Land represents the total area of land used for rice production and the price of land represents the price per acre of land. Labour includes both family and hired labour engaged in rice production and the price of labour indicates the wage per man-day (wages for family labour are imputed). Irrigation is the total area of land irrigated for rice production and the price of irrigation represents irrigation price per acre. Fertilizer includes all organic and inorganic fertilizer and is measured in kilograms. The fertilizer price indicates the average price of all fertilizer per kilogram. Pesticides is the total quantity of pesticides used per acre of land and is measured also in kilograms. The price of pesticides is the price of all pesticides per kilogram. Seeds represents the amount of seeds used in per acre of land and is measured in kilograms. The seed price means the average prices of seeds per kilogram (includes both HYV and traditional type of seeds).

We now discuss socio-economic and infrastructural variables, which affect production and efficiency of the farmers. The first variable denotes the year of the schooling of the farmer; second variable denotes the duration of rice cultivation experience of the farmer; third variable represents the land fragmentation; forth variable is the extension services dummy which assumes the value one if the farmer takes extension services from the related officials and zero otherwise; fifth variable is credit facilities dummy which assumes the value one if the farmer takes any kind of credit from government and non-government sources and zero otherwise and sixth variable is the land degradation dummy which takes the value one if the land is un-degraded and zero otherwise.

4.1.6 Factors Associated with Inefficiency

Factors associated with inefficiency have played an important role in this study. Therefore, we should carefully identify and isolate the factors as far as efficiency is concerned. From the review related literature we have seen some socio-economic and demographic factors associated with inefficiency. These factors include land use, credit availability, land tenure, and households labour's education (Seyoum *et.al.*, 1998; Coelli and Battese, 1996; Wilson *et.al.*, 1998; Kumbhakar, 1994). Techniques of cultivation, share tenancy, farm holding size also influence the efficiency of farmers (Ali and Choudhury, 1990; Coelli and Battese, 1996; Kumbhakar, 1994). Apart from this some environmental factors and some non-physical factors such as availability of 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 will discuss what about this situation in context of Bangladesh particularly in Barind area.

In the High Barind area the following variables, viz., age of farmer, experience of cultivation, year of schooling, land plot size, that is, land fragmentation, extension services, and credit facilities may be considered as relevant. The age of the farmer could have a positive or a negative effect on efficiency. Years of farming experience may reduce the inefficiency of the farmers but sometimes the farmers are less receptive and more conservative in nature to adopt new technologies in production. *A priori*, more years of schooling, that is, more formal education will generally increase efficiency. Because, educated farmers can learn the new technology quickly and so, they can improve techniques of cultivation accordingly. Levels of increased education and extension services are related to allocative efficiency of Indian farmers (Ram, 1980). Extension services and education prompt the adjustment process in the application of fertilizer in response to a decrease in its price in the U.S. corn output (Huffman, 1977).

Land fragmentation, that is, land 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 the 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.

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 of irrigation system in Barind area. BMDA (Barind Multipurpose Development Authority) has done this job by setting a large number of Deep Tube Wells (DTWs). *A posteriori*, this improved irrigation infrastructure could have a positive impact upon the production as well as the 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.

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 cultivation. Generally, more and easy availability of credit could have positive effect on efficiency of the farmer.

Environmental factors are given more attention to the 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).

4.1.7 Problems in Conducting Survey

In the course of conducting survey, in most cases we have got positive response from the farmers. The farmers are co-operative and helpful. They are spontaneous during answering the questions. They have given information whatever asked to them without any hesitation. But we have faced some problems in the process of conducting surveys. **Firstly**, a considerable number of respondents are not prepared to answer the questions. **Secondly**, the farmers are not habituated to restore the relevant data of the inputs what they have used in cultivation process. **Thirdly**, measurement unit is another problem, because they have used local units of measurement which differs from one region to another. **Fourthly**, some of them are afraid, because they thing that the researcher come from government offices and for that reason they are not interested to response the questions. But later the farmers had understood the fact and give the researcher full co-operation, and **finally**, sometimes they have concealed the information and underscore the data due to unwanted fear whether they have forced to burden extra duty or taxes.

4.2 The Survey Results

In this section, we have shown results what we have got from the primary survey of the study area. We are interested to know that what the primary conditions of the farmer are. For example, what are the age, experience of cultivation, and educational status of the farmer? And we also try to know about the area of total land and area of the cultivated land, average plot size, average production cost, average yield and profit of the farmers. Now we have given the survey results in details.

4.2.1 Age of the Farmer

We have taken different types of farmers in the High Barind area as far as age is concerned. The age limit of the farmers is from 20 years to 75 years. The survey result shows that most of the farmers are young and energetic. Forty seven per cent farmers have the age limit between 30 years to 45 years and 72 per cent farmer's age lie between 30 years to 55 years. On the other hand, a significant number (13 per cent) of farmers have the age of 60 years or more. In both aman and boro season, the same kind of respondent is chosen. So, there is no difference in both seasons as far as age of the farmer is concerned. We have shown these results in details in Table 4.1 and Figure 4.1.

Table 4.1: Plot Survey by the Age of the Farmer

Age (year)	No. of Farmer	Age (year)	No. of Farmer
20-25	3	50-55	21
25-30	15	55-60	14
30-35	26	60-65	18
35-40	32	65-70	7
40-45	36	70-75	3
45-50	30	Total	205

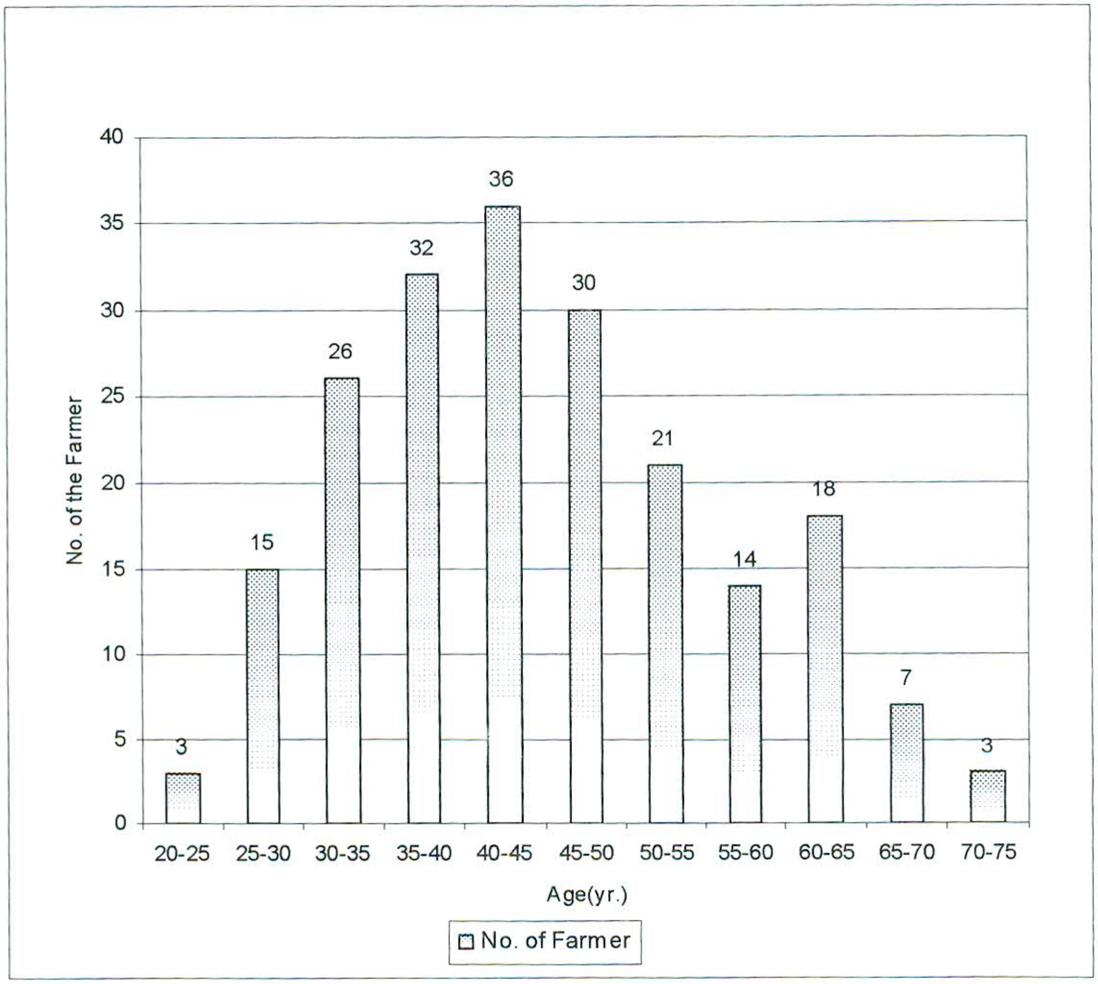


Figure 4.1: Age Classification of the Farmer

4.2.2 Experience of Rice Cultivation of the Farmer

For most of the farmer in the study area of Barind tract, we have found experienced as far as rice production is concerned. They use traditional system of cultivation. They have actually no training of modern cultivation system. They do not use required proportion of fertilizer and pesticides. They have no academic training or experience in this regard. But for a long period, they produce rice. For example, 57 per cent farmers have an experience of 10 years to 25 years of cultivation and 26 per cent have an experience of 30 years to 45 years. Importantly, 10 per cent farmers have an experience of forty years or more. In both season, it is found that farmers have almost similar period of experience. Therefore, we have not show it separately. But undoubtedly, they have a lot of experience in rice cultivation. We have shown these results in Table 4.2 and Figure 4.2.

Table 4.2: Experience of the Farmer

Experience	No. of the Farmer	Experience	No. of the Farmer
0-5	1	30-35	21
5-10.	18	35-40	13
10-15.	36	40-45	21
15-20	30	45-50	1
20-25	48	Total	205
25-30	16		

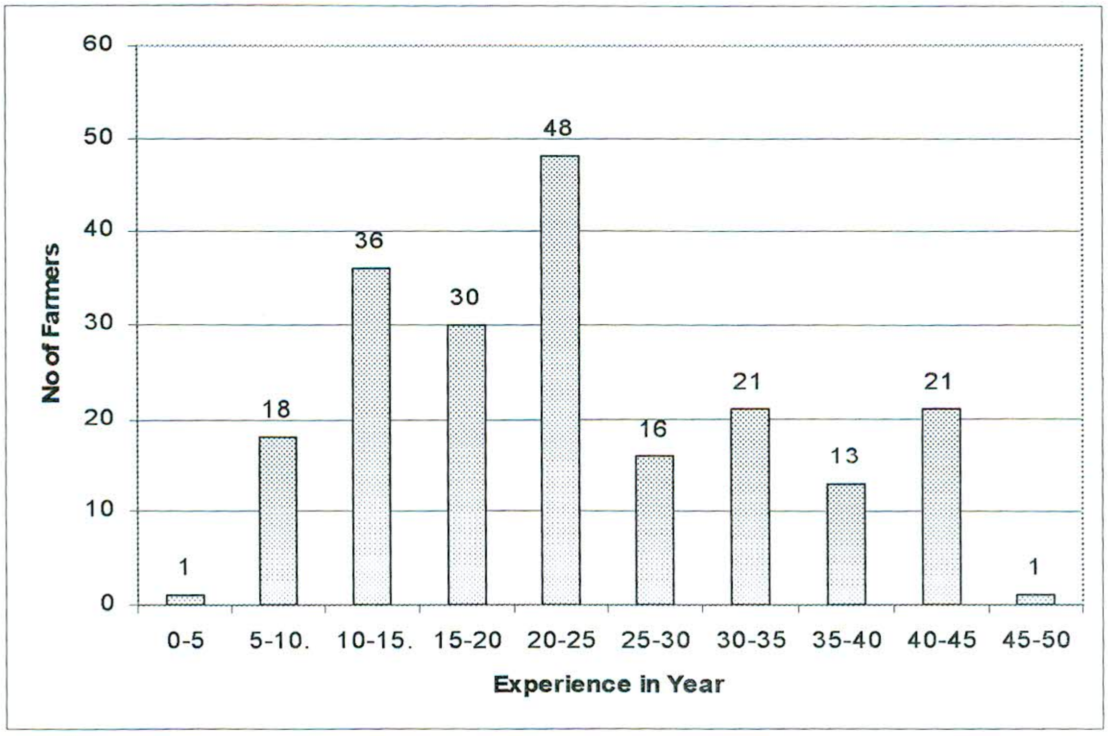


Figure 4.2: Rice Cultivation Experience of the Farmer

4.2.3 Duration of Schooling of Farmers

A major portion (31 per cent) of farmers has the experience of formal education less than 5 years. Of them, 58 per cent have never attended the school. Thirty three per cent of farmers do pass primary level but do not complete Secondary School Certificate (SSC) examination. On the other hand, 36 per cent have SSC to graduation level formal education. Only one farmer has post graduation degree. We show this result in Table 4.3 and Figure 4.3.

Table 4.3: Classification by duration of Schooling of the Farmer

Year of schooling	No. of farmer
0-5	63
5-10	68
10-15	61
15-20	13
Total	205

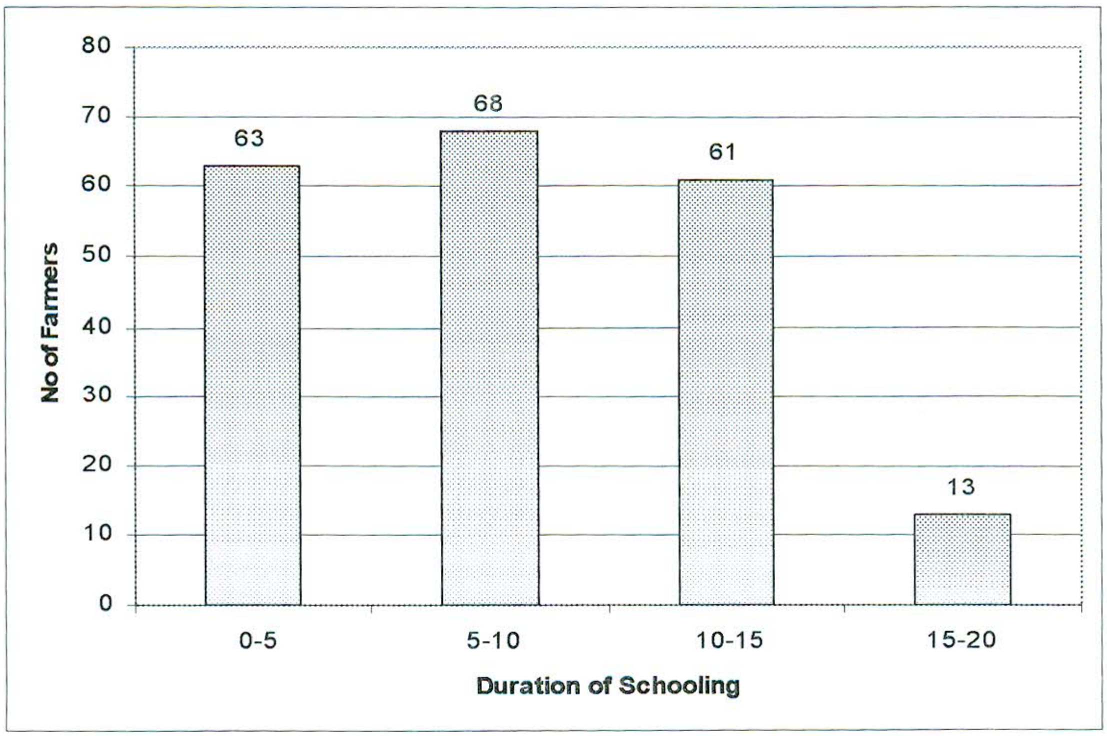


Figure 4.3: Duration of Schooling of the Farmer

4.2.4 Total Land Owned by the Farmers

In the study area, the survey results show that most of the farmers are marginal type farmer. In aman season of 2002, 31 per cent farmers have total land less than 2 acres and 31 per cent have more than 2 acres land but less than 4 acres, and 17 per cent farmers have more than 4 acres land but less than 6 acres. Fifteen per cent farmers have 6 acres to 10 acres land. Only 6 per cent farmers have more than 10 acres of total land. These survey results are shown in Table 4.4 and Figure 4.4. In boro season of 2003 we have investigated exactly same respondents, therefore, no difference is found as far as total land is concerned.

Table 4.4: Classification of Total Land Owned by the Farmer

Land (acre)	No. of farmer	Land (acre)	No. of farmer
0-2	65	10-12	4
2-4	63	12-14	4
4-6	35	14-16	2
6-8	16	16-18	2
8-10	14	Total	205

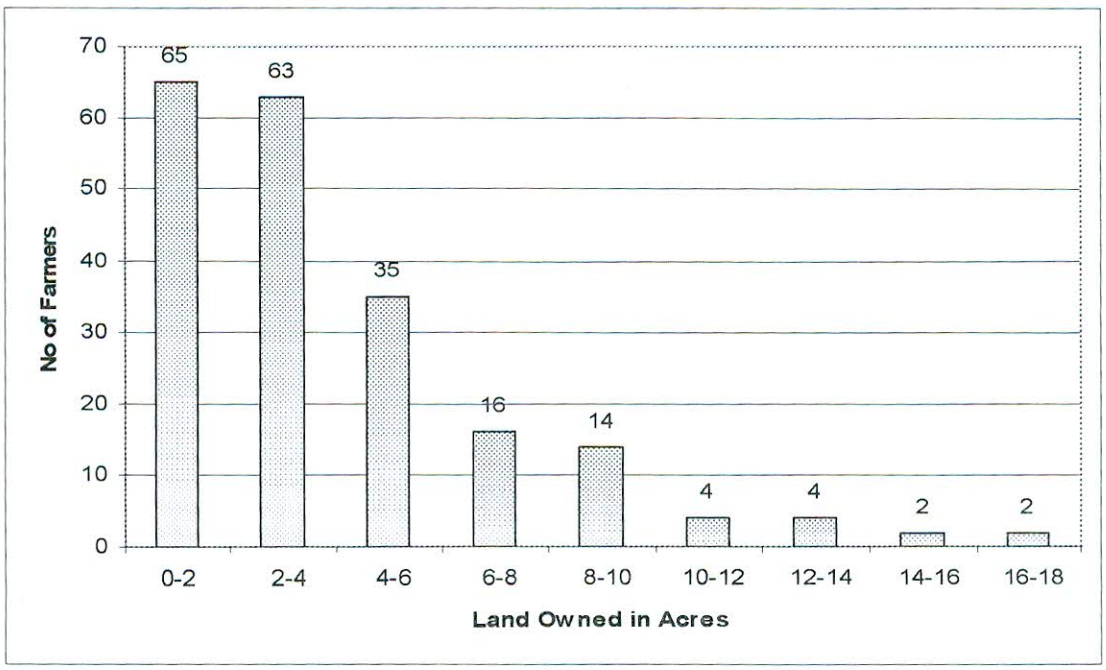


Figure 4.4: Total Land Owned by the Farmer

4.2.5 Total Land Cultivated by the Farmers

We have seen in our study area that a large number of farmers are marginal farmers as far as aman rice cultivation is concerned. For example, 70 per cent of farmers have cultivated aman rice in 2002, who have less than 4 acres of land. On the other hand, 26 per cent farmers have cultivated aman rice in 2002, who have just 4 acres to 10 acres of land. Only 4 per cent farmers have cultivated more than 10 acres of land in 2002 aman season. This result depicted in Table 4.5(a) and Figure 4.5(a).

Table 4.5(a): Total Land Cultivated by the Farmer in Aman Season, 2002

Land (acre)	No. of Farmer	Land(acre)	No. of Farmer
0-2	65	10-12.	4
2-4	77	12-14.	2
4-6	31	14-16	2
6-8	19	Total	205
8-10	5		

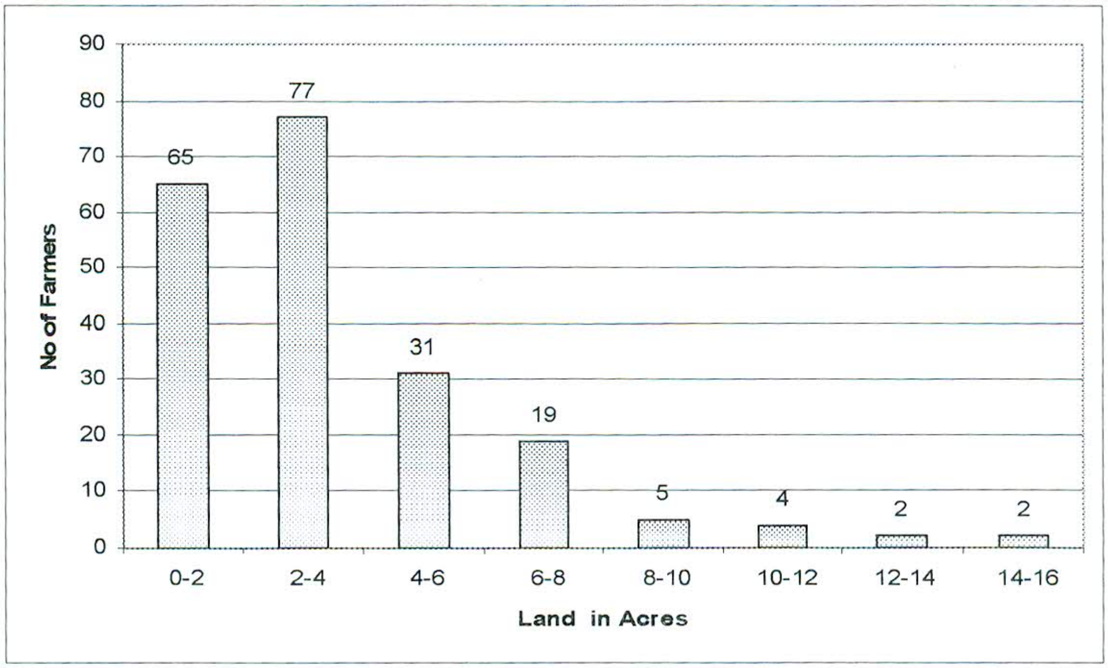


Figure 4.5(a): Total Land Cultivated in Aman Season, 2002

On the other hand, in boro season of 2003 more than eighty per cent (81%) farmers have cultivated boro rice who have less than 4 acres of cultivable land and 17 per cent farmers have cultivated 4 acres to 10 acres of land. Only 2 per cent farmers have cultivated 10 acres or more land. This result is shown in Table 4.5(b) and Figure 4.5(b).

Table 4.5(b): Total Land Cultivated by the Farmers in Boro Season, 2003

Land (acre)	No. of Farmer	Land (acre)	No. of Farmer
0-2	78	10-12	5
2-4	86	12-14	1
4-6	22	14-16	0
6-8	12	Total	205
8-10	1		

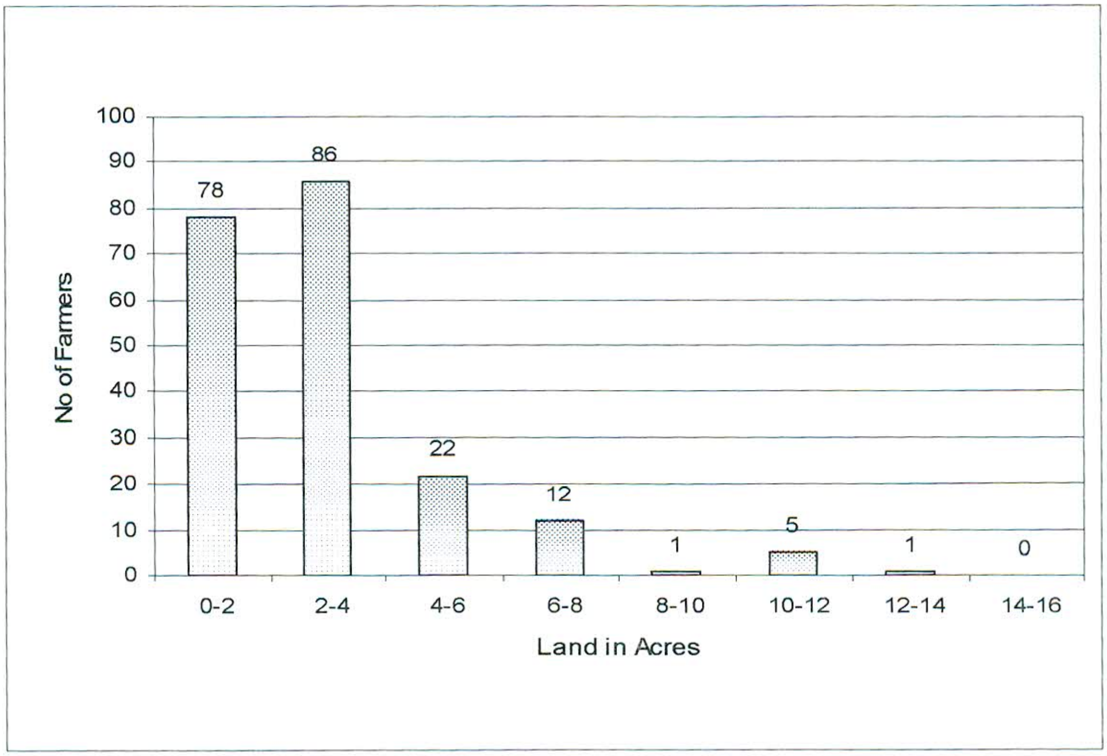


Figure 4.5(b): Total Land Cultivated by the Farmers in Boro Season, 2003

4.2.6 Plot Size of the Farmer in Aman Season, 2002

In the Barind area, land is small and fragmented. The survey results show this fact. Sixty three per cent farmers' average plot size is less than half an acre and 29 per cent have a plot size only half an acre to one acre. Eight per cent farmers have land size one acre to 2 acres. Only one farmer has a land size 3 acre or more. This result is shown in Table 4.6 and Figure 4.6.

Table 4.6: Plot Size of the Farmer in Aman Season, 2002

Land (acre)	No. of Farmer	Land (acre)	No. of Farmer
0-0.5	128	2-2.5	0
0.5-1	59	2.5-3	0
1-1.5	16	3-3.5	1
1.5-2	1	TOTAL	205

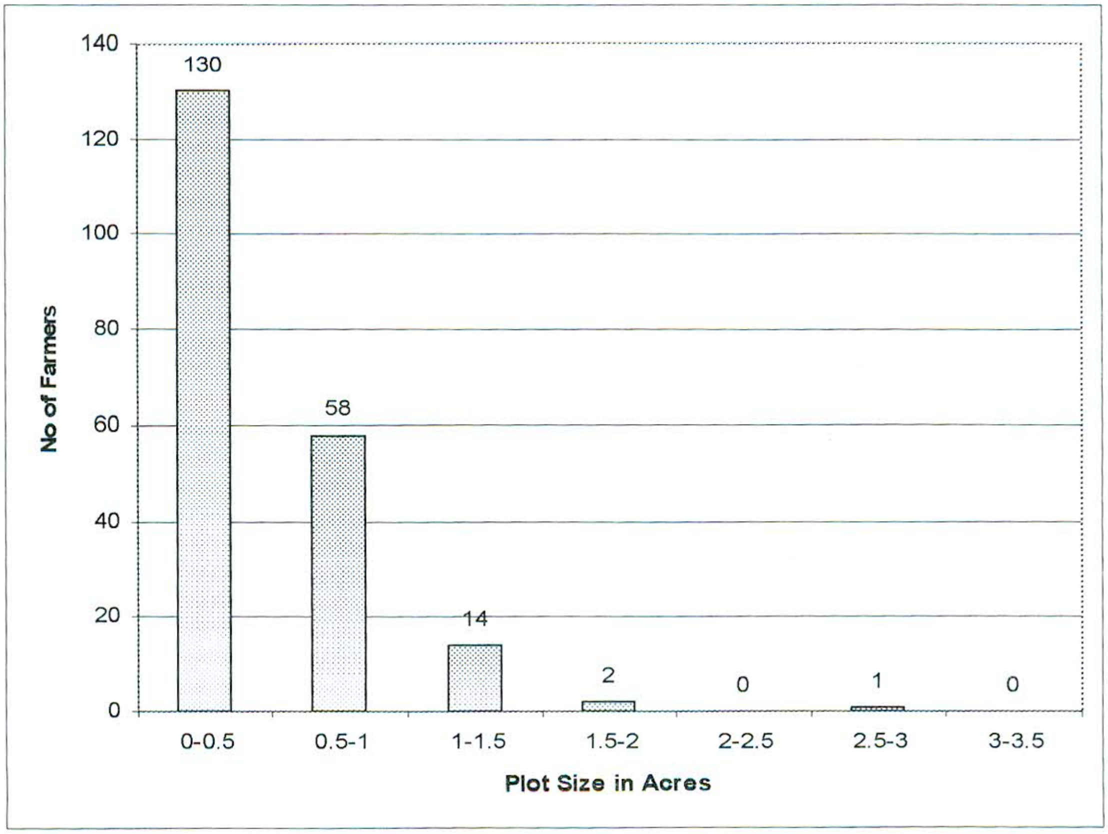


Figure 4.6: Plot Size of the Farmer in Aman Season, 2002

On the other hand, the plot size of the farmer in boro season is almost similar to aman season. There is no big difference in plot size. So, we do not show it separately.

4.2.7 Total Costs of the Farmers during Aman and Boro Seasons

Total costs during aman season depend on how many area of land they have cultivated in that season and how much inputs they have used for cultivation. Though a major portion of farmers are marginal farmers as we have stated earlier, so they have expenses less amount for this purpose. Survey results show that 43 per cent farmers spend less than Tk. 10,000 for aman cultivation in 2002 season, 34 per cent farmers' total expenditure are between Tk. 10,000 to Tk. 20,000 and 21 per cent have a total cost more than Tk. 20,000 but less than Tk. 50,000. Only 2 per cent have total expenditure in aman season of 2002 more than Tk. 50,000. These results are shown in Table 4.7(a) and Figure 4.7(a).

Table 4.7(a): Total Costs (TC) of the Farmer during Aman Season, 2002

TC (thousand taka)	No. of farmer	TC (thousand taka)	No. of farmer
0-5	21	40-45	4
5-10	65	45-50	3
10-15	37	50-55	0
15-20	31	55-60	2
20-25	8	60-65	3
25-30	11	65-70	0
30-35	15	70-75	0
35-40	4	75-80	1

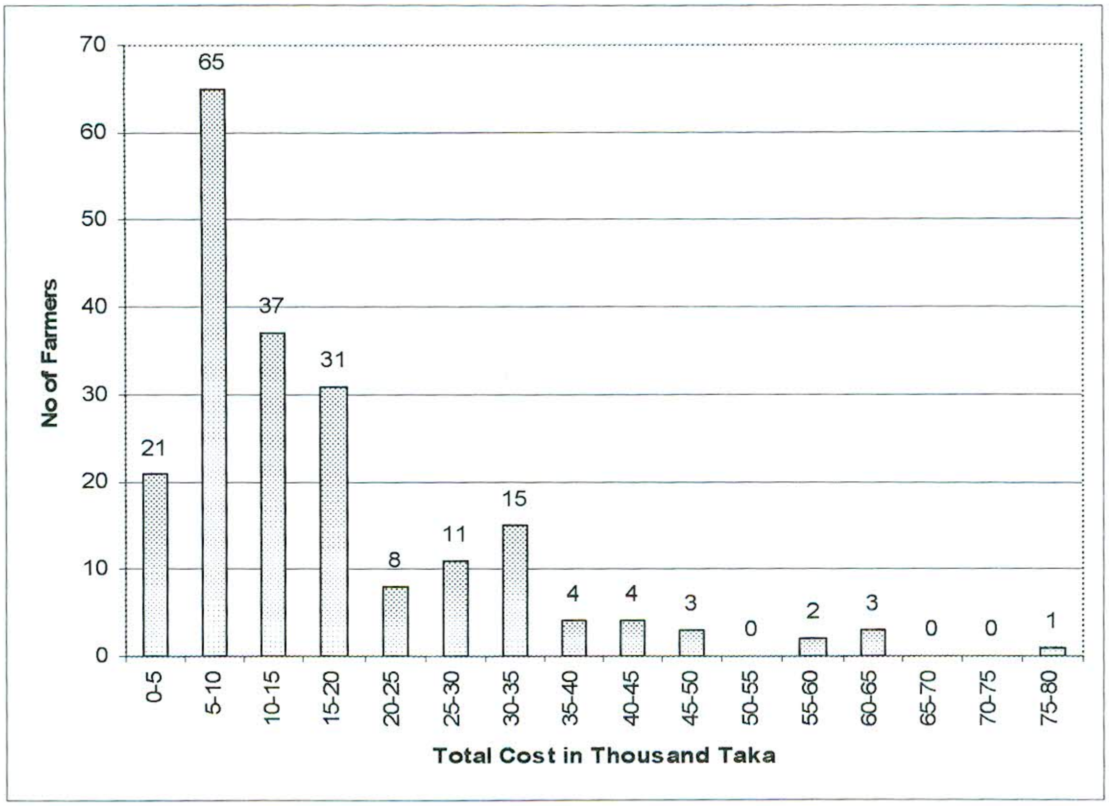


Figure 4.7(a): Total Costs of the Farmer during Aman Season, 2002

On the other hand, in boro season farmers spend more money than aman season. Specially, irrigation and fertilizer costs are more than in aman season. For example, only 24 per cent farmers' spend less than 10 thousand taka and 44 per cent farmers' total costs are more than ten thousand but less than 20 thousand taka, 27 per cent farmers spend 20 to 50 thousand taka and 5 per cent farmers are doing their expenses more than 50 thousand taka in a single season. These results are shown in Table 4.7(b) and Figure 4.7(b).

Table 4.7(b): Total Costs of the Farmer during Boro Season, 2003

TC (thousand taka)	No. of farmer	TC (thousand taka)	No. of farmer
5-10	48	45-50	5
10-15	57	50-55	3
15-20	29	55-60	4
20-25	24	60-65	0
25-30	10	65-70	1
30-35	6	70-75	1
35-40	11	75+	5
40-45	1	Total	205

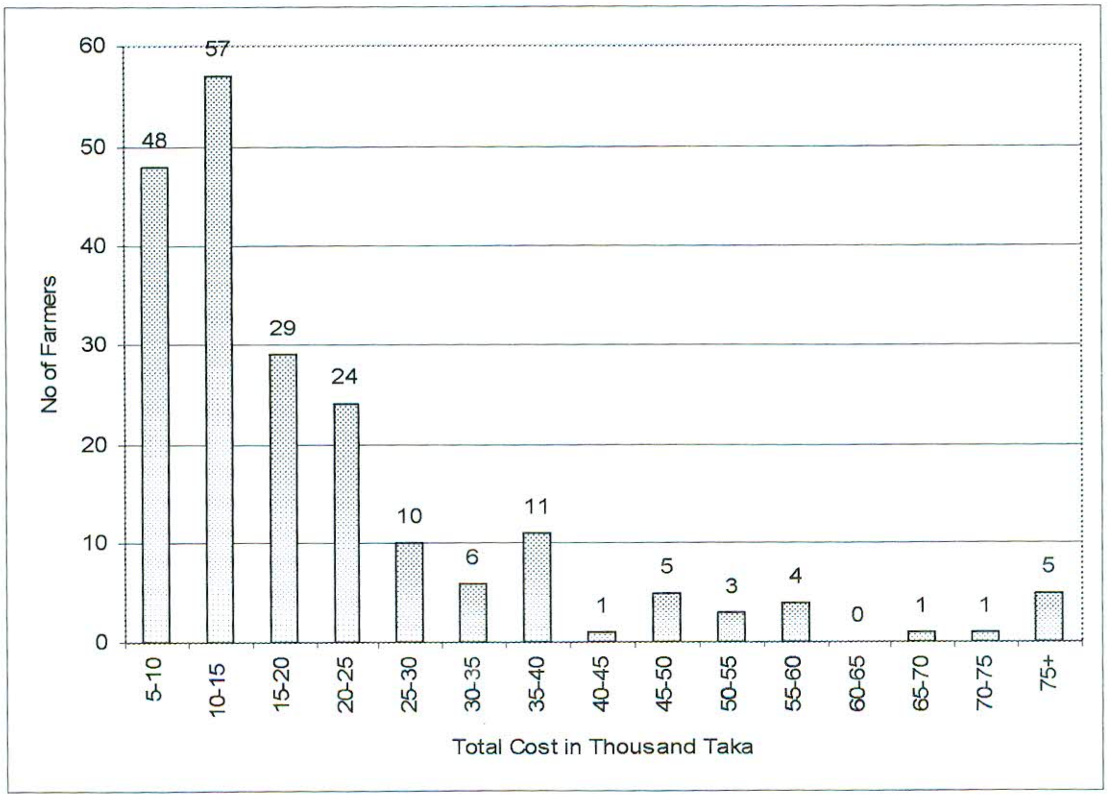


Figure 4.7(b): Total Costs of the Farmer during Boro Season, 2003

4.2.8 Cost per acre during Aman and Boro Seasons

The survey results show the cost per acre of 2002 aman season at Barind area exists between the range of Tk. 3000 to Tk. 6500. Thirteen per cent farmers' cost per acre is less than Tk. 4000. Seventeen per cent have costs per acre between Tk. 4000 to Tk. 4500 and majority farmers (51 per cent) cost per acre is found more than Tk. 4500 but less than Tk. 5500. Sixteen per cent farmers have an expediture between Tk. 5500 to Tk. 6000. Only 3 per cent farmers spends more than Tk. 6000 per acre of land in 2002 aman season. These results are shown in Table 4.8(a) and Figure 4.8(a).

Table 4.8(a): Cost per Acre during Aman Season, 2002

Cost per acre	No. of farmer	Cost per acre	No. of farmer
3000-3500	8	5000-5500	35
3500-4000	18	5500-6000	32
4000-4500	35	6000-6500	6
4500-5000	71		

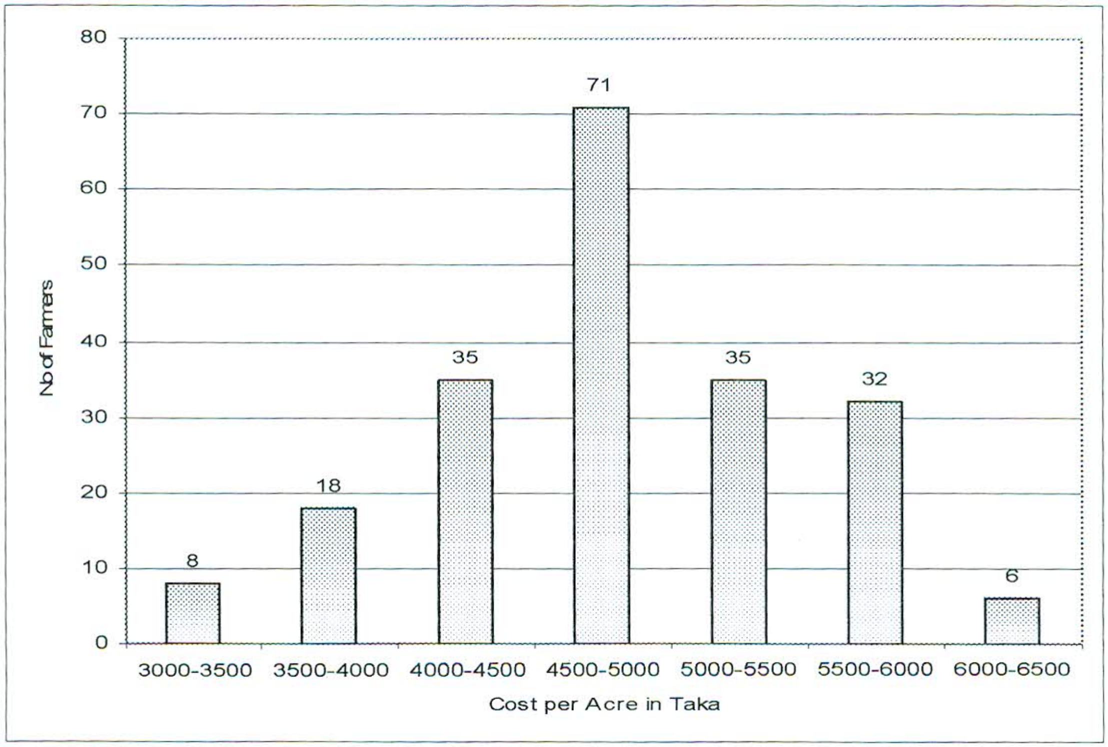


Figure 4.8(a): Cost per Acre during Aman Season, 2002.

On the other hand, generally cost per acre in boro season is higher than in aman season. In boro season of 2003, production cost per acre ranges from Tk. 6000 to Tk. 9500. Only 16 per cent farmers cost per acre is less than seven thousand taka. Majority farmers (71%) have an expense between Tk. 7000 to Tk. 8000 for an acre in boro season. Rest of the farmers (13%) has expensed more than eight thousand taka for an acre in boro season. We will show this result in Table 4.8(b) and Figure 4.8(b).

Table 4.8(b): Cost per Acre in Boro Season, 2003

Cost per acre	No. of farmer	Cost per acre	No. of farmer
6000-6500	7	8000-8500	26
6500-7000	27	8500-9000	0
7000-7500	67	9000-9500	1
7500-8000	77		

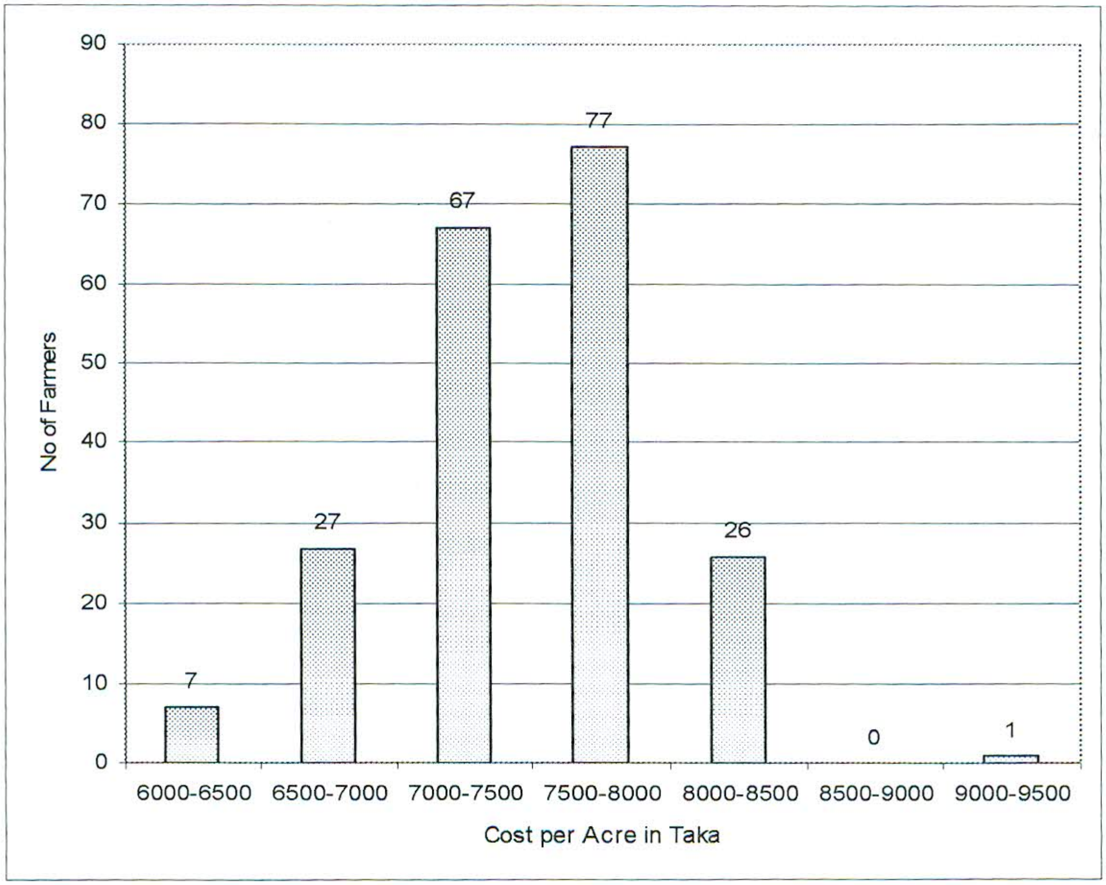


Figure 4.8(b): Cost per acre in Boro Season, 2003

4.2.9 Total Production during Aman and Boro Seasons

Since majority of the farmers are marginal, so total production has not been found in big amount. As we have seen in the study results that more than 60 per cent farmers have total production less than 100 mounds in aman season, 25 per cent farmers produce total aman rice from100 mounds to 200 mounds in this particular season and only 7 per cent farmers produce between 200 mounds and 300 mounds. Only 3 per cent farmers have a total aman production in 2002 season more than 300 mounds. We have shown these survey results in Table 4.9(a) and Figure 4.9(a).

Table 4.9(a): Total Production during the Aman Season of the Farmer

TP (mound)	No. of farmer	TP (mound)	No. of farmer
0-50	51	250-300	1
50-100	82	300-350	2
100-150	33	350-400	2
150-200	19	400-450	2
200-250	13	450-500	0

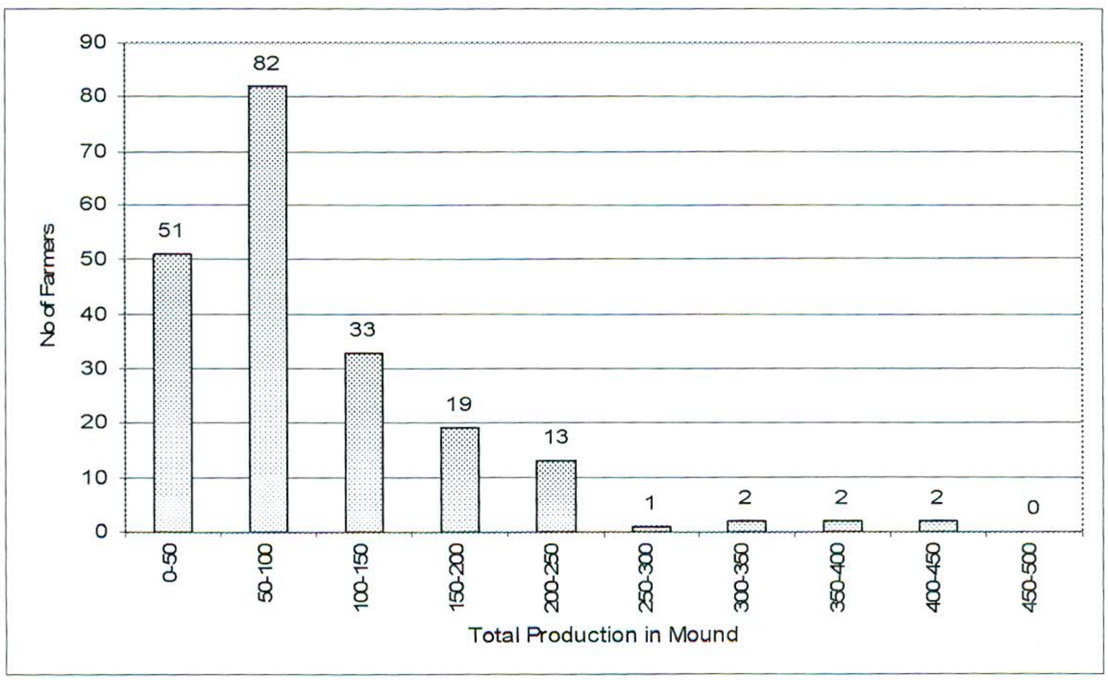


Figure 4.9(a): Total Production during the Aman Season of the Farmer

On the other hand, in boro season more than 50 per cent farmers are marginal and they produce less than 100 mound of rice. Twenty eight per cent farmers produce from 100 to 200 mounds in a season and 9 per cent farmers produce from 200 to 300 mounds. Only 7 per cent farmers have a total boro production in 2003 season more than 300 mounds. We have shown these survey results in Table 4.9(b) and Figure 4.9(b).

Table 4.9(b): Total Production during the Boro Season, 2003

TP (mound)	No. of Farmer	TP (mound)	No. of Farmer
0-50	32	300-350	4
50-100	82	350-400	5
100-150	38	400-450	3
150-200	18	450-500	2
200-250	12	500-550	1
250-300	7	550-600	1

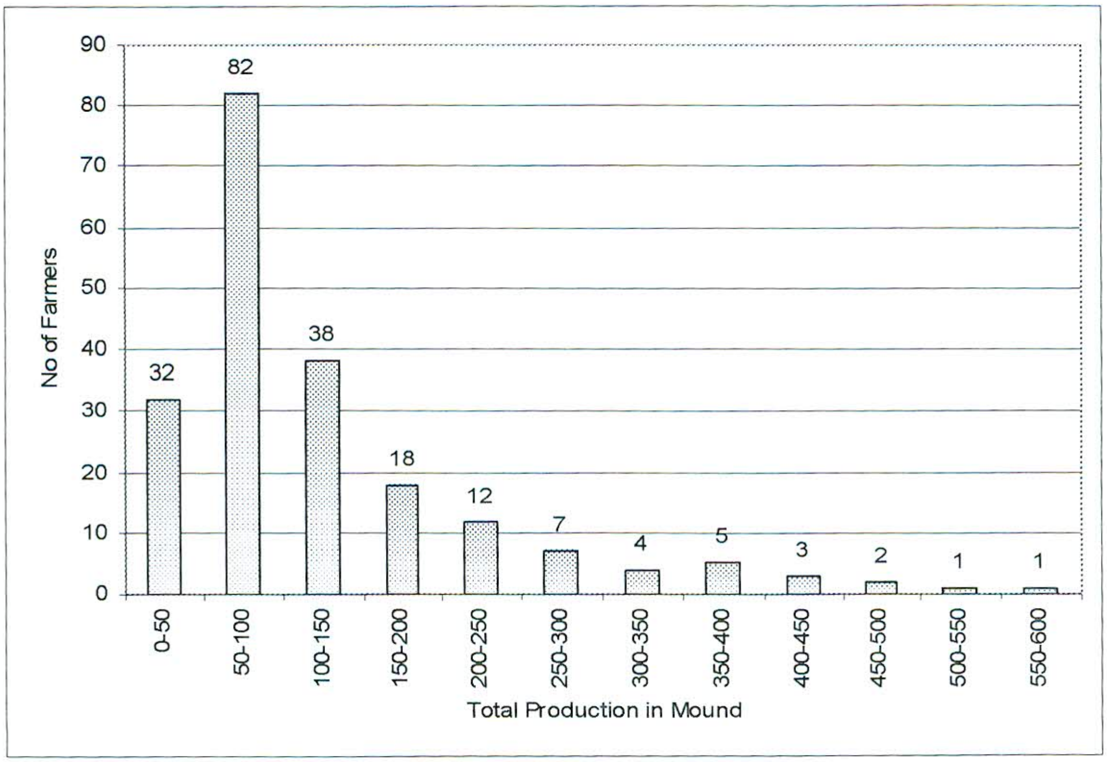


Figure 4.9(b): Total Production during the Boro Season, 2003

4.2.10 Production per acre during Aman and Boro Seasons

Production per acre in aman season in Barind area found very low and frustrating. From investigation to the grassroots level farmers, two main reasons have been found out. Firstly, in the very beginning stage of the aman cultivation, there was a serious shortage of water. Secondly, at the last stage of the production, when the paddy has almost grown up, there occurs an over flow of water and a flood takes place. The survey results show that 20 per cent farmers aman production per acre are less than 25 mounds and 65 per cent farmers production per acre are more than 25 mounds but less than 40 mounds. Only 13 per cent farmers' aman production per acre is 40 mounds to 50 mounds. Only 2 per cent farmers produce in 2002 aman season more than 50 mound per acre. These results are shown in Table 4.10(a) and Figure 4.10(a).

Table 4.10(a): Production per Acre during the Aman Season

Production per acre	No. of farmer	Production per acre	No. of farmer
15-20	13	35-40	17
20-25	29	40-45	12
25-30	61	45-50	14
30-35	54	50-55	5

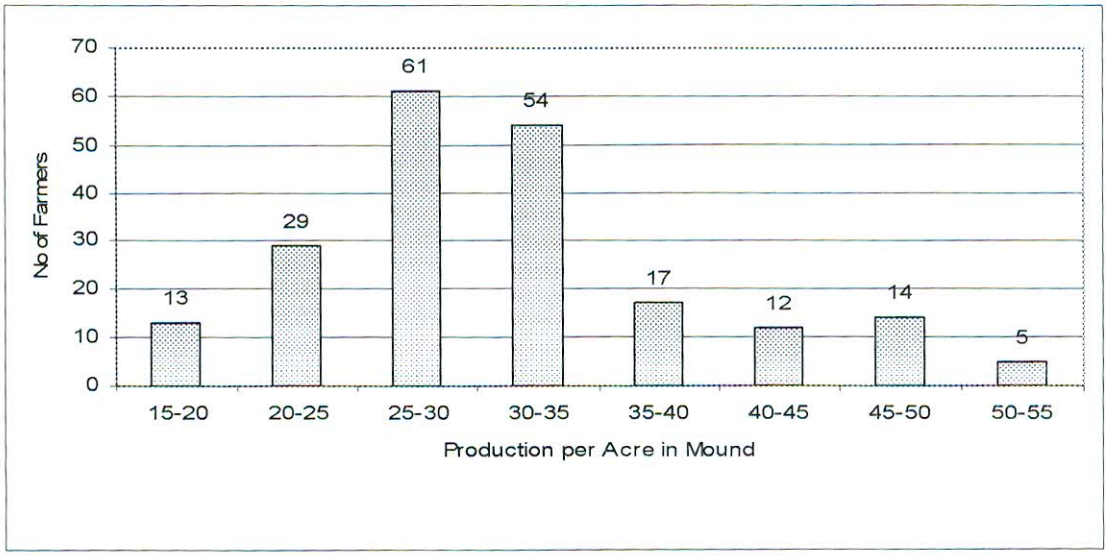


Figure 4.10(a): Production per Acre during the Aman Season

On the other hand, the production boro rice of 2003 is not impressive. There are some reasons for that. Major problem was seed crisis. Almost every farmer in 2003 boro season has lost their initial seed ground due to bad weather. Survey results show that 7 per cent farmers produce less than 40 mounds per acre. Majority farmers (63%) produce 40 to 50 mounds per acre in that season. Another 28 per cent farmers produce more than 50 mounds but less than 60 mounds per acre. Only 2 per cent farmers produce more than 60 mounds per acre. These results have been shown in Table 4.10(b) and Figure 4.10(b).

Table 4.10(b): Production per Acre during the Boro Season, 2003

Production per acre	No. of farmer	Production per acre	No. of farmer
30-35	2	50-55	36
35-40	12	55-60	20
40-45	39	60-65	6
45-50	90		

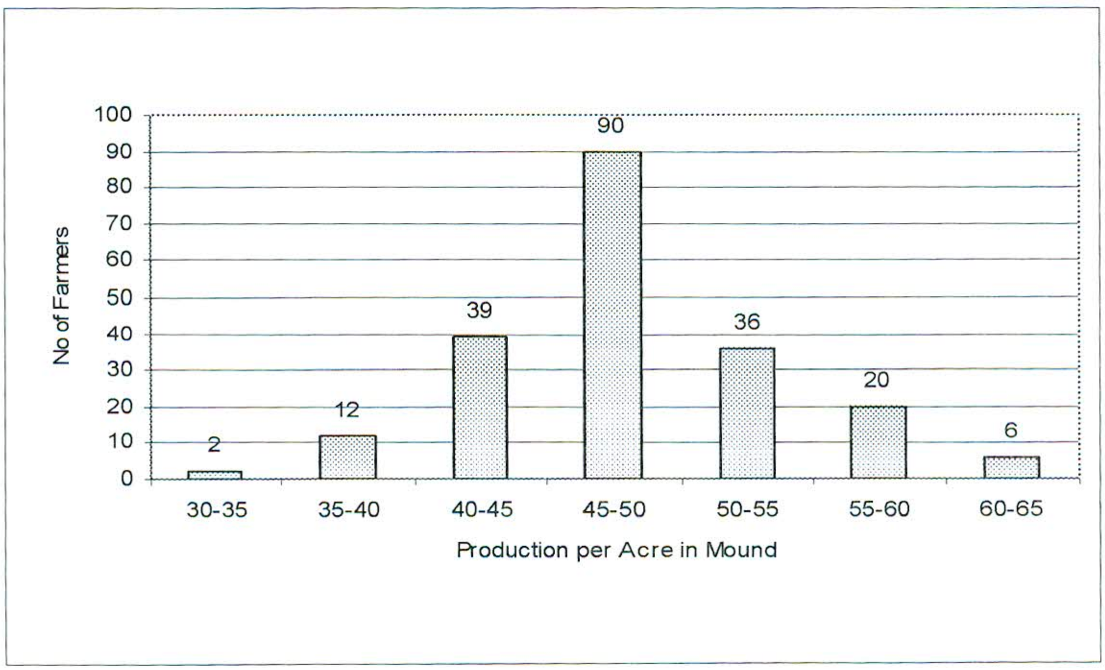


Figure 4.10(b): Production per Acre during the Boro Season, 2003

4.2.11 Total Revenue of Farmers during Aman and Boro Seasons

As we have seen earlier that aman production in Barind area has hampered by various reasons such as serious shortage of water at early stage of production, flood or over flow of water at the final stage of production etc. Therefore, aman rice productivity in 2002 season is not satisfactory. The survey results show that 6 per cent farmers' total revenue is less than Tk. 10,000 and 55 per cent farmers' total revenue is accounted to Tk.10, 000 to Tk. 30,000. But 20 per cent farmers' total revenue is more than Tk.30, 000 and less than Tk.50, 000. Survey shows that 16 per cent farmers' total revenue is over Tk.50, 000 in aman season of 2002 but less than Tk.100, 000. Only 3 per cent farmers make total revenue more than Tk.100, 000 in a season. Table 4.11(a) and Figure 4.11(a) have depicted these survey results.

Table 4.11(a): Total Revenue (TR) of Farmers during Aman Season, 2002

TR in thousand Tk.	No. of farmer	TR in thousand Tk.	No. of farmer
0-10	13	70-80	5
10-20	61	80-90	2
20-30	51	90-100	0
30-40	27	100-110	2
40-50	13	110-120	1
50-60	16	120-130	1
60-70	11	130-140	2

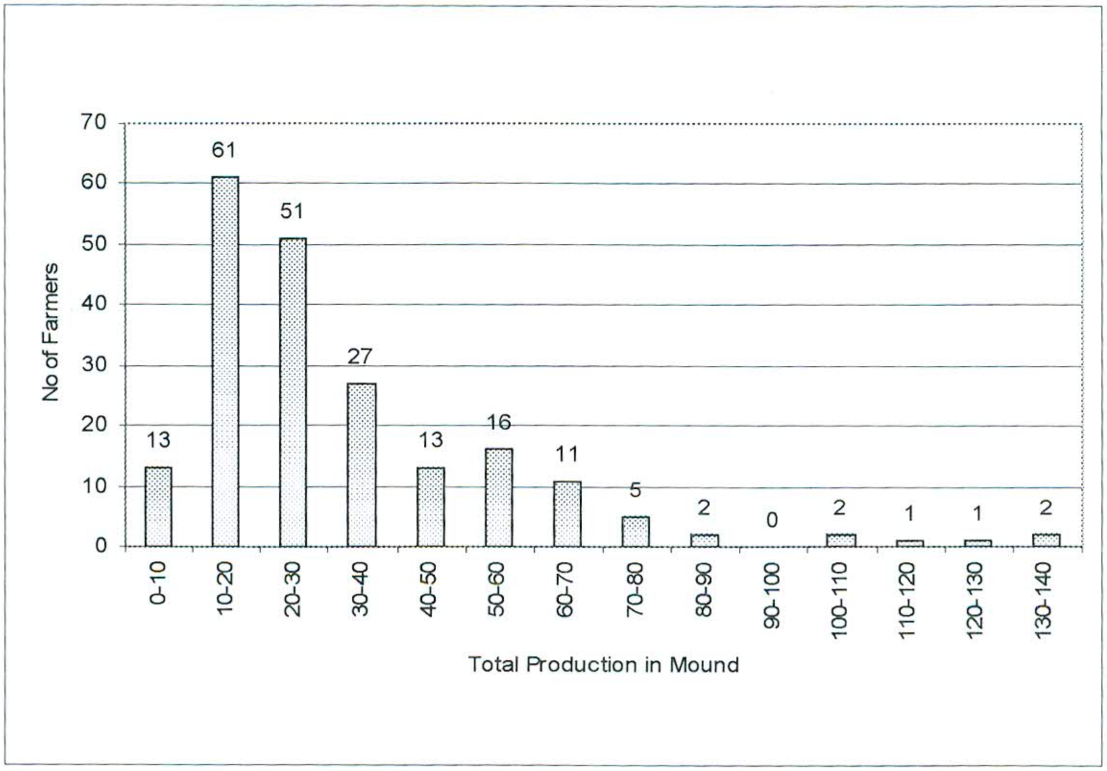


Figure 4.11(a): Total Revenue of Farmers during Aman Season, 2002

On the other hand, Boro production in 2003 has also been affected due to initial seed crisis by the farmers. Survey results show that 27 per cent farmers' total revenue is less than twenty thousand taka. Forty five per cent farmers total revenue is more than Tk. 20000 but less than Tk. 40000. Another 23 per cent farmers' total revenue is more than forty thousand but less than one lakh taka. Only 5 per cent farmers' total revenue is more than one lakh taka in 2003 Boro season. These results have shown in Table 4.11(b) and Figure 4.11(b).

Table 4.11(b): Total Revenue of Farmers during Boro Season, 2003

TR	No. of farmer	TR	No. of farmer
0-20	55	100-120	7
20-40	90	120-140	5
40-60	28	140-160	1
60-80	14	160-180	1
80-100	4	Total	205

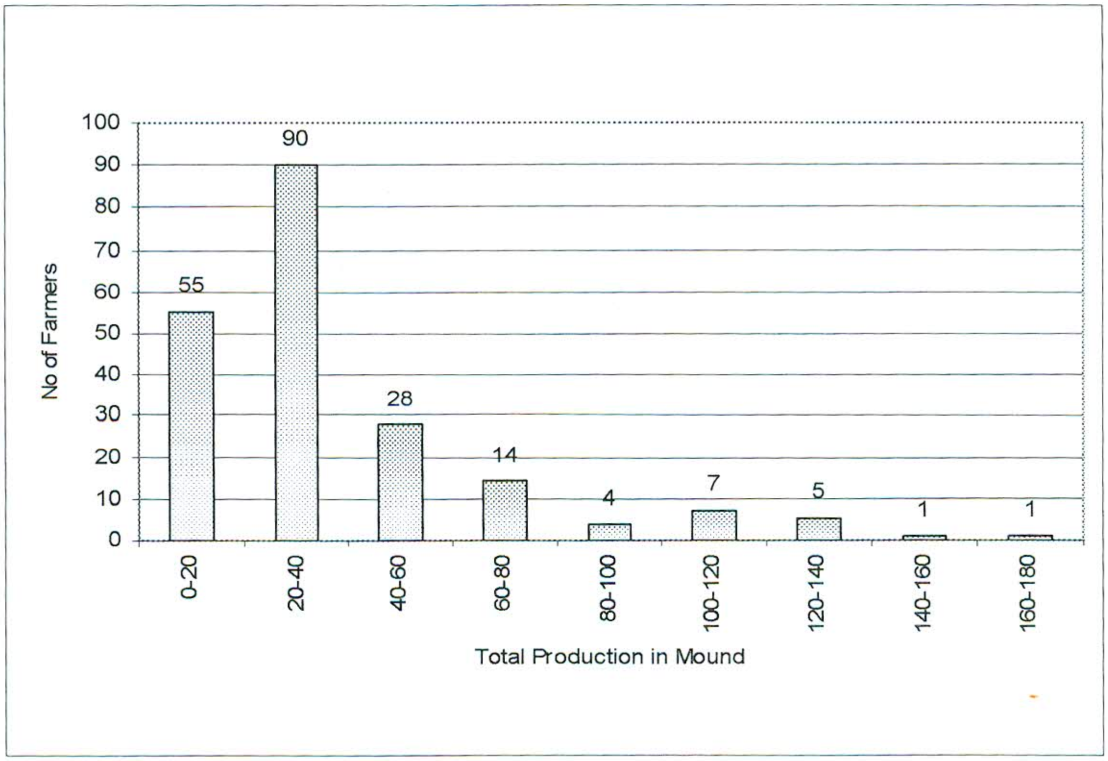


Figure 4.11(b): Total Revenue of Farmers during Boro Season, 2003

4.2.12 Total Profit of the Farmers during Aman and Boro Seasons

Profit depends on total production, total cost and price of the product. As we have seen earlier that production per acre in aman season is not satisfactory in Barind area. Cost per acre is comparatively high. Another important thing is that the marginal farmers do not get proper price of their product. In most cases, they have taken required inputs such as, fertilizer, pesticide, irrigation etc. by local loan system. After harvesting the new crops, they are obliged to pay the loan of inputs first. So, they could not stock the product. Consequently, they are forced to sell the product at a price which is lower than the market price. This real fact is found in our survey results. Therefore, the farmers at Barind area could not be able to make a handsome profit in aman season. Survey results show that 41 per cent farmers make a profit less than Tk.10, 000. Another 49 per cent farmers make a profit more than Tk.10, 000 but less than Tk.30, 000. Only 10 per cent farmers could be able to make a profit more than Tk.30, 000 during aman season, 2002.

Table 4.12(a): Total Profit of the Farmer during Aman Season

Total profit in thousand Tk.	No. of farmer	Total profit in thousand Tk.	No. of farmer
0-10	82	50-60	1
10-20.	74	60-70	3
20-30	25	70-80	0
30-40	15	80-90	1
40-50	4		

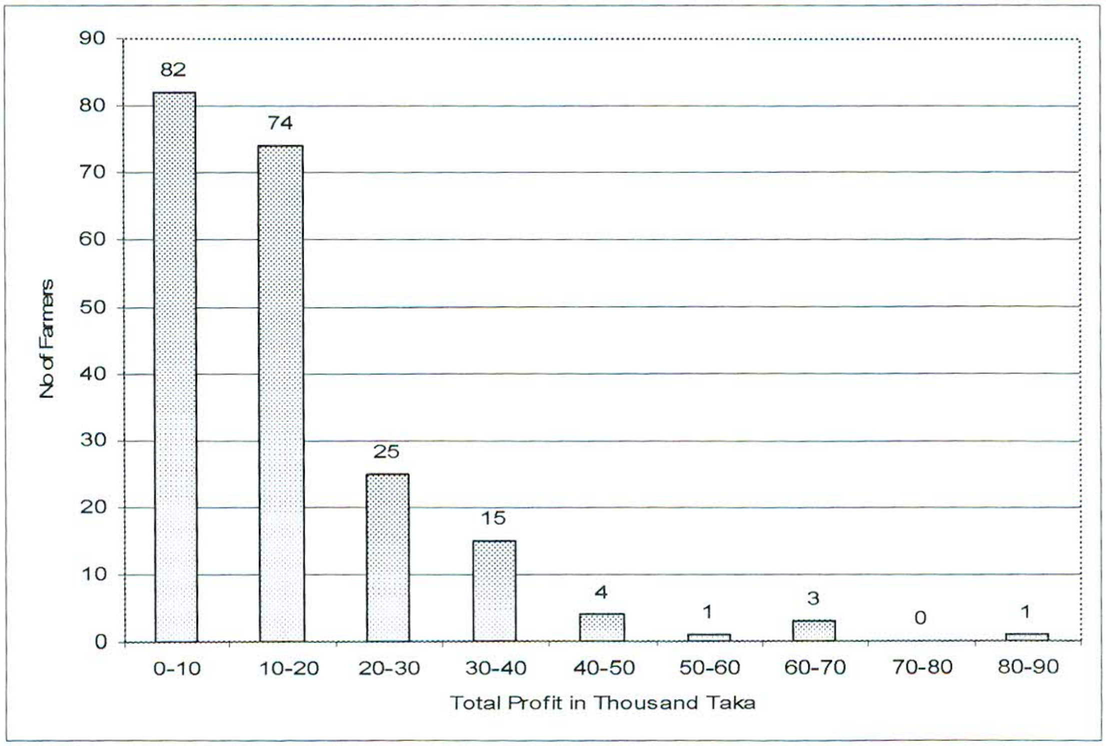


Figure 4.12(a): Total Profit of the Farmer during Aman Season

On the other hand, in boro season of 2003 about 40 per cent farmers have a total profit less than ten thousand taka. Another 50 per cent farmer's total profit is in between Tk. 10000 to Tk.30000. Only 12 per cent farmers' have a total profit more than thirty thousand taka. We have shown the results in Table 4.12(b) and Figure 4.12(b).

Table 4.12(b): Total Profit of Farmers in Boro Season, 2003

Total profit	No. of farmer	Total profit	No. of farmer
0-10	78	50-60	6
10-20	78	60-70	2
20-30	23	70-80	1
30-40	12	80-90	1
40-50	4	Total	205

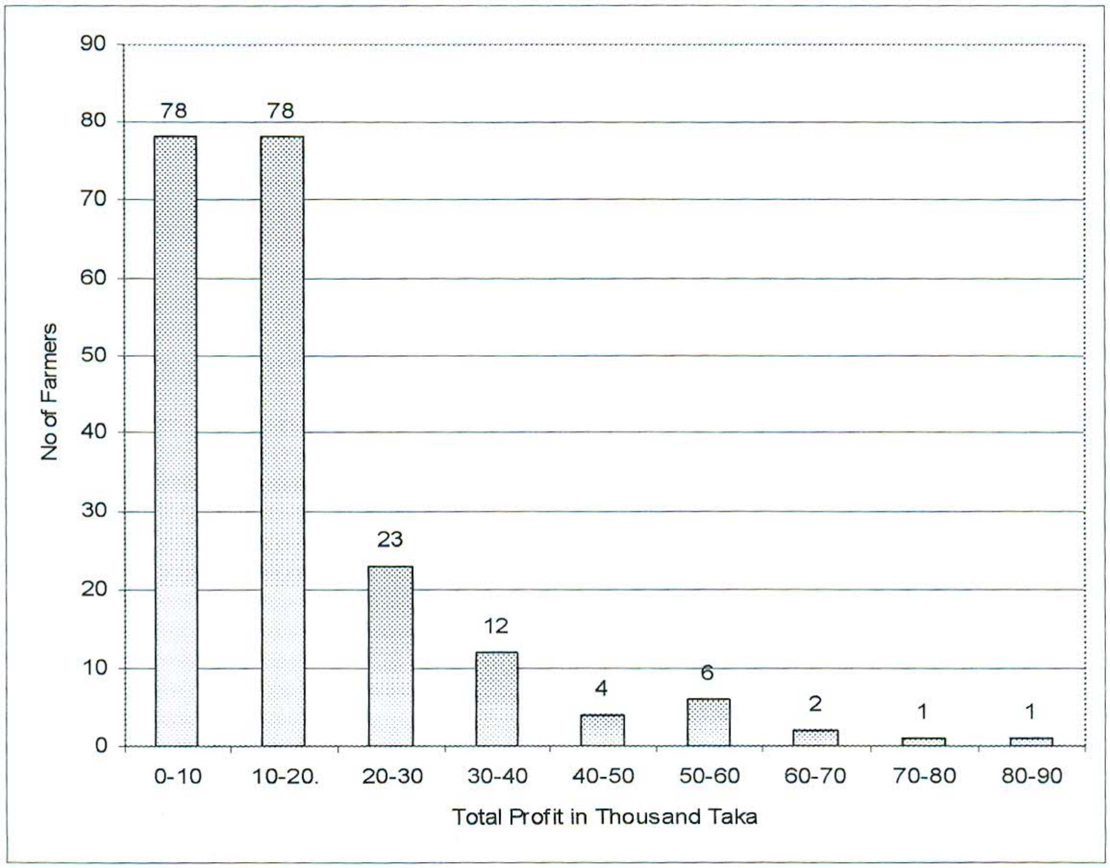


Figure 4.12(b): Total Profit of Farmers in Boro Season, 2003

4.3 Conclusion

In this chapter, we have shown survey methods of collecting data and survey results. Job of selecting samples is carefully done. In our study both probability and non-probability sampling techniques are used. In many cases, purposive and stratified random sampling techniques are chosen.

During preparing the questionnaire, we have used both open-ended and close-ended method. For gathering more information, we have included four sections in the questionnaire such as personal, production related, non-farm activities and livestock information. Six structural or ordinary variables are chosen in the study, viz., land, labour, irrigation, fertilizer, pesticides and seeds. Inefficiency variables with some socio-economic and infrastructural variables are given special attention. There are three dummy variables in this study; these are extension services, credit facilities, and land-degradation dummy.

During collection of data, the researcher faces some difficulties like, non-cooperation from the respondent, not-habituated to keep the data, different measuring units in different region of the study area. Some have the tendency to over-score and some have tendency to under-score the data. Despite all these difficulties, we become able to tackle the situation successfully and collect required data and information.

Chapter 5

Theoretical Issues: Production Function and Efficiencies

CHAPTER 5 THEORETICAL ISSUES: PRODUCTION FUNCTION AND EFFICIENCY

5.1 Introduction

We shall conduct a depth analysis about various types of efficiencies – such as technical, allocative and economic efficiency in this research. So, we need clear and concrete concepts about production functions and efficiencies. We first introduce the concept of a production function in simplest way with one output and two inputs. Total product, average product and marginal product of production process are defined. Cost minimization and output maximization situation of a production process are described. Finally, the concepts of various types of efficiencies in production, such as technical, allocative and economic efficiency are stated. The measurement of efficiency begins with Farrell (1957). The failure to produce the maximum output from a given input mix at minimum cost results in inefficiency. Inefficiency can be explained by, *inter alia*, restricted access to technology, a lack of knowledge, minimum access to extension services, an inappropriate scale of production and sub-optimal allocation of resources. Efficiency of a farm consists of two components: technical and allocative efficiency. Technical efficiency means the ability of a farm to produce maximum output from a given set of inputs using existing technology; allocative efficiency refers the ability of a farm to choose the inputs in optimal proportions, given their input prices; and a combination of these two measures provide economic efficiency. Thus the economic efficiency reflects the ability of a farm to produce output at minimum cost by using inputs in an efficient way (technical efficiency) and by choosing a cost-minimizing optimal combination of inputs, given input prices (allocative efficiency).

5.2 Production Function

The concept of the production function is basic to the development of the theory of farm in microeconomics. In the classical non-stochastic theory of the farm a production function is defined as a schedule showing the maximum amount of output that can be produced from a specified set of inputs, giving the existing technology (Ferguson, 1966).

In general, we may describe production function as a technical relationship between inputs and outputs of a production process. Alternatively, production function defines the maximum output attainable from a given set of inputs.

Following Beattie and Taylor (1985) we may take these assumptions for a simple production function:

a) The production process is mono-periodic,
b) All inputs and outputs are homogeneous,
c) The production function is twice continuously differentiable,
d) Output and input prices are known with certainty,
e) The goal of the farm is to maximize profit (or minimize cost for a specified output level).

As x_1 increases, *ceteris paribus*, output y increases and we move along the curve depicting the production function. In Figure 5.2, each curve shows the relation between y and x_2 given x_1, ν, γ. As x_2 increases, *ceteris paribus* output y increases and we move along the curve.

Marginal Product: The slopes of the curves in Figure 5.1 and 5.2 are marginal product of the factors of production. The marginal product of a factor is defined as the change in output resulting from a very small change of this factor, keeping all others factors constant.

Mathematically the marginal product of each factor is the partial derivative of the production function with respect to this factor. Thus,

$$MP_{x_1} = \frac{\partial y}{\partial x_1} \text{ and } MP_{x_2} = \frac{\partial y}{\partial x_2}$$

Graphically the marginal product of x_1 is shown by the slope of the production function:

$$y = f_1(x_1, \bar{x}_2, \bar{\nu}, \bar{\gamma}) \tag{5.2}$$

and the marginal product of x_2 is shown by the slope of the production function:

$$y = f_2(x_2, \bar{x}_1, \bar{\nu}, \bar{\gamma}) \tag{5.3}$$

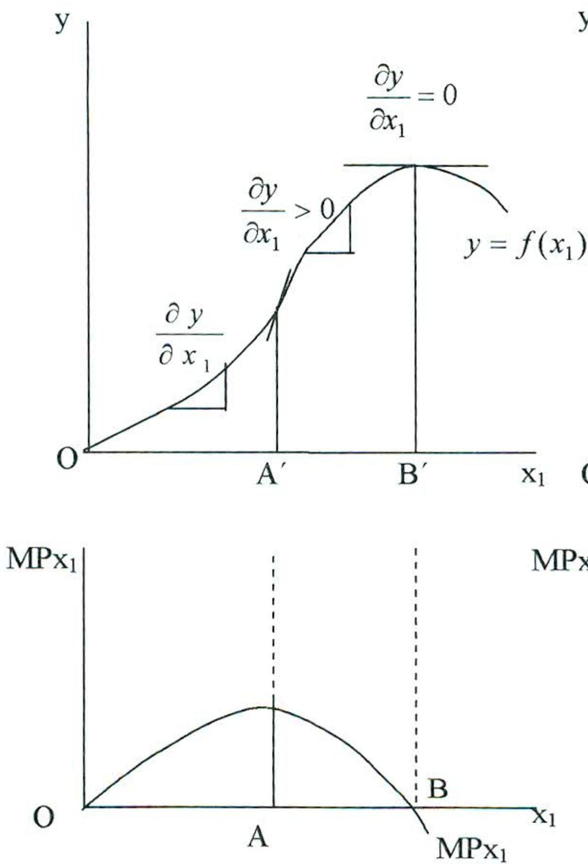


Figure: 5.3: TP and MP for x_1

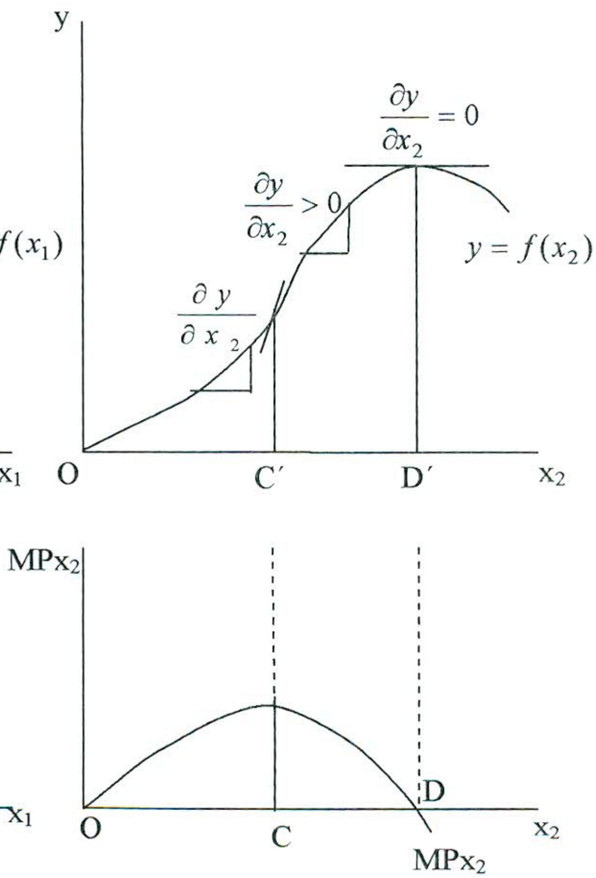


Figure: 5.4: TP and MP for x_2

In principle, the marginal product of a factor may assume any value - positive, zero or negative. However, basic production theory concentrates only on the efficient part of the production function, that is, on the range of output over which the marginal products of the factors are positive. No rational farm would employ input x_1 beyond OB in Figure 5.3 or input x_2 beyond OD in Figure 5.4, because an increase in the factors beyond these levels would result in the reduction of the total output.

Average Product: The average product (AP) of x_1 is the total product divided by its quantity:

$$AP_{x_1} = \frac{y}{x_1} = \frac{f(x_1)\bar{x}_2, \bar{v}, \bar{\gamma}}{x_1} \tag{5.4}$$

and average product of x_2 is the total output divided by its quantity:

$$AP_{x_2} = \frac{y}{x_2} = \frac{f(x_2)\bar{x}_1, \bar{v}, \bar{\gamma}}{x_2} \tag{5.5}$$

The average and marginal product curves are shown in Figure 5.5. The average product at a point on a total product curve equals the slope of a line segment connecting that point with the origin. AP increases for movements along the total product curve from the origin to point J, and decreases after that point. Point J corresponds to the maximum point on the AP curve in Figure 5.5. Point N indicates maximum average product. At point M, marginal product is maximum and thereafter, MP decreases. At point B′, MP is zero. This point indicates maximum TP and thereafter TP decreases.

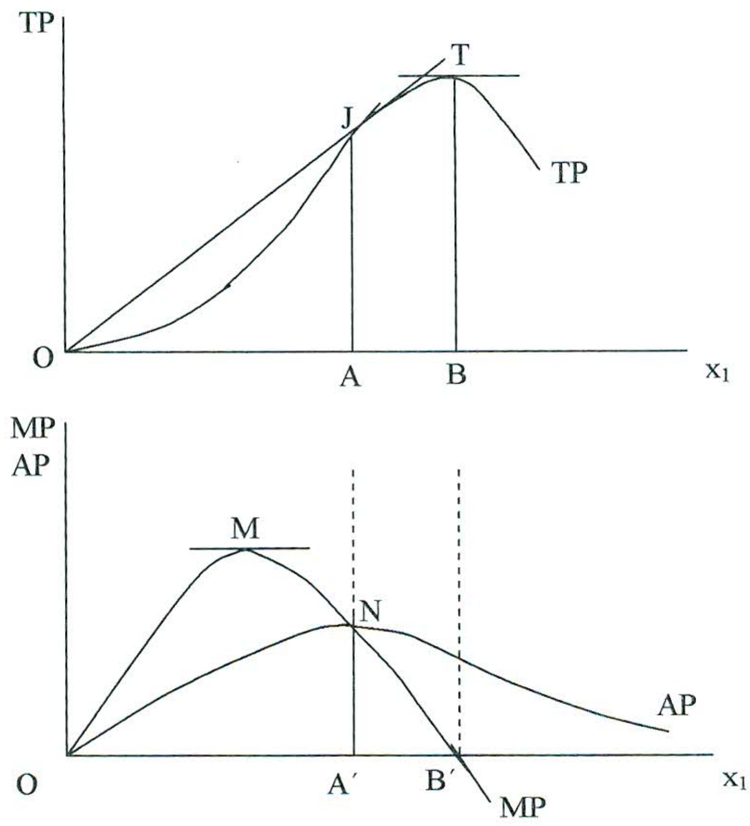


Figure 5.5: Total, Average and Marginal Product

Elasticity: The output elasticity of x_1, denoted by ω_1, is defined as the proportionate change of output, y with respect to x_1:

$$\omega_1 = \frac{\partial(\ln y)}{\partial(\ln x_1)} = \frac{x_1}{y}.\frac{\partial y}{\partial x_1} = \frac{MP}{AP} \tag{5.6}$$

Output elasticity may be expressed as ratios of marginal and average products, and are positive if MP and AP are positive. The output elasticity of an input will be greater than, equal to, or less than unity as its marginal product respectively greater than, equal to, or less than its average product.

Isoquant: An isoquant or production indifference curve is defined as the locus of all the efficient combinations of inputs which produce the same output. It shows the rate at which inputs are substituted in production keeping output constant. For simplicity, we may consider the two variable production function:

$$y = f(x_1, x_2)$$

The equation of an isoquant is obtained when output is held constant, say y_0:

$$y_0 = f(x_1, x_2)$$

This represents the isoquant which displays all combinations of inputs that can be used to produce output y_0.

Marginal Rate of Technical Substitution (MRTS): The slope of the isoquant at any point is derived by differentiating with respect to one of the inputs, say x_1. This yield:

$$f_1 + f_2 \frac{dx_2}{dx_1} = 0 \qquad \text{or,} \quad \frac{dx_2}{dx_1} = -\frac{f_1}{f_2}$$

The negative of the slope of an isoquant is the marginal rate of technical substitution (MRTS) which measures the rate at which inputs can be substituted, keeping output constant. The MRTS is not independent of units of measurement.

Elasticity of Substitution: The elasticity of factor substitution is a better measure of factor substitution as it does not depend on the units of measurement. The elasticity of substitution (σ) is defined as the proportionate rate of change of the input ratio divided by the proportionate rate of change of the marginal rate of technical substitution of inputs:

$$\sigma = \frac{d(x_2 / x_1) / (x_2 / x_1)}{d(MRTS_{x_1,x_2}) / (MRTS_{x_1,x_2})}$$

The larger the value of σ, the greater the degree of substitutability between the two factors. The Cobb-Douglas production has a constant and unitary elasticity of substitution.

Returns to Scale: Output can be increased by changing all factors of production. It is possible only in the long-run. Thus the laws of returns to scale refer to the long-run analysis of production. The term 'returns to scale' refers to the changes in output as all factors change by the same proportion.

For example, we have an initial level of inputs and output as:

$$y_0 = f(x_1, x_2)$$

and we increase all the factors by the same proportion, k. So, a new level of output y_0^* is obtained which is clearly higher than the original level of output y_0,

$$y_0^* = f(kx_1, kx_2)$$

if we can factor out k, then:

$$y_0^* = k^v f(x_1, x_2)$$

$$= k^v y_0$$

Here, the power v of k is called the degree of homogeneity of the production function and is a measure of the return to scale:

If $v = 1$, we have constant returns to scale. This means that the production function is called linearly homogeneous.

If $v < 1$, we have decreasing returns to scale.

If $v > 1$, we have increasing returns to scale.

In case of large scale industrial production process, the returns to scale may be increasing in nature, because of technical and managerial potentialities. Mass production processes are more efficient than the best available process for producing small levels of output, because they may achieve lower prices of its raw materials, lower cost of external finance; lower advertising prices since they advertise at large scales, transport rates are often lower for them.

In agricultural sector, we usually find the law of decreasing returns to scale. This is because of diminishing returns to management. Another reason for decreasing returns in agriculture is that the exhaustible characteristics of natural resources. For example, doubling the amount of fertilizer may not lead to a doubling of the production of output. Fertility of land may be decreasing.

5.3 Choice of Optimal Combination of Factors of Production

In this section we show the situation in which the farm can make a optimal choice of factors of production. We can examine two cases: firstly, maximizing output for a given cost and secondly, minimizing cost subject to a given output.

We can make the following assumptions:

i) The goal of the farm is profit maximization, *i.e.*,

$Max\ \pi = Max\ R - C$, where $\pi =$ profit, R= revenue and C= cost,

ii) The price of the output is given, $\overline{p}_y$ and

iii) The prices of the factors are given.

5.3.1 Maximization of Output Subject to a Cost Constraint

We may assume:

(a) The production function is $y = f(x_1, x_2, v, \gamma)$

(b) Given the factor prices, w_1 and w_2 for x_1 and x_2.

The farm is in equilibrium when it maximizes its output given its total cost and prices of the factors, w_1 and w_2.

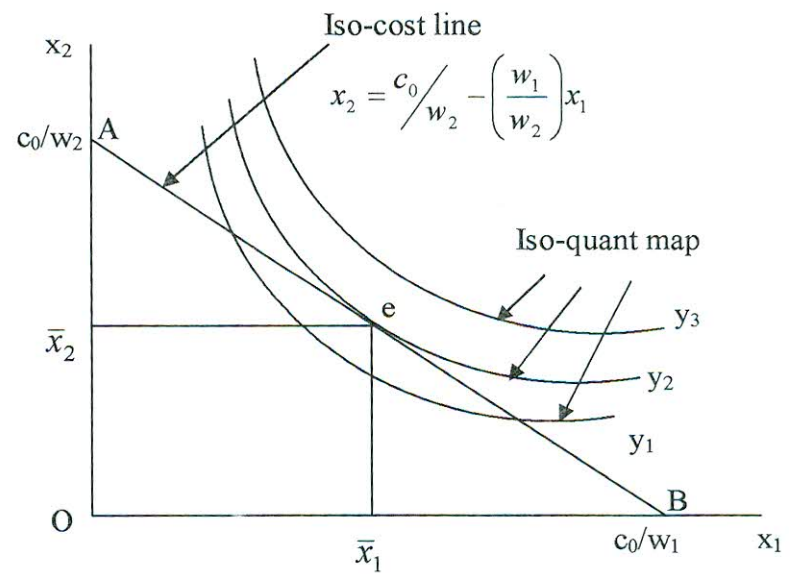


Figure 5.6: Output Maximization

In figure 5.6, we can see that at equilibrium, the farm produces the maximum level of output at iso-quant y_2 and it can be defined by the tangency of the iso-cost line and the highest iso-quant. The optimum combination of factors of production is $\bar{x}_1$ and $\bar{x}_2$ for price w_1 and w_2. Higher levels of output are not attainable because of cost constraint. Other points on AB or below of it lie on a lower iso-quant than y_2. Hence, the maximum level of output is obtained from iso-quant y_2. At point of tangency (e), the slope of the iso-cost line (w_1/w_2) is equal to the slope of the iso-quant $\left(\frac{MP_{x_1}}{MP_{x_2}}\right)$. So, the necessary condition is:

(a) Slope of iso-quant = Slope of iso-cost line

$$\text{or, } \frac{w_1}{w_2} = \frac{MP_{x_1}}{MP_{x_2}} = \frac{\partial y/\partial x_1}{\partial y/\partial x_2} = MRS_{x_1 x_2} \qquad (5.7)$$

(b) The iso-quants must be convex to the origin.

Both conditions are fulfilled. So, the equilibrium is ensured.

5.3.2 Minimization of Cost for a Given Level of Output

The equilibrium conditions for cost minimization of the farm are same as the output maximization, describe in section 5.3.1. That is, there must be tangency of the (given) iso-quant with the lowest possible iso-cost curve. The sufficient condition is that the iso-quant must be convex to the origin. The farmer wants to produce a given output with the minimum cost outlay.

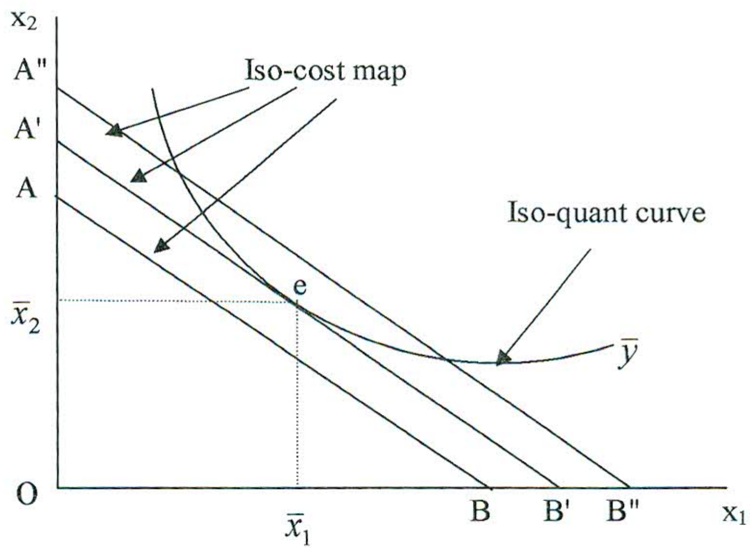


Figure 5.7: Cost- minimization

The farmer minimizes its cost by employing the combination of x_1 and x_2. Points below e are desirable but not attainable for output $\overline{y}$. Points above *e* show the higher cost. So, point *e* denotes the least cost combination. Both conditions are satisfied.

5.4 Technical, Allocative and Economic Efficiency

Farrell's (1957) seminal article has led to the development of several techniques for the measurement of efficiency of production. The term 'efficiency' implies the success with which a farm best utilizes its available resources to produce maximum levels of potential outputs (Dinc et. al., 1998). A farm is efficient if and only if it is not possible to increase output (or decrease inputs) without more inputs (or without decreasing output) (Cooper, et. al., 1995). Any failure to obtain this potential maximum output results in inefficiency. The neoclassical theory of production defines the production function based on the notion of efficiency that gives the maximum possible output for given amounts of inputs. It is not realistic to recognize this 'maximum' output simply by observing the actual amount of output unless the observed output is assumed to be a maximum; different farms produce different output levels even if they utilize the same input vector (Kumbhakar, 1994).

Farrell (1957) proposed that efficiency of a farm consists of two components: technical efficiency and allocative efficiency. The concept **technical efficiency**, which represents the ability of a farm to obtain maximum output from a given set of inputs, or the ability to minimize input use in the production of a given output vector. Thus the production frontier is associated with the maximum attainable level of output, given the level of inputs, or the minimum level of inputs required to produce a given output. In other words, it is the locus of maximum attainable output for each input mix. Technical inefficiency is attributed to a failure of the farm to produce the frontier level of output, given the quantities of inputs (Kumbhakar, 1994).

Allocative efficiency reflects the ability of a farm to use the inputs in optimal proportions, given their respective prices. Alternatively, allocative inefficiency arises if farms fail to allocating inputs which minimize the cost of production of a output, given relative input prices. Failure in allocating resources optimally results in increased cost and decreased profit. In particular, a farm is said to be allocatively inefficient if the marginal rate of technical substitution between any two inputs is not equal to the corresponding ratio of input prices, that is, allocative inefficiency exists when the farm fails to use cost-minimizing input mixes. The distinction between technical and allocative efficiency provides four ways for explaining the relative performance of farms. Firstly, a farm might be technically and allocatively inefficient, secondly; it may be technically efficient, but allocatively inefficient; thirdly, it may show allocative efficiency, but technical inefficiency; finally, it may be both technically and allocatively efficient.

These two measures technical efficiency and allocative efficiency - are then combined to provide a measure of **economic efficiency**, which reflects the ability of a farm to produce output at minimum cost. Thus, either one of the efficiencies may be necessary but not sufficient conditions to ensure economic efficiency for a farm. The simultaneous attainment of both efficiencies gives the sufficient condition to ensure economic efficiency (Ellis, 1988).

5.4.1 Input-Oriented Measures

Farrell illustrated technical and allocative efficiency concepts using a simple example involving farms, which use two inputs (x_1 and x_2) to produce a single output (y), under an assumption of constant returns to scale. A unit iso-quant of the fully efficient farm, represented by *SS'* in Figure 5.8, permits the measurement of technical efficiency. If a given farm uses quantities of inputs, defined by the point *P*, to produce a unit of output, the technical inefficiency of that farm could be represented by the distance *QP*, which is the amount by which all inputs could be proportionally reduced without any reduction in any output. This is usually expressed in percentage terms by the ratio *QP/OP*, which represents the percentage by which all inputs need to be reduced to achieve technically efficient production. The technical efficiency (TE) of a farm is most commonly measured by the ratio:

$$TE_i = \frac{OQ}{OP} \qquad (5.8)$$

$$= 1 - \frac{QP}{OP}$$

It will take a value between zero and one, and hence provides an indicator of the degree of technical inefficiency of the farm. A value of one indicates the firm is fully technically efficient. For example, the point Q is technically efficient because it lies on the efficient iso-quant.

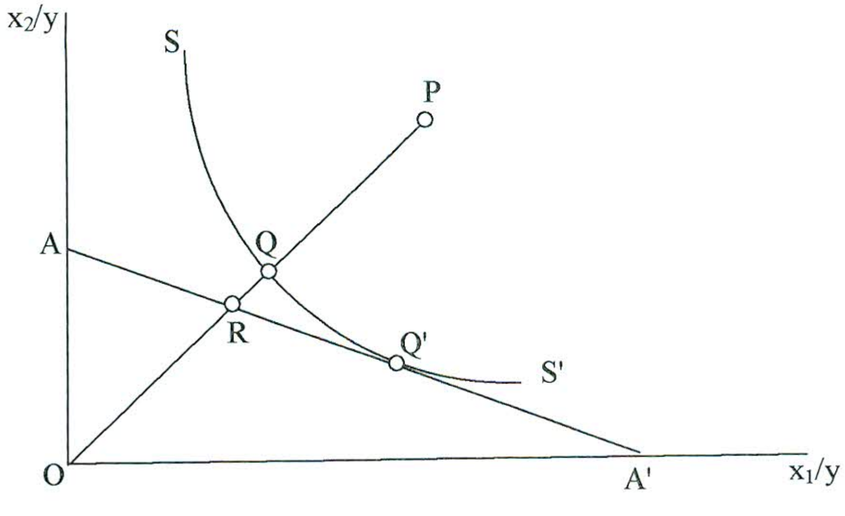


Figure 5.8: Technical and Allocative Efficiency from Input-Oriented Method

If the input price ratio, represented by the slope of the iso-quant line, *AA'*, in Figure 5.8, is known, allocative efficiency may be calculated. The allocative efficiency of the farm operating at *P* is defined to be the ratio:

$$AE_i = \frac{OR}{OQ} \tag{5.9}$$

since the distance *RQ* represents the reduction in production costs that could occur if production was done at the allocatively (and technically) efficient point *Q'*, instead of at the technically efficient, but allocatively inefficient point *Q*.

The product of technical and allocative efficiency provides economic efficiency

$$EE_i = \left(\frac{OR}{OP}\right) = \left(\frac{OQ}{OP}\right) \times \left(\frac{OR}{OQ}\right) = TE_i \times AE_i \tag{5.10}$$

Thus, the economic efficiency is defined to be the ratio:

$$EE_i = \frac{OR}{OP} \tag{5.11}$$

where the distance RP can also be interpreted in terms of a cost reduction. All these three measures are bounded by zero and one.

5.4.2 Output-Oriented Measures

We can also illustrate the output-oriented measures by considering the case where production involves two outputs (y_1 and y_2) and a single input (x_1). If we consider the input quantity fixed at a particular level, the production technology can represent by a production possibility curve in two dimensions. This is depicted in Figure 5.9 where the line ZZ' is the production possibility curve and the point A corresponds to an inefficient firm. An inefficient farm operating at point A lies below the curve, because ZZ' represents the upper bound of production possibility curve.

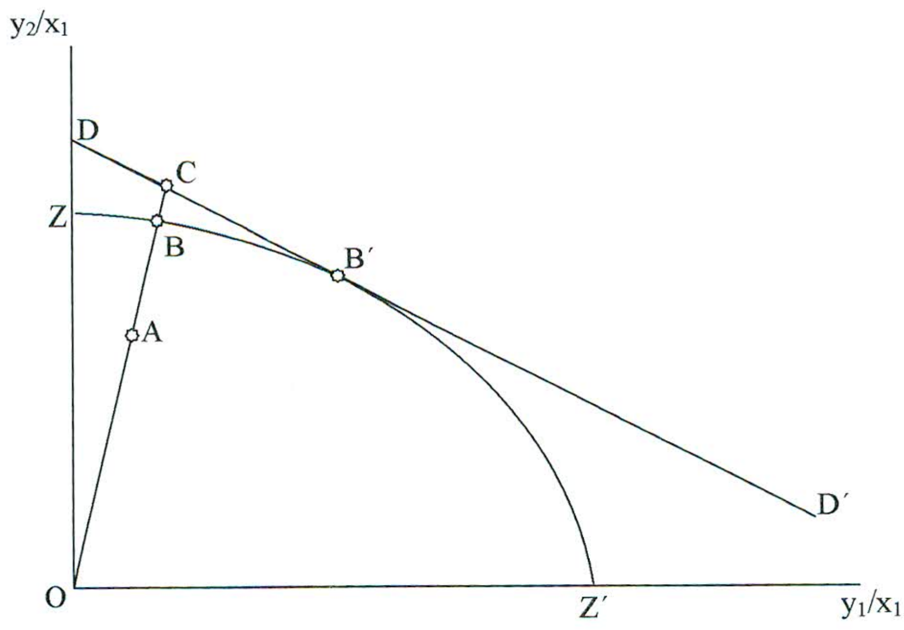


Figure 5.9: Technical and Allocative Efficiencies from an Output Orientation Method

The output oriented efficiency measures (Färe, Grosskopf and Lovell, 1985, 1994) are defined as follows. In Figure 5.9, the distance AB represents technical inefficiency. That is, the amount by which outputs could be increased without requiring extra input. Hence the measure of output-oriented technical efficiency is the ratio:

$$TE_0 = \frac{OA}{OB} \tag{5.12}$$

If we have price information then we can draw the iso-revenue line, DD', and define the allocative efficiency to be:

$$AE_0 = \frac{OB}{OC} \tag{5.13}$$

This has a revenue increasing interpretation (similar to the cost reducing interpretation of allocative inefficiency in the input-orientated case). Furthermore, we can define overall economic efficiency as the product of these two measures

$$EE_0 = \left(\frac{OA}{OC}\right) = \left(\frac{OA}{OB}\right) \times \left(\frac{OB}{OC}\right) = TE_0 \times AE_0 \tag{5.14}$$

Again all these three measures are bounded by zero and one.

From long ago agricultural economists had the interest to measure the productive efficiency of a farm or relative to other farms. But partial measures of productivity such as yield per hectare or output per unit of labour is imperfect. Farrell (1957) suggested method of measuring the technical efficiency of a farm by estimating the production function of farms which are fully efficient, i.e., on a frontier production function.

5.5 Conclusion

We have given a description about production function, average and marginal products, output elasticities and returns to scale in this chapter. We have initially started with an elementary discussion of production function using just two inputs. The marginal productivity of an input explains the change of output for a very small change in that input, keeping all other inputs fixed. Output elasticity is a unit free measure of marginal productivity and it describes the percentage change in output resulting from a percentage change in an input, assuming all other inputs constant. Returns to scale is the proportional is the proportional change in output resulting from the proportional changes in all inputs. Then, discussed the output maximization and cost minimization nature of production process.

We discuss the concepts of efficiency. The efficiency implies the success with which a farm produces maximum output utilizing its available resources with minimum cost. In other words, a production function describes the maximum potential output from a given input mix and failure to achieve this output with minimum cost results in inefficiency. Efficiency has two components: technical and allocative efficiency. Technical efficiency reflects the ability to produce maximum output with given input mix utilizing the existing technologies. On the other hand, allocative efficiency means the capacity to use an optimum combination of inputs at the cost minimizing situation, given the prices of inputs. Therefore, failure to produce with the least cost combination results in allocative inefficiency. The overall economic efficiency combines these two measures - technical efficiency and allocative efficiency. Input- and output orientation methods of efficiency estimation are also described in this chapter.

Chapter 6

The Stochastic Frontier Analysis

CHAPTER 6 THE STOCHASTIC FRONTIER ANALYSIS

6.1 Introduction

Many years ago Hicks (1935) observed that "people in monopolistic positions … are likely to exploit their advantage much more by not bothering to get very near the position of maximum profit, than by straining themselves to get very close to it. The best of all monopoly profits is a quiet life." Hick's suggestion is that the absence of competitive pressure might allow the producers for the freedom to not fully optimize conventional textbook objectives. The presence of competitive pressure might force the producers to do so and later on, this implication has been adopted by many writers. Debate continues on private and public type ownership in farms. But ownership forms are more variegated than just private or public. Hansmann (1988) identified investor-owned farms, customer-owned farms, worker-owned farms and farms without owners (nonprofit enterprises). Each deals with difficulty which is associated with hierarchy, coordination, incomplete contracts, and monitoring with agency costs. This leads to the expectation that different ownership forms will generate differences in performances.

Later on, Leibenstein (1966, 1975, 1976, 1978, and 1987) argued that production is bound to be inefficient as a result of motivation, information, monitoring, and agency problems within the farm. This is referred to as X-inefficiency. But latter, Stigler (1976) and de Alessi (1983) criticized it on the ground that it reflects an incompletely specified model rather than a failure to optimize. Therefore, in retrospect this literature does suggest that the development of Stochastic Frontier Analysis (SFA) was a useful idea if it could be used to the shed empirical light on the theoretical issues raised.

The thing that did directly influence the development of SFA was the theoretical literature on productive efficiency, which began in 1950s with the work of Koopmans (1951) and Debreu (1951), and Shephard (1953). Koopmans provided a definition of technical efficiency: A producer is technically efficient if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some input. Debreu and Shephard introduced distance functions as a way of modeling multiple-outputs. But more importantly he is Farrell (1957) who introduced first to measure productive efficiency empirically. Farrell showed how to define efficiency, and how to decompose efficiency into its technical and allocative components. He also provided an empirical application to U.S. agriculture, although he did not use econometric methods. He just used the linear programming techniques. Eventually he influenced the development of data envelopment analysis (DEA) by Charnes, Cooper, and Rhodes (1978). DEA is now a well-established non-parametric efficiency measurement technique widely employed in management science.

The extraordinary work of Farrell (1957) exerted on Aigner and Chu (1968), Seitz (1971), Timmer (1971), Afriat (1972), and Richmond (1974). All of these works had a great influence for the development of SFA.

Frontier refers to a bounding function. In microeconomic theory bounding functions, such as, production function represents the maximum output attainable from a given set of inputs; a cost function represents minimum cost, given input prices and output; a profit function represents maximal profit, given input and output prices; and so on. Generally for empirical works in all fields of economics, including agricultural economics, it is practiced to do this by ordinary least squares (OLS) regression and its variants, which fit a line of best fit through the sample data.

The two main benefits of estimating frontier functions rather than average (e.g., OLS) functions are as follows: (a) estimating of an average function will provide a picture of the shape of technology of an average farm, while the estimation of a frontier function will be most heavily influenced by the best performing farms and hence reflect the technology they are using, and (b) the frontier function represents a best-practice technology against which the efficiency of farms can be measured. It is the second use of frontiers which has provided the greatest impetus for the estimation of frontier functions in recent years.

Simple econometric or linear programming method of estimation of efficiency has a serious deficiency. For example, using tons of rice per hectare or litres of milk per cow as measures of farmer's efficiency is not perfectly correct, because they consider only land input and ignore all other inputs, such as labour, machinery, fuel, fertilizer, pesticide, etc. So, using this ordinary measure may give misleading information in the case of management formation and policy advice. Similar problems occur when other simple measures of efficiency, such as litre of milk per cow or output per unit, are used.

The term productivity and efficiency has some differences. They are not used for the same meaning in all time. For example, a production frontier defines the correct state of technology in production. Farms would be operating either on that frontier, if they are fully efficient or beneath the frontier if they are not fully efficient. So, productivity improvements can be achieved in two ways either by technological progress or efficiency improvement. One can improve the state of technology by inventing new ploughs, pesticides, rotation plans, etc. Generally it is referred to a technological change and takes long time. Alternatively one can implement procedures, such as by improving farmers' education, by ensuring farmers' use the existing technology more efficiently. Therefore, the policies required to address these two issues are likely to be quite different.

There are two methods of frontier estimation, stochastic frontier analysis (SFA) and data envelopment analysis (DEA), which involve econometric methods and mathematical programming, respectively.

6.2 The Origin of Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) originated with two papers, published nearly simultaneously by Meeusen and van den Broeck (MB) (1977) appeared in June; and Aigner, 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 models applied in these three original papers used the composed error structure and each was developed in a production frontier context.

The model can be expressed as:

$$y = f(x;\beta).\exp\{\xi - \zeta\}$$

where y is a scalar output, x is a vector of inputs, and β is a vector of technology parameters. The first error component $\xi \sim N(0,\sigma_\xi^2)$ is intended to capture the effects of statistical noise, and the second error component $\zeta \geq 0$ is intended to capture the effects of technical inefficiency. Thus producers operate on or beneath their stochastic production frontier [$y = f(x;\beta).\exp\{\xi\}$] according as $\zeta = 0$ or $\zeta > 0$. Meeusen and van den Broeck assigned an exponential distribution to ζ, Battese and Corra assigned a half normal distribution to ζ, and Aigner, Lovell, and Schmidt considered both distributions for ζ. Parameters to be estimated include β, σ_ξ^2, and a variance parameter σ_ζ^2 associated with ζ. Either distributional assumption on ζ implies that the composed error $(\xi - \zeta)$ is negatively skewed. After estimation, an estimate of mean technical inefficiency in the sample was provided by

$$E(-\zeta) = E(\xi - \zeta) = -(2/\pi)^{1/2}\sigma_\zeta \text{ in the normal-half normal case}$$

and by

$$E(-\zeta) = E(\xi - \zeta) = \sigma_\zeta \text{ in the normal-exponential case.}$$

6.3 Improvements in the Stochastic Frontier Analysis since 1977

In an early survey of various approaches to frontier analysis and efficiency measurement, Førsund, Lovell, and Schmidt (1980) said that the main weakness of the stochastic frontier model is that it is not possible to decompose individual residuals into their two components, and so it is not possible to estimate technical inefficiency by farms. The best that one can do is to obtain an estimate of mean inefficiency over the sample.

But Jondrow *et. al,.* (1982) (JLMS) responded very quickly and detected an error in that statement. In their paper, either the mean or the mode of the conditional distribution $[ui|v_i - u_i]$ was proposed to provide estimates of the technical inefficiency of each producer in the sample.

The half normal and exponential distributions, assigned to the one-sided inefficiency error component, are single-parameter distributions, and researchers soon developed more flexible two-parameter distributions for the inefficiency error component. Getting inspiration from Afriat (1972) and Richmond (1974), Greene (1980) proposed a Gamma distribution, and Stevenson (1980) proposed Gamma and truncated normal distributions. Lee (1983), even more flexible, proposed the four-parameter Pearson family of distributions. Nonetheless the two original single-parameter distributions remain the distribution of choice in the vast majority of empirical works.

With a simple change to the sign of the inefficiency error component ζ, the stochastic production frontier model may be converted to a stochastic cost frontier model as:

$$E = c(y, w; \beta).\exp\{\xi + \zeta\},$$

where E is expenditure, $[E = c(y, w; \beta).\exp\{\xi\}]$ is a stochastic cost frontier, and ζ is intended to capture the cost of technical and allocative inefficiency. The JLMS technique may be used to provide an estimate of the overall cost inefficiency, but there remains some difficulties to decompose the estimate of ζ into technical and allocative inefficiency components. Schmidt and Lovell (1979) accomplished the decomposition for the Cobb-Douglas case and Kopp and Diewert (1982) obtained the decomposition for the more general translog case, although the econometric difficulties with their decomposition remain to this day.

Cross-section data provide a snapshot of producers and their efficiency. Panel data provide more reliable evidence on their performance, because they enable us to track the performance of each producer through a sequence of time periods. Long ago Hoch (1955, 1962) and Mundlak (1961) started to estimate the parameter of agricultural production, but eventually Pitt and Lee (1981) extended cross-sectional maximum likelihood estimation techniques to panel data, and Schmidt and Sickles (1984) extended the pioneering work of Hoch and Mundlak by applying fixed-effects and random effects methods to the efficiency measurement problem, where the effects are one-sided. A significant advantage of panel data is that they permit consistent estimation for the efficiency of individual producers, whereas the JLMS technique does not generate consistent estimators in a cross-section context (Kumbhakar and Lovell, 2000).

Early panel data models were based on the assumption of time invariant efficiency. The longer the panel the less tenable this assumption becomes. Eventually this assumption was relaxed in a series of papers by Cornwell, Schmidt and Sickles (1990), Kumbhakar (1990), and Battese and Coelli (1992).

Early studies adopted a two-stage approach, in which efficiencies are estimated in the first stage, and estimated efficiencies are regressed against a vector of explanatory variables in a second stage. More recent studies, including those of Kumbhakar, Ghose, and McGukin (1991), Reifschneider and Stevenson (1991), Huang and Liu (1994), and Battese and Coelli (1995), Zellner *et. al.*, (1996), Wilson *et. al.*, (1998), Wadud and

White (2000), Wadud (2003) have adopted a single-stage approach in which explanatory variables incorporated directly into the inefficiency error component. In this approach either the mean or the variance of the inefficiency error component is hypothesized to be a function of explanatory variables. Abramovitz (1956) and later Solow (1957) referred productivity change with technical change. Generally, in frontier analysis productivity change due to technical change is not considered. However, if productive efficiency changes through time, then it must also contribute to productivity change. Bauer (1990) incorporated efficiency change into models of productivity change.

6.4 Stochastic Frontier Production Function

Farrell's (1957) seminal article has led to the development of several techniques for the measurement of efficiency of production. These techniques can be categorized into two approaches: parametric and nonparametric. The parametric stochastic frontier production function approach (Aigner *et. al.*, 1977; Meeusen and van den Broeck, 1977) and the nonparametric mathematical programming approach, commonly referred to as data envelopment analysis (DEA) (Charnes *et. al.*, 1978) are the two most popular techniques used in efficiency analyses.

Battese (1992) has depicted the basic structure of the stochastic frontier model where two farms i and j are engaged in production activities. This is presented in Figure 6.1. Here farm i obtains output y_i by using input x_i. However, its corresponding frontier output (y_i^*) exceeds the value on the deterministic production function f(x_i, β) as its production activity is associated with 'favourable' conditions for which the random error ξ_i is positive.

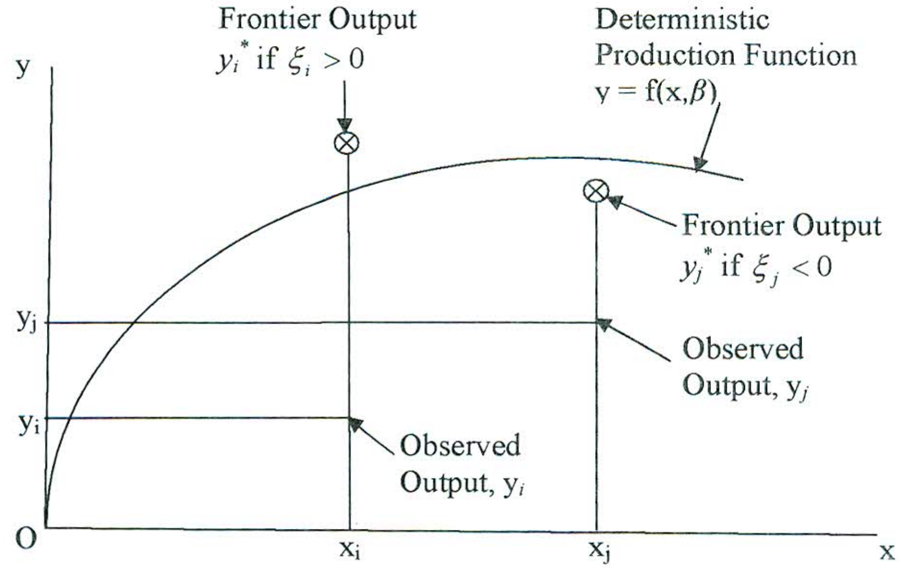


Figure 6.1: Stochastic Frontier Production Function

Farm j, on the other hand, uses input x_j and produces output y_j, having its corresponding frontier output y_j^*. This is less than the value on the deterministic production function, f(x_j,β), as its productive activity is associated with ' unfavourable' conditions for which the error term ξ_j is negative.

Later on, Farrell's ideas have been extended in many ways. The literature related to efficiency estimation roughly divided into two groups according to the method chosen to estimate the frontier production, namely, mathematical programming versus econometric estimation. Debate continues over which approach is the most appropriate to use. The answer often depends upon the application considered. The mathematical programming approach to frontier estimation is usually termed as Data Envelopment Analysis (DEA). The primary criticism of the DEA approach is that measurement errors can have a large influence upon the shape and positioning of the estimated frontier.

Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function to account for the presence of measurement error in production in the specification and estimation of frontier production functions. Stochastic frontier production functions have two error terms: one to account for the existence of technical inefficiency of production and the other to account for factors such as measurement error in the output variable, luck, weather, etc. and the combined effects of unobserved inputs on production.

In agricultural economics literature the stochastic frontier approach has generally been preferred. This probably associated with a number of factors. The assumption that all deviations from the frontier are associated with inefficiency, as assumed in DEA, is difficult to accept, given the inherent variability of agricultural production, due to weather, fires, pests, diseases, etc. Furthermore, because many farms are small family-owned operations, the keeping of accurate records is not always a priority. Thus much available data on production are likely to be subject to measurement errors.

There have been many applications for frontier production functions on agricultural industries over the years. Battese (1992), and Bravo-Ureta and Pinheiro (1993), Bravo-Ureta and Evenson (1994), Coelli and Battese (1996), Ajibefun *et.al.* (1996), Heshmati and Kumbhakar (1997), Ellis (1998), Wadud and White (2000), Wadud (2003) provide surveys of applications in agricultural economics. Battese (1992) has given particular attention to the applications in developing countries. Bravo-Ureta and Pinheiro (1993) also draw attention to those applications which attempt to investigate the relationship between technical efficiencies and various socio-economic variables, such as age and level of education of the farmer, farm-size, access to credit and utilization of extension services. The identification of those factors which influence the level of technical efficiencies of farmers is, undoubtedly, a valuable exercise. The information provided may be of significant use to policy makers attempting to raise the average level of farm efficiency.

In the context of farming, soil characteristics, climatic and some socio-economic factors may affect efficiency of a farm. If the producer makes mistakes in allocating inputs, the resulting inefficiency labeled as allocative inefficiency. It is always associated with some behavioral objective like profit maximization or cost minimization. Mistakes in the allocation of resources and production of suboptimal level of output increase cost and, therefore, decrease profit. Consequently, identification of the inefficient producers is very important, especially for government policy design to promote efficient utilization of resources.

6.5 The Stochastic Frontier Model and Efficiency Measurement

Standard econometric production function models assume that all farms become successful in maximizing output so that a systematic stochastic error term, with zero mean, attributes the discrepancies between the observed and the expected output values. A frontier production relaxes the assumption of equal efficiency and hence the assumption of systematic error terms with zero mean.

Reviews of the various stochastic frontier models are provided by Førsund *et. al.*, (1980), Schmidt (1986), Bauer (1990), Greene (1993) and Coelli (1995), Kumbhakar *et. al.*, (1991), Huang and Liu (1994) and Battese and Coelli (1995) proposed various stochastic frontier models in which the technical inefficiency effects are modeled as a function of other observable explanatory variables.

We can define a general stochastic frontier function as follows:

$$y_i = f(x_i;\beta)e^{u_i} \qquad (u_i = \xi_i - \zeta_i) \quad \text{and } (i = 1,2,3,\ldots,n) \tag{6.1}$$

where y_i denotes output of the i-th farm; x_i is a $(1 \times K)$ vector of inputs used by the *i-th* farm and β is a vector of parameters. The error term u_i is decomposed into a symmetric random error ξ_i and a asymmetric non-negative random error ζ_i . The random component ξ_i, accounts for random variations in output because of factors not under the control of the farm households and are assumed to be independently and identically distributed (*iid*) as N (0, σ^2_ξ). The asymmetric non-negative random error, ζ_i, measures the technical inefficiency relative to the stochastic frontier and is also assumed to be independently and identically distributed (*iid*) non-negative truncations (at zero from below) of the N (μ, σ^2_ζ) distribution. Thus $\zeta_i = 0$ implies the farm lies on the stochastic production frontier and hence the farm is efficient and $\zeta_i > 0$ indicates the farm is inefficient. Furthermore ξ_i and ζ_i are assumed to be independent of each other and also independent of the input vector x.

The variance parameters of the models are expressed as:

$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2 \; ; \quad \gamma = \sigma_\zeta^2 / \sigma_u^2 \quad \text{and } 0 \le \gamma \le 1 \tag{6.2}$$

The γ parameter lies between zero and one such that a value of zero represents the absence of stochastic technical inefficiency turning the stochastic frontier model to the average frontier model, the one most often used in econometric studies and a value of one indicates the absence of the stochastic random error term making the stochastic frontier model a full frontier model which is considered by Aigner and Chu (1968).

The technical efficiency of the *i-th* farm is defined as the ratio of the observed output (y_i) to the corresponding frontier output (y_i^*), given the levels of the inputs utilized by the farm.

The farm specific technical efficiency, τ_i, can be measured as :

$$\tau_i = \frac{y_i}{y_i^*} = \frac{f(x_i, \beta)e^{(\xi_i - \zeta_i)}}{f(x_i, \beta)e^{\xi_i}} = e^{-\zeta_i} \qquad (0 \le \tau \le 1) \tag{6.3}$$

given the distributional assumptions of ξ_i and ζ_i, the estimate of ζ_i can be derived from the conditional expectation of ζ_i given u_i. Applying standard integral we can get the estimate as:

$$\tau = E\left(^{-\zeta_i} \middle| u_i\right) = \mu_i^* + \sigma_i^* \left[\frac{\phi\left(-\mu_i^* / \sigma_{i\zeta}^*\right)}{1 - \Phi\left(-\mu_i^* / \sigma_{i\zeta}^*\right)}\right] \tag{6.4}$$

where $\mu_i^* \equiv \frac{\mu\sigma_\xi^2 - u_i\sigma_\zeta^2}{\sigma_\xi^2 + \sigma_\zeta^2}$, $\sigma_\zeta^{*2} \equiv \frac{\sigma_\zeta^2\sigma_\xi^2}{\sigma_\xi^2 + \sigma_\zeta^2}$ and $\Phi()$ is the cumulative distribution function (Battese and Coelli, 1988). Technical inefficiency is estimated as $1 - E\left\{^{-\zeta_i} \middle| u_i = \xi_i - \zeta_i\right\}$. The efficiency index, $-\zeta_i^*$, of each farm can be constructed using the results from the above equation.

The mean technical efficiency of the farms, $\bar{\tau} = E[\zeta_i]$, is obtained as:

$$\bar{\tau} = \mu + \sigma_\zeta \left[\frac{\phi(-\mu / \sigma_\zeta)}{1 - \Phi(-\mu / \sigma_\zeta)}\right] \tag{6.5}$$

Assume that the technical inefficiency term is half-normally distributed, a special case of the truncated normal distribution, the farm-specific technical efficiencies and mean technical efficiency are obtained as (Jondrow *et al.*, 1982):

$$\tau_i = E\left[e^{-\varsigma_i}|u_i\right] = 1 - \Phi\left(\sigma_i^*\right)e^{\frac{1}{2}\sigma_i^{*2}} \text{ and } \bar{\tau} = 1 - \Phi\left(\sigma^*\right)e^{\frac{1}{2}\sigma^{*2}} \quad (6.6)$$

6.6 Measures of Technical, Allocative and Economic Efficiency

To get technical, allocative and economic efficiency estimates simultaneous, we find out the corresponding dual stochastic frontier cost function. We require a functional form of stochastic frontier production function which is self-dual to obtain the dual stochastic frontier cost function. The Cobb-Douglas stochastic frontier production model, as self-dual, is specified for cross-section farm level data and six inputs as:

$$\ln y_i = \beta_0 + \sum_{i=1}^{6} \beta_i \ln x_i + \xi_i - \zeta_i = f(x;\beta) \quad (6.7)$$

where the definitions of the variables are given earlier in (6.1) and (6.2). The maximum likelihood estimation (Appendix 1 for details) of (6.7) produces the estimators for β, $\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2$ and $\gamma = \sigma_\zeta^2 / \sigma_u^2$. The technical efficiency estimates are obtained using (6.4). If we now replace the parameters of the stochastic frontier production function model in (6.7) and in the technical efficiency predictor in (6.4) by their maximum likelihood estimates, we obtain the estimates for ξ_i and ζ_i.

Now, subtracting e^{ξ_i} from the both side of the equation 6.1, we have

$$\tilde{y}_i = y_i - \xi_i = f(x_i\beta) - \zeta_i \quad (6.8)$$

where, $\tilde{y}_i$ is the observed output of the ith farm for the stochastic random noise captured by ξ_i. One can assume that the functional form of the production technology is self dual, the corresponding dual stochastic frontier cost function can be obtained analytically as $C_i = C(p_i, \tilde{y}_i, \alpha)$, where C_i represents the minimum cost of the ith farm associated with the production of output vector $\tilde{y}_i$, p_i the vector of input prices for the ith farm and α is the vector of parameters. A system of cost-minimizing input demand functions is

$$\partial C(p_i, \tilde{y}_i, \alpha) / \partial p_i = x_i(p_i, \tilde{y}_i, \tilde{\alpha})$$

where $\tilde{\alpha}$ is a vector of estimated parameters. By substituting the input prices and output level of the farms into the system of minimum cost input demand functions, we will get the economically efficient (technically and allocatively efficient) input vector x_i^E. The cost of the observed operating input mix is $x_i p_i$ while the technically efficient and economically efficient costs of production of the farm are estimated as $x_i^T p_i$ and $x_i^E p_i$ respectively, given the actual level of output.

On the basis of these three measures of production costs we are now able for calculating the technical efficiency (TE), economic efficiency (EE) and allocative efficiency (AE) as:

$$TE = \left(x_i^T p_i \big/ x_i p_i \right) \tag{6.9}$$

$$EE = \left(x_i^E p_i \big/ x_i p_i \right) \tag{6.10}$$

and

$$AE = (EE / TE) = \left(x_i^E p \big/ x_i^T p \right) \tag{6.11}$$

6.7 Cobb-Douglas Production Function

We use Cobb-Douglas(C-D) production function in our study; because the Cobb-Douglas functional form is usually preferred on account of it's well known advantages. The input-demand function of Cobb-Douglas production may be derived as follows.

Let us assume that the C-D production function is $y = Ax_1^{\alpha} x_2^{\beta}$, where $\alpha>0$ and $\beta>0$ and $(\alpha+\beta)<1$. If p is the price of per unit output and w and r is the price of x_1 and x_2 respectively.

Then $R = p.y = p.Ax_1^{\alpha} x_2^{\beta}$ and $C = w x_1 + r x_2$.

so, the profit function is $\pi = p.Ax_1^{\alpha} x_2^{\beta} - wx_1 - rx_2$

Now, getting the first derivative of the profit function and equals with zero, we have,

$$\frac{\partial \pi}{\partial x_1} = p\alpha A x_1^{\alpha-1} x_2^{\beta} - w = 0 \tag{6.12}$$

$$\frac{\partial \pi}{\partial x_2} = p\beta A x_1^{\alpha} x_2^{\beta-1} - r = 0 \tag{6.13}$$

for getting the value of x_1 and x_2, multiplying (6.12) by βx_1 and (6.13) by αx_2 and subtracting, we have,

$$\alpha r x_2 - \beta w x_1 = 0$$

or, $$x_2 = \left(\frac{\beta}{\alpha}.\frac{w}{r}\right) x_1 \tag{6.14}$$

For finding the value of x_1, we put this value of x_2 in (6.12) or (6.13)

$$p\alpha A x_1^{\alpha-1} \{(\beta w / \alpha r) x_1\}^{\beta} = w$$

$$\text{or, } x_1^{\alpha-1+\beta} = \frac{w}{p.\alpha A\left(\frac{\beta}{\alpha}.\frac{w}{r}\right)^{\beta}}$$

$$\text{or, } x_1^{1-\alpha-\beta} = \frac{p.\alpha A\left(\frac{\beta}{\alpha}.\frac{w}{r}\right)^{\beta}}{w}$$

$$\text{or, } x_1^{1-\alpha-\beta} = Ap\left(\frac{\alpha}{w}\right)^{1-\beta}\left(\frac{\beta}{r}\right)^{\beta}$$

$$\text{Therefore, } x_1 = \left(\frac{\alpha}{w}\right)^{\frac{1-\beta}{1-\alpha-\beta}}\left(\frac{\beta}{r}\right)^{\frac{\beta}{1-\alpha-\beta}}.(AP)^{\frac{1}{1-\alpha-\beta}} = \Phi_{x_1}(w,r,p)$$

$$\text{Similarly, we can get, } x_2 = \left(\frac{\alpha}{w}\right)^{\frac{1}{1-\alpha-\beta}}\left(\frac{\beta}{r}\right)^{\frac{1-\alpha}{1-\alpha-\beta}}.(AP)^{\frac{1}{1-\alpha-\beta}} = \Phi_{x_2}(w,r,p)$$

These are the input demand functions of Cobb-Douglas production function.

6.8 Conclusion

In this chapter, we discuss the stochastic frontier production function in details. We start with the brief history of the stochastic frontier, and then the improvements of the stochastic frontier since 1977 are discussed. This chapter theoretically describes the stochastic econometric frontier approach for measuring efficiency. The econometric frontier approach has the advantage over the deterministic approach because it includes a stochastic error component. Firstly, we describe a general stochastic frontier production model which includes the technical inefficiency effects, for estimating technical efficiency. We then explain the Cobb-Douglas form of production function which is restricted to a unitary elasticity of substitution. Input demand function of Cobb-Douglas production is also discussed.

Finally, we examine the decomposition method to obtain the estimates of technical, allocative and economic efficiency using the self-dual Cobb-Douglas stochastic frontier. We explain the dual stochastic frontier cost function which is analytically obtained from the stochastic frontier production function. We derive the economically efficient input vector. From the primal stochastic frontier production function and dual stochastic frontier cost function, technically efficient input vectors are derived. These technically and economically efficient input vectors and observed input vectors along with respective input price vectors provide the technical and economic efficiency estimate. Allocative efficiency is then obtained from the ratio of economic and technical efficiency estimates.

Chapter 7

Empirical Results: The Stochastic Frontier Model

CHAPTER 7

EMPIRICAL RESULTS: THE STOCHASTIC FRONTIER MODEL

7.1 Introduction

In chapter 6 we have discussed the stochastic frontier model theoretically in details. Here, we will produce results of the stochastic frontier model based on data what have been collected from the field level survey. In this chapter, we also narrate estimation results of technical, allocative and economic efficiency using the self-dual Cobb-Douglas stochastic frontier model applying stochastic decomposition procedure. We calculate first the technical efficiency in a single stage method in which the technical inefficiency effects are modeled as a function of socioeconomic characteristics and other factors. Then we calculate allocative and economic efficiency applying stochastic cost decomposition method. We also use Tobit regression model to identify and quantify factors which affect allocative and economic efficiency.

7.2 Estimated Model

In our study we apply a Cobb-Douglas frontier because it is self-dual and its dual cost frontier model forms the basis for computing technical, allocative and economic efficiency. We specify the Cobb-Douglas stochastic frontier as:

$$\ln y_i = \beta_0 + \sum_{k=1}^{6} \beta_{ik} \ln x_{ik} + \xi_i - \zeta_i \quad (i=1, 2, \ldots, 205, \text{ number of farms}) \qquad (7.1)$$

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

$$\ln \widetilde{y}_i = \ln y_i - \xi_i = \beta_0 + \sum_{k=1}^{6} \beta_{ik} \ln x_{ik} - \zeta_i$$

where $\widetilde{y}_i$ now denotes the farm's observed output adjusted for the stochastic random noise captured by ξ_i. This equation constitutes the basis for obtaining the technically efficient input vector x_{ik}^{T} and algebraically deriving the dual stochastic frontier cost function which is the basis for calculating the economically efficient (technically and allocatively efficient) input vector x_{ik}^{E}. The dual stochastic frontier cost function model is analytically derived from the stochastic frontier production model as (Appendix 2 for details):

$$C\left(p_{ik}, \widetilde{y}_i\right) = \alpha_0 \prod_{k=1}^{6} p_{ik}^{\beta_{ik}\alpha_{ik}} \widetilde{y}_i^{\alpha_{ik}} \tag{7.2}$$

where $\alpha_0 = \left(\frac{1}{\beta_0^{\alpha_{ik}}}\right)\left(\sum_{k=1}^{6}\beta_{ik} \Big/ \prod_{k=1}^{6}\beta_{ik}^{\beta_{ik}\alpha_{ik}}\right)$ and $\alpha_{ik} = \frac{1}{\sum_{k=1}^{6} \beta_{ik}}$

Differentiating (7.2) with respect to each input's price and applying Shephard lemma provide the system of input demand function as:

$$x_{ik}^{E} = \frac{\partial C\left(p_{ik}, y\right)}{\partial p_{ik}}$$

$$= x_{ik}^{E}\left(p_{ik}, \widetilde{y}_i\right) = \alpha_0\left(\beta_{ik}\alpha_{ik}\right)\prod_{k=1}^{6}\frac{1}{p_{ik}} p_{ik}^{\beta_{ik}\alpha_{ik}} \widetilde{y}_i^{\alpha_{ik}} \tag{7.3}$$

Alternatively:

$$x_{ik}^{E} = \frac{\partial C(p_{ik}, y)}{\partial p_{ik}} = \frac{\partial C}{\partial p_{ik}} = C.\frac{\alpha_{ik}}{p_{ik}}$$

where C denotes $C(p_{ik}, \tilde{y})$ is cost function and $\alpha_{ik} = \beta_{ik} \Big/ \sum_{k=1}^{6} \beta_{ik}$ (i=1, 2, ..., 205, number of farms). We also solve for the technically efficient input vectors x_{ik}^{T} using the results from the stochastic frontier production function in (7.1). Multiplying the observed input vectors x_{ik}, technically efficient input vectors x_{ik}^{T} and economically efficient input vectors x_{ik}^{E} by the input price vectors provides the observed, technically efficient and economically efficient costs of production of the ith farm equal to $p_{ik}x_{ik}$, $p_{ik}x_{ik}^{T}$ and $p_{ik}x_{ik}^{E}$ respectively which compute the TE, AE and EE indices for the ith farm as:

$$TE = p_{ik}x_{ik}^{T} \big/ p_{ik}x_{ik} \, ;$$

$$AE = p_{ik}x_{ik}^{E} \big/ p_{ik}x_{ik}^{T} \text{ and}$$

$$EE = p_{ik}x_{ik}^{E} \big/ p_{ik}x_{ik} \text{ respectively.}$$

For empirical study, we define output, y_i as the observed rice production and are measured in kilograms (km). Land, x_{i1} represents the total amount of land used for rice production and the price of land, p_{i1} represents the price per acre of land. Labour, x_{i2} includes both family and hired labour engaged in rice production and the price of labour, p_{i2} indicates the wage per man-day (wages for family labour are imputed). Irrigation, x_{i3} is the total amount of land irrigated for rice production and the price of irrigation, p_{i3} represents irrigation price per acre. Fertilizer, x_{i4} includes all organic and inorganic fertilizer and is measured in kilograms. The fertilizer price, p_{i4} indicates the average price all fertilizer per kilogram. Pesticides, x_{i5} is the total quantity of pesticides used per acre of land and is measured also in kilograms. The price of pesticides, p_{i5} is the price of all pesticides per kilogram. Seeds, x_{i6} represents the amount of seeds used in per acre of land and is measured in kilograms. The seed price, p_{i6} means the average prices of seeds per kilogram (includes both HYV and traditional type of seeds).

To assess the role of human capital variables, extension services, irrigation infrastructure and environmental factors in technical, allocative and economic efficiency, the following inefficiency effects model is estimated separately by using Tobit Regression Model

$$IE_i = \delta_0 + \delta_1 z_{i1} + \delta_2 z_{i2} + \delta_3 z_{i3} + \delta_4 z_{i4} + \delta_5 z_{i5} + \delta_6 z_{i6} + w_i \qquad (7.4)$$

where the z_i are the socio-economic and infrastructural variables which affect production as well as efficiency of farmers. The variable z_{i1} denotes the year of schooling of farmer; z_{i2} denotes the year of rice cultivation experience of farmer; the variable z_{i3} represents land fragmentation; z_{i4} denotes extension services dummy which assumes the value one if farmer takes extension services from the related officials and zero otherwise; 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 and z_{i6} denotes the degradation dummy which takes the value one if land is un-degraded and zero otherwise. The value one for z_{i6} implies that most of lands 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 σ_w^2. The Tobit model is used as inefficiency, IE_i, is a limited dependent variable. The value of IE_i falls between zero and one; some of the values of IE_i are likely to be zero.

7.3 Cobb-Douglas Stochastic Frontier Results

The maximum likelihood estimates of parameters of the Cobb-Douglas stochastic frontier model are estimated using Frontier 4.1 (Coelli, 1996). These are presented in Table 7.1 and 7.2 for aman and boro seasons respectively. We obtain positive coefficients for all six parameters. In field level survey, we have observed some significant behaviour for labour and seeds. It shows that there are already abundant supplies of labour in agriculture sector of Bangladesh, particularly in the study area of northern part of Bangladesh. In case of seed, they use excessive amount of seed. Therefore, we have some unusual results and behaviours of both coefficients of labour and seeds. All the coefficients are significant except seeds.

Table 7.1: Maximum Likelihood Estimates of the Stochastic Frontier Model for Aman Season

Stochastic Frontier

Name of Variables	Parameters	Coefficients	t-ratios
Constant	β_0	0.7911	3.1907
Land	β_1	0.1050	5.8141
Labour	β_2	0.3881	2.3340
Irrigation	β_3	0.5147	6.1976
Fertilizer	β_4	0.1063	4.3600
Pesticides	β_5	0.3059	3.1668
Seeds	β_6	0.2426	1.2856
Inefficiency Model			
Constant	δ_0	0.155	6.482
Year of Schooling	δ_1	0.0035	2.931
Experience	δ_2	0.00161	2.043
Land Fragmentation	δ_3	-0.00868	-6.340
Extension Services Dummy	δ_4	-0.0737	-0.631
Credit Facilities Dummy	δ_5	0.08693	0.750
Land Degradation Dummy	δ_6	-0.03228	-3.906
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1974	3.2103
Gamma	$\gamma = \left(\sigma_\zeta^2 / \sigma^2 \right)$	0.9529	6.3842
	σ_ξ^2	0.0093	
	σ_ζ^2	0.1881	
Log likelihood Value		66.6368	

Table 7.2: Maximum Likelihood Estimates of the Stochastic Frontier Model for Boro Season

Stochastic Frontier

Name of Variables	Parameters	Coefficients	t-ratios
Constant	β_0	0.4641	3.2048
Land	β_1	0.1448	4.2643
Labour	β_2	0.8898	2.2554
Irrigation	β_3	0.9092	5.1000
Fertilizer	β_4	0.3695	2.7491
Pesticides	β_5	0.4157	2.4813
Seeds	β_6	0.2788	0.3269
Inefficiency Model			
Constant	δ_0	0.136	9.501
Year of Schooling	δ_1	0.0011	1.021
Experience	δ_2	0.00176	3.735
Land Fragmentation	δ_3	-0.0108	-13.174
Extension Services Dummy	δ_4	0.0296	0.424
Credit Facilities Dummy	δ_5	0.00749	0.108
Land Degradation Dummy	δ_6	-0.0819	-8.081
Variance Parameters			
Sigma-squared	$\sigma^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.1437	5.9550
Gamma	$\gamma = \left(\sigma_\zeta^2 / \sigma^2 \right)$	0.5882	6.7013
	σ_ξ^2	0.0592	
	σ_ζ^2	0.0845	
Log likelihood Value		16.8526	

The estimates of the variance parameter σ^2 and the parameter γ are significantly different from zero. This indicates that the inefficiency effects are significant in determining the level and variability of output of farm households in Bangladesh. This result is consistent with Sharma *et. al.* (1997) and Coelli and Battese (1996). This shows that a conventional production function is not an adequate representation of the data.

7.4 Estimated Production, Cost and Input-Demand Functions

We now find the frontier cost function. Let us first construct the stochastic production function from Table 7.1 for aman season as:

Stochastic production function for aman season is:

$$\ln y_i = 0.7911 + 0.1050 \ln x_{i1} + 0.3881 \ln x_{i2} + 0.5147 \ln x_{i3} + 0.1063 \ln x_{i4} + 0.3059 \ln x_{i5} + 0.2426 \ln x_{i6}$$

or, alternatively,

$$y_i = 0.7911\, x_{i1}^{0.1050} x_{i2}^{0.3881} x_{i3}^{0.5147} x_{i4}^{0.1063} x_{i5}^{0.3059} x_{i6}^{0.2426} \qquad (7.5)$$

(where i=1, 2, …, 205, number of farms)

Its dual stochastic frontier cost function is analytically derived as follows:

$$C(p_{ik}, \widetilde{y}_i) = 6.3629 p_{i1}^{0.0631} p_{i2}^{0.2334} p_{i3}^{0.3095} p_{i4}^{0.0639} p_{i5}^{0.1839} p_{i6}^{0.1458} \widetilde{y}_i^{0.6014}$$

Thus, the stochastic cost function for aman season is:

$$C_i = 6.3629 p_{i1}^{0.0631} p_{i2}^{0.2334} p_{i3}^{0.3095} p_{i4}^{0.0639} p_{i5}^{0.1839} p_{i6}^{0.1458} \tilde{y}_i^{0.6014} \qquad (7.6)$$

(where i=1, 2, …, 205, number of farms)

Input demand function for aman season

Differentiating the stochastic cost function with respect to each input's price and applying Shephard Lemma provide the system of input demand function for aman season.

For example, input demand function for input 1 in aman season is:

$$x_{i1} = \frac{\partial c}{\partial p_{i1}} = 6.329\,(0.0631)\, p_{i1}^{(0.0631-1)} p_{i2}^{0.2334} p_{i3}^{0.3095} p_{i4}^{0.0639} p_{i5}^{0.1839} p_{i6}^{0.1458} \tilde{y}_i^{0.6014}$$

or, alternatively, $$x_{i1} = \frac{0.3993\, p_{i2}^{0.2334} p_{i3}^{0.3095} p_{i4}^{0.0639} p_{i5}^{0.1839} p_{i6}^{0.1458} \tilde{y}_i^{0.6014}}{p_{i1}^{0.9369}} \qquad (7.7)$$

(where i=1, 2, …, 205, number of farms)

Now, we solve for the technically efficient input vector x_{i1}^T using results in (7.7) and observed input ratios $x_1/x_{i1} = k_1\ (i \neq 1)$. Then multiply the observed input vectors x_{i1}, technically efficient input vectors x_{i1}^T and economically efficient input vectors x_{i1}^E by their input price vectors that provides the observed, technically efficient and economically efficient costs of production of the 1st farm equal to $p_{i1}x_{i1}$, $p_{i1}x_{i1}^T$ and $p_{i1}x_{i1}^E$ respectively. Then we compute technical, allocative and economic efficiency for farm 1 in aman season as:

$$TE = p_{i1}x_{i1}^T / p_{i1}x_{i1}$$

$$AE = p_{i1}x_{i1}^{E} / p_{i1}x_{i1}^{T} \text{ and}$$

$$EE = p_{i1}x_{i1}^{E} / p_{i1}x_{i1} \text{ respectively.}$$

In the same way we can derive the estimated production function and its corresponding dual cost function, input demand function and efficiency for boro season.

Production function for boro season

$$\ln y_i = 0.4641 + 0.1448 \ln x_{i1} + 0.8898 \ln x_{i2} + 0.9092 \ln x_{i3} + 0.3695 \ln x_{i4} + 0.4157 \ln x_{i5} + 0.2788 \ln x_{i6}$$

or, alternatively,

$$y_i = 0.4641\, x_{i1}^{0.1448}\, x_{i2}^{0.8898}\, x_{i3}^{0.9092}\, x_{i4}^{0.3695}\, x_{i5}^{0.4157}\, x_{i6}^{0.2788} \quad (7.8)$$

(where i=1, 2, …, 205, number of farms)

The corresponding **dual cost stochastic frontier function** is analytically derived as follows:

$$C(p_{ik}, \tilde{y}_i) = 6.5195\, p_{i1}^{0.1448(0.3324)}\, p_{i2}^{0.8898(0.3324)}\, p_{i3}^{0.9092(0.3324)}\, p_{i4}^{0.3695(0.3324)}\, p_{i5}^{0.4157(0.3324)}\, p_{i6}^{0.2788(0.3324)}\, \tilde{y}_i^{0.3324}$$

Thus, the **stochastic cost function for boro season** is:

$$C_i = 6.5195\, p_{i1}^{0.0481}\, p_{i2}^{0.2957}\, p_{i3}^{0.3022}\, p_{i4}^{0.1228}\, p_{i5}^{0.1381}\, p_{i6}^{0.0926}\, \tilde{y}_i^{0.3324} \quad (7.9)$$

(where i=1, 2, …, 205, number of farms)

Input demand function for boro season is:

Differentiating the cost function with respect to each input's price and applying Shephard Lemma provide the system of input demand function for boro season.

For example, input demand function for input 1 in boro season is:

$$x_{i1} = \frac{\partial c}{\partial p_{i1}} = 6.5195\ (0.0481\ )\, p_{i1}^{(0.0481\ -1)}\, p_{i2}^{0.2957}\, p_{i3}^{0.3022}\, p_{i4}^{0.1228}\, p_{i5}^{0.1381}\, p_{i6}^{0.09268}\, \tilde{y}_i^{0.3324}$$

or, alternatively, $$x_{i1} = \frac{0.3135\, p_{i2}^{0.2957}\, p_{i3}^{0.3022}\, p_{i4}^{0.1228}\, p_{i5}^{0.1381}\, p_{i6}^{0.0926}\, \tilde{y}_i^{0.3324}}{p_{i1}^{0.9519}} \qquad (7.10)$$

(where i=1, 2, …, 205, number of farms).

Similarly, we solve for the technically efficient input vector x_{i1}^{T} using the results in (7.10) in boro season and observed input ratios $x_1/x_{i1} = k_1\ (i \neq 1)$. We then multiply the observed input vectors x_{i1}, technically efficient input vectors x_{i1}^{T} and economically efficient input vectors x_{i1}^{E} by their input price vectors provides the observed, technically efficient and economically efficient costs of production of the 1[st] farm in boro season equal to $p_{i1}x_{i1}$, $p_{i1}x_{i1}^{T}$ and $p_{i1}x_{i1}^{E}$ respectively. Then we compute technical, allocative and economic efficiency for farm 1 in boro season as:

$TE = p_{i1}x_{i1}^{T} / p_{i1}x_{i1}$

$AE = p_{i1}x_{i1}^{E} / p_{i1}x_{i1}^{T}$ and

$EE = p_{i1}x_{i1}^{E} / p_{i1}x_{i1}$ respectively.

7.5 Estimated Technical, Allocative and Economic Efficiency

Technical, allocative and economic estimates of farms for aman and boro seasons and their summary statistics are presented in Table 7.3 and 7.4, 7.5 and 7.6 respectively.

Table 7.3: Technical, Allocative and Economic Efficiency of Farms in Aman Season.

Efficiency Index (%)	Stochastic Frontier					
	Number of Farms			Percentage of Farms		
	TE	AE	EE	TE	AE	EE
1.00-40	0	15	24	0	7.32	11.7
40-45	0	5	12	0	2.44	5.85
45-50	8	8	21	3.9	3.9	10.2
50-55	4	11	22	1.95	5.37	10.7
55-60	5	16	27	2.44	7.8	13.2
60-65	2	15	31	0.98	7.32	15.1
65-70	8	22	27	3.9	10.7	13.2
70-75	12	18	18	5.85	8.78	8.78
75-80	13	28	13	6.34	13.7	6.34
80-85	22	17	7	10.7	8.29	3.41
85-90	45	24	2	22	11.7	0.98
90-95	60	14	0	29.3	6.83	0
95-100	26	12	1	12.7	5.85	0.49
Total	205	205	205	100	100	100

Table 7.4: Summary Statistics of Efficiency in Aman Season

Statistics	Stochastic Frontier		
	TE	AE	EE
Mean	**84.11**	**70.61**	**58.36**
Minimum	46.06	32.08	31.01
Maximum	97.17	99.65	95.18
Standard deviation	12.45	17.13	13.64
Skewness	-1.48	-0.43	-0.11
Kurtosis	1.540	-0.60	-0.50

Table 7.5: Technical, Allocative and Economic Efficiency of Farms in Boro Season.

Efficiency Index (%)	Stochastic Frontier					
	Number of Farms			Percentage of Farms		
	TE	AE	EE	TE	AE	EE
1.00-40	0	16	20	0	7.8	9.76
40-45	1	3	12	0.49	1.46	5.85
45-50	0	13	18	0	6.34	8.78
50-55	2	15	14	0.98	7.32	6.83
55-60	1	11	11	0.49	5.37	5.37
60-65	3	4	17	1.46	1.95	8.29
65-70	8	8	24	3.9	3.9	11.7
70-75	6	15	27	2.93	7.32	13.2
75-80	16	19	26	7.8	9.27	12.7
80-85	33	16	21	16.1	7.8	10.2
85-90	42	21	9	20.5	10.2	4.39
90-95	55	24	6	26.8	11.7	2.93
95-100	38	40	0	18.5	19.5	0
Total	205	205	205	100	100	100

Table 7.6: Summary Statistics of Efficiency in Boro Season

Statistics	Stochastic Frontier		
	TE	AE	EE
Mean	**86.82**	**75.00**	**64.13**
Minimum	41.95	30.49	30.01
Maximum	99.18	99.72	94.77
Standard deviation	9.686	20.47	16.33
Skewness	-1.52	-0.59	-0.39
Kurtosis	3.164	-0.87	-0.82

Table 7.3 shows that 4 per cent farmers are below 50 per cent technical and allocative efficiency index and 12 per cent farmers are below 50 per cent economic efficiency index in aman season. On the other hand, 42 per cent farmers are above 90 per cent technically efficiency index and 13 per cent farmers have that score for allocative efficiency index and only 0.5 per cent farmers score 90 per cent or more for economic efficiency index in aman season.

Table 7.5 shows that 45 per cent farmers are 90 per cent or more technically efficient, 31 per cent farmers are more than 90 per cent allocatively efficient and only 3 per cent farmers are more than 90 per cent economically efficient in boro season.

The frequency distribution and summary statistics of the estimated technical, allocative and economic efficiency of farms in aman and boro seasons are presented in Table 7.4 and 7.6 respectively. The estimated mean technical, allocative and economic efficiency in aman season are 84, 71 and 58 per cent respectively. This indicates that there is considerable inefficiency in aman production in that region and therefore rooms for production gain through efficiency improvement. More specifically, it can be said that farm households could reduce their production cost by 16, 29 and 42 per cent if they could operate at full technical, allocative and economic efficiency levels respectively.

On the other hand, mean efficiency scores in boro season for technical, allocative and economic efficiency are 87, 75 and 64 per cent respectively. It means that 13, 25 and 36 per cent inefficiency exists as far as technical, allocative and economic efficiencies are concerned. So, farmers can reduce production cost by improving efficiency.

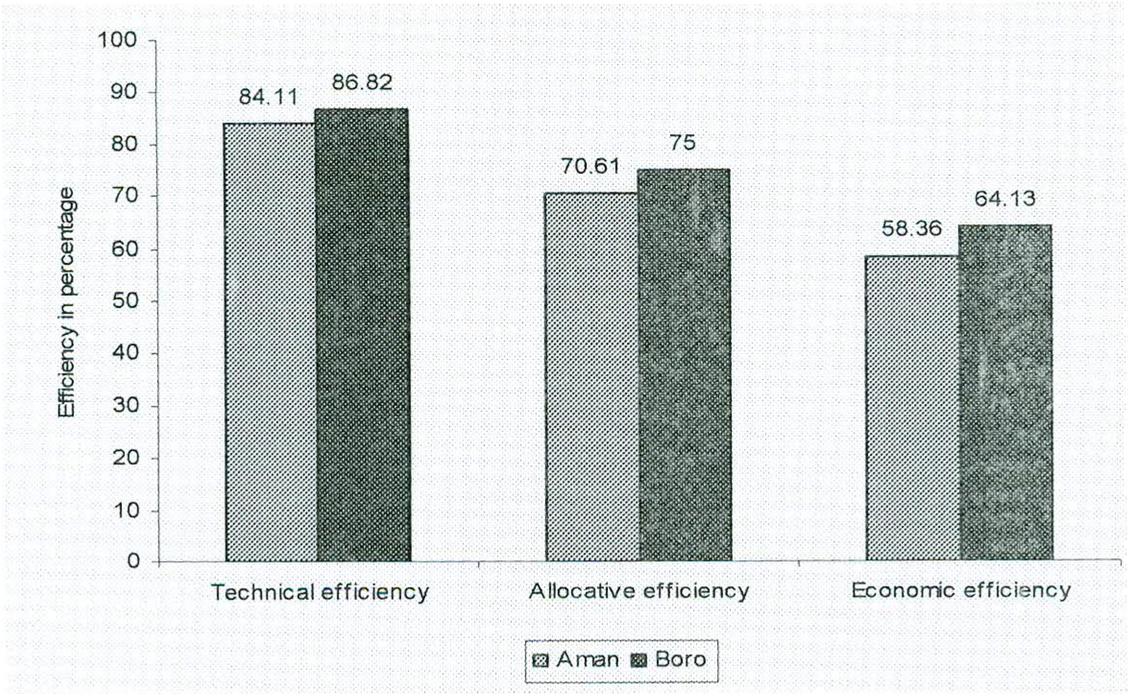


Figure 7.1: Average Efficiency Scores of Farms in Aman and Boro Season

The average estimates of technical, allocative and economic efficiency for farms in aman and boro seasons are shown in Figure 7.1. We have a comparison of these efficiency scores between aman and boro seasons. Figure 7.1 shows that all three efficiency scores are slightly higher in boro season than in aman season.

Frequency histogram of technical, allocative and economic efficiency index for aman and boro seasons are given in diagrams from Figure 7.2 to Figure 7.7 to have a quick look at efficiency indices.

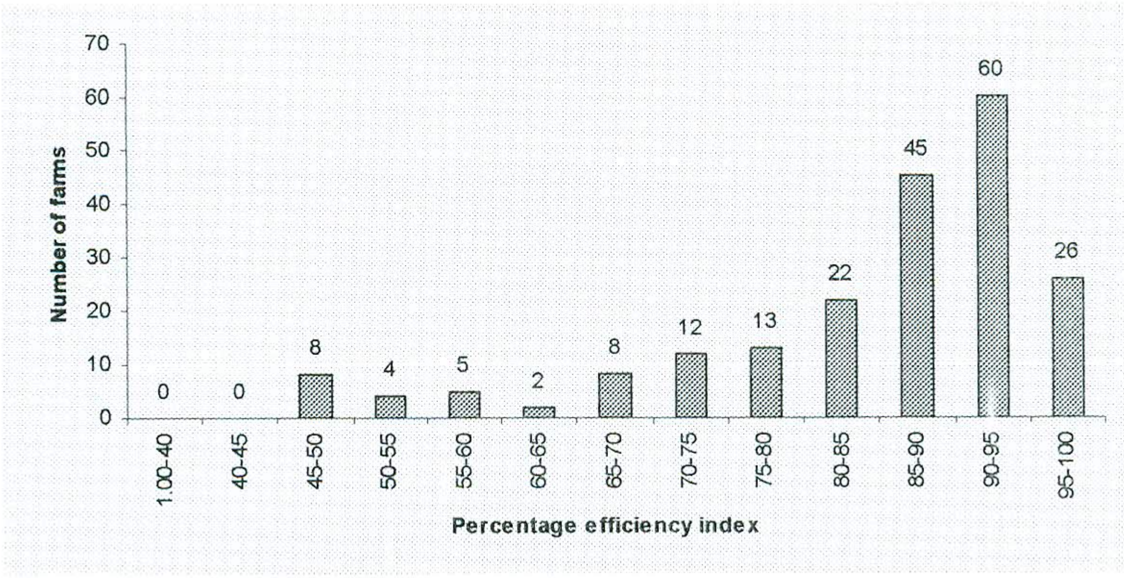


Figure 7.2: Frequency Histogram of Technical Efficiency Index for Aman Season

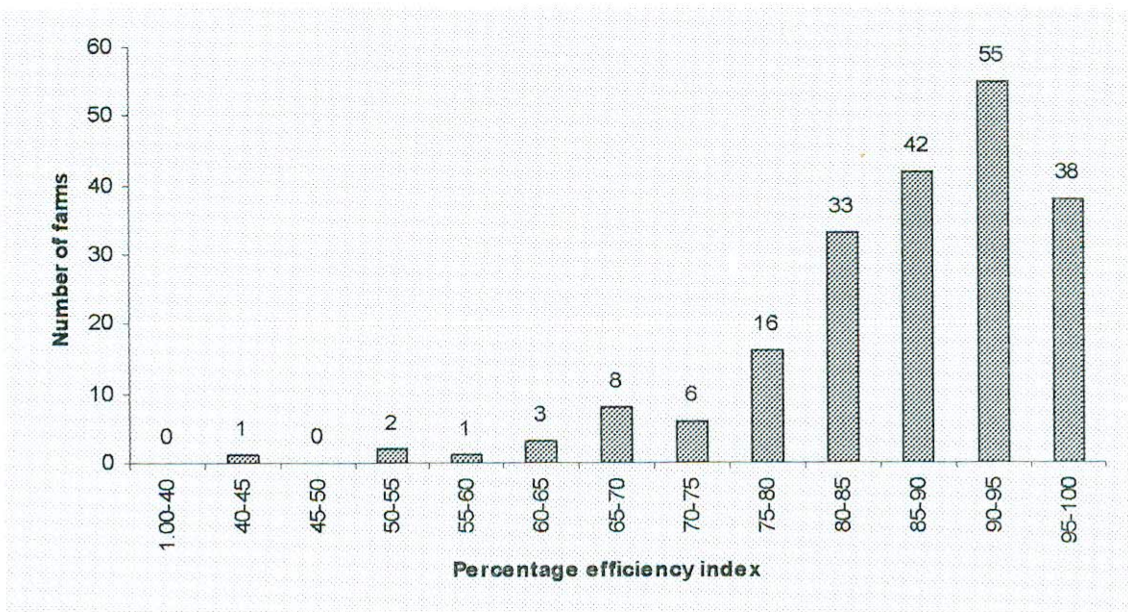


Figure 7.3: Frequency Histogram of Technical Efficiency Index in Boro Season

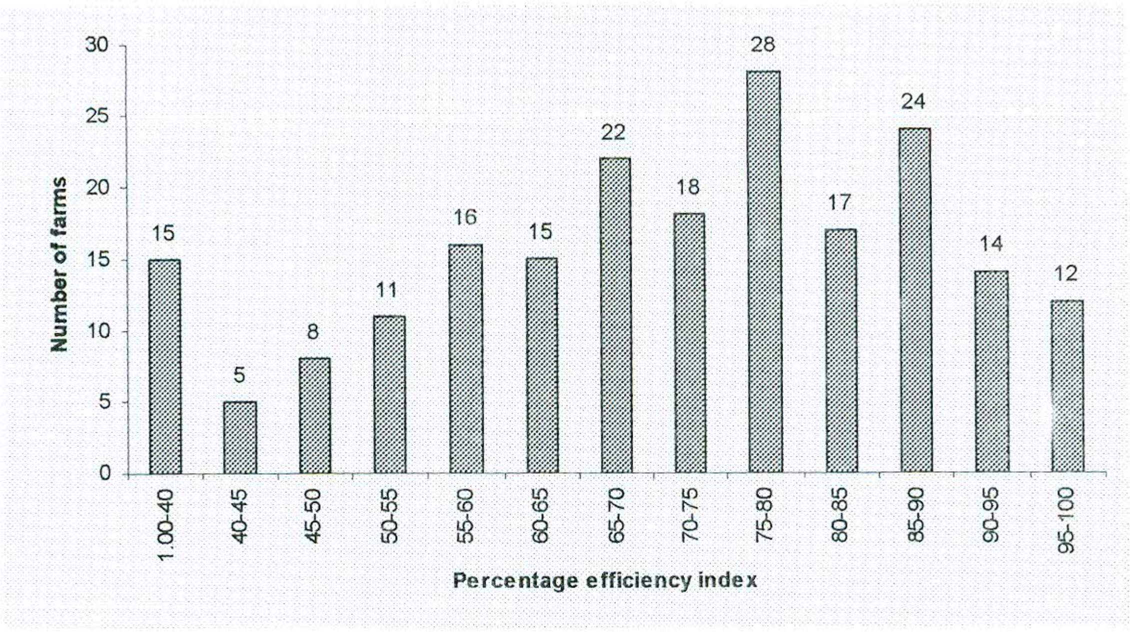


Figure 7.4: Frequency Histogram of Allocative Efficiency Index in Aman Season

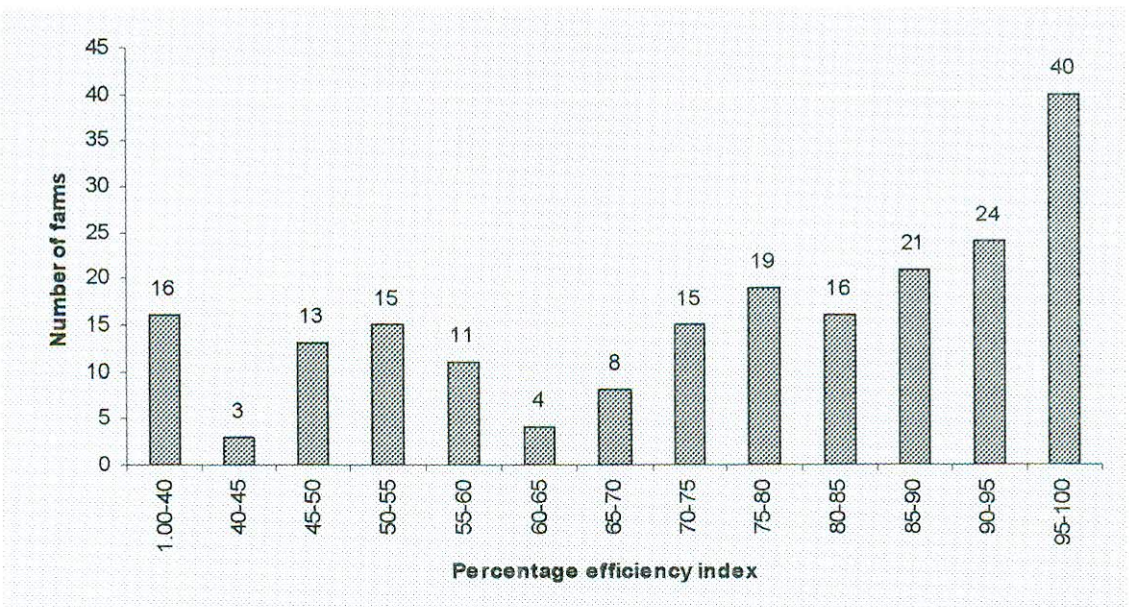


Figure 7.5: Frequency Histogram of Allocative Efficiency Index in Boro Season

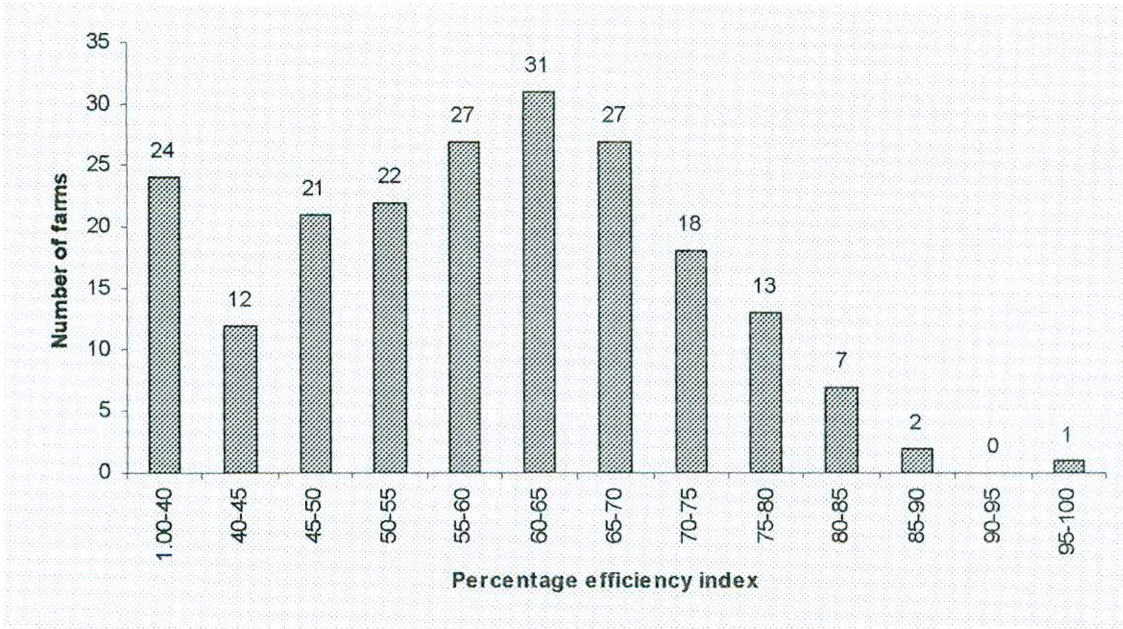


Figure 7.6: Frequency Histogram of Economic Efficiency Index in Aman Season

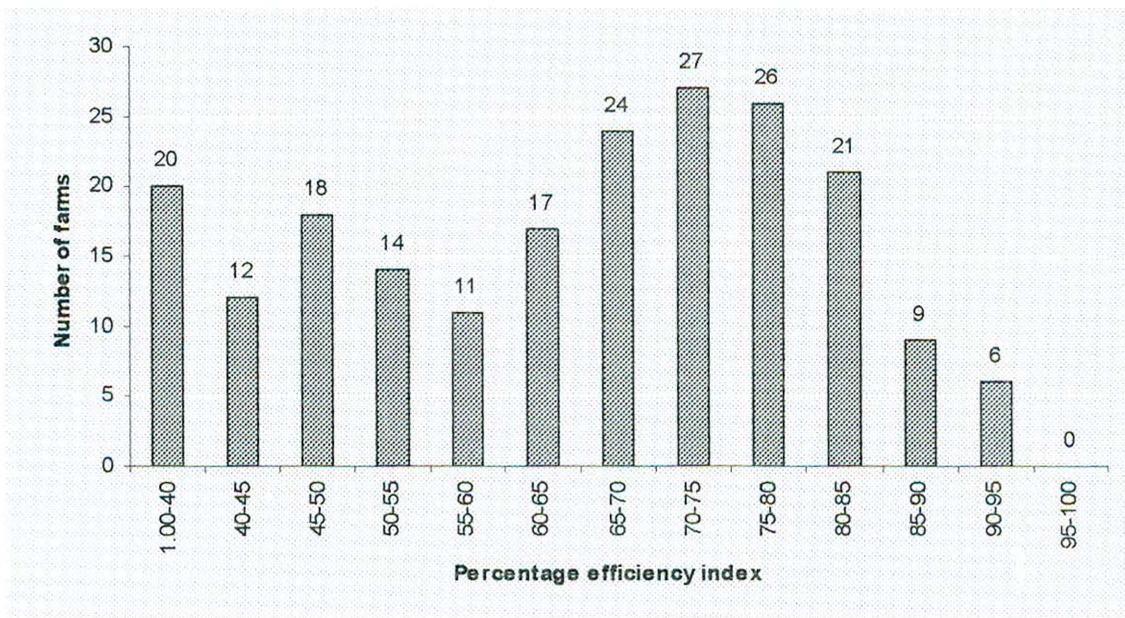


Figure 7.7: Frequency Histogram of Economic Efficiency Index in Boro Season

Highest numbers of technically efficient farms are found in 90-95 per cent efficiency class interval. In case of allocatively efficient farms, different results are found in aman and boro season. Highest numbers of allocatively efficient farms are seen in 75-80 per cent efficiency class interval at aman season and in 70-75 percent efficiency class interval at boro season. On the other hand, maximum economically efficient farms are in 60-65 per cent efficiency class interval at aman season and in 70-75 per cent efficiency class interval at boro season.

7.6 Results of Tobit Regression Model for Inefficiency Effects

We assess the role of human, socio-economic and environmental factors to explain the causes of inefficiency of farmers during aman and boro season. Results of Tobit regression model for factors affecting inefficiency during aman and boro season are presented in Table 7.7.

Table 7.7: Factors Affecting Inefficiency during Aman and Boro Season

Factors						
Aman Season	TI		AI		EI	
	Co-efficients	t-ratios	Co-efficients	t-ratios	Co-efficients	t-ratios
Constant	0.155	6.482	0.178	6.400	0.367	12.073
Yrs. of Schooling	-0.0035	-2.931	0.00118	0.559	0.00338	1.755
Exp. of the Farmers	0.00161	2.043	-0.00124	-1.352	0.00023	0.276
Land Fragmentation	-0.00868	-6.340	-0.01764	-11.081	-0.00908	-6.242
Extension Service Dummy	-0.0737	-0.631	-0.267	-1.962	0.155	1.246
Credit Facilities Dummy	-0.08693	-0.750	0.268	1.990	0.143	1.157
Land Degradation Dummy	-0.03228	-3.906	-0.0314	-1.595	-0.00198	-0.110
Log Likelihood	82.02		104.41		177.20	
Boro Season						
Constant	0.136	9.501	0.08893	2.401	0.212	6.839
Yrs. of Schooling	-0.0011	-1.021	0.00607	2.162	0.00639	2.723
Exp. of the Farmers	0.00176	3.735	-0.00057	-0.443	0.00092	0.897
Land Fragmentation	-0.0108	-13.174	0.01456	0.869	-0.00486	-2.746
Extension Service Dummy	0.0296	0.424	-0.137	-0.757	-0.0877	-0.580
Credit Facilities Dummy	-0.00749	-0.108	0.183	1.018	0.147	0.982
Land Degradation Dummy	-0.0819	-8.081	-0.0133	-0.508	-0.05615	-2.561
Log Likelihood	100.04		111.47		151.60	

The coefficient of year of schooling for TI is negative and significant. This means a positive effect on efficiency. In other words, more educated persons are technically more efficient in both aman and boro seasons. In contrast, less educated persons are allocatively and economically more efficient in both seasons.

The coefficients of length of experience for technical and economic inefficiency are positive, but of allocative inefficiency is negative. This means that relatively new farmers are technically and economically more efficient but experienced farmers can handle inputs more efficiently.

The coefficients of land fragmentation for all efficiencies are negative and significant, except AI in boro season. This indicates that greater land size provides more efficiency for the farmers. Because the farmers can easily apply modern technology in bigger size of lands and also it is more economic. The better performance of farms with larger plot size is attributed to better application of new technologies like power tillers, tractors etc. and better application and management of irrigation (Wadud, 1999). So, the policy implication is that farmers could be encouraged to keep their land with greater plot size and therefore, could utilize the benefits of the modern facilities for cultivation and harvesting, and irrigation facilities.

The coefficients of extension services dummy are negative, but insignificant. This implies that it has a positive effect on efficiency of farmers. As we increase the quality extension services, farmers become able to allocate their inputs more efficiently, and cost of production decreases. In aman season, extension services do not have a great impact on input allocation. But negative coefficients on TI and EI may be explained that there is a good opportunity to reduce the technical and economic inefficiency by giving quality extension services to the farmers. On the other hand, extension services have a positive effect to increase allocative and economic efficiency for boro season. So, policy implication is that the quality extension services could be encouraged more to reduce inefficiency, particularly technical and economic efficiency for aman season and allocative and economic efficiency for boro Season.

The coefficients of credit facilities dummy are negative and but insignificant. This implies that it has a positive effect on efficiency of farmers. Therefore, if we provide more credits in easiest way to the poor and marginal farmers, they become more efficient in production process. Credit facilities do have great impact for reducing technical inefficiency in aman season. But it is a useful component to improve the technical, allocative and economic efficiency in boro season. So, policies in relation to credit facilities should be improved and possibly make available to the farmers of all sectors.

The coefficients of environmental factors dummy i.e., soil degradation dummy are negative in all cases, but significant in TI in aman and boro and EI in boro seasons, as is expected. 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 soil fertility. So, less soil degradation will increase farm efficiency. Land degradation not only creates obstacles in applying new technology but also hinders the cost minimizing input utilization in rice production in Barind area in 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 farmer could be increased.

7.7 Conclusion

In this chapter we have estimated technical, allocative and economic efficiencies following a stochastic cost decomposition technique specifying a self-dual Cobb-Douglas stochastic frontier production model. The model is estimated by the maximum likelihood method. The estimated parameters of the model are all positive, as expected.

In both aman and boro seasons we have almost similar stochastic frontier and DEA results, but the efficiency score in boro season is slightly high. It can be explained that the farmers are more serious about the boro cultivation. They invest more in boro season. They also use more fertilizer and pesticide in boro season than in aman season. As a result, productivity and efficiency in boro season is higher than in aman season. Sixteen per cent technical efficiency, 29 per cent allocative efficiency and 42 per cent economic efficiency could be improved in aman season without changing or improving cultivation technologies if farmers operate at full efficiency scale. Similarly, 14 per cent technical efficiency, 25 per cent allocative efficiency and 36 per cent economic efficiency could be improved in boro season without changing or improving cultivation technologies if farmers operate at full efficiency scale. So, it is clear that there are rooms to enhance the productivity of rice cultivation as far as efficiency is concerned. Therefore, policy makes could give more attention for improving production of farmer by increasing their efficiency levels.

The inefficiency effects are assessed by using Tobit regression analysis. The results of human, socio-economic and environmental factors are reported. More educated farmers are more technically efficient. On the other hand, more experienced farmers are capable of managing inputs efficiently. Less fragmented land gives more opportunity to use modern technology. Better and appropriate land tenure policy will be helpful for the farmers to improve efficiency. Finally, land degradation hampers the efficiency of the farmers. So, policy makers could think to improve the environment of the soil as well as working condition of the area.

Chapter 8

The Data Envelopment Analysis

CHAPTER 8 THE DATA ENVELOPMENT ANALYSIS

8.1 Introduction

Frontiers can be estimated using many different methods. Two principal methods are data envelopment analysis (DEA) and stochastic frontiers (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 disadvantaged 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 use the optimization method of mathematical programming to generalize the Farrell (1957) single-output/input technical efficiency measure to the multiple-output /multiple-input case by constructing a single "virtual" output to a single "virtual" input relative efficiency measure. Thus, DEA begins as a new Management Science Tool for technical efficiency analyses of public-sector decision-making units (DMUs).

8.2 Data Envelopment Analysis: The Concept

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). 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 DMU. In contrast, DEA optimizes the performance of each DMU. 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 averages and estimation of parameters that are associated with single-optimization statistical approaches.

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 variable(s).

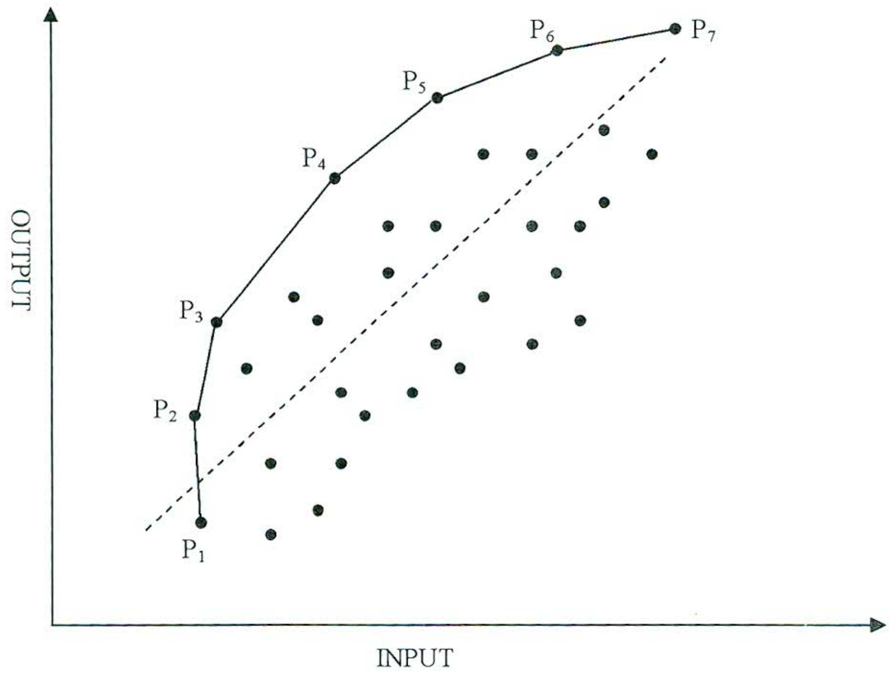


Figure: 8.1: Comparison of DEA and regression

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 maximal performance for each DMU relative to all other DMUs in the observed population with the sole requirement that each DMU lie on or below the frontier.

The solid line in Figure 8.1 represents a frontier derived by DEA from data on a population of DMUs, each utilizing different amounts of a single input to produce various amounts of a single output. It is important to note that DEA calculations, because they are generated from actual observed data for each DMU, produce only relative efficiency measures. The relative efficiency of each DMU is calculated in relation to all other DMUs, using the actual observed values for the outputs and inputs of each DMU. DEA produces a piecewise empirical extremal production surface (e.g., the solid line in Figure 8.1), which in economic terms represents the revealed best practice production frontier – the maximum output empirically obtainable from any DMU in the observed population, given its level of inputs.

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

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

8.3 Efficiency Measurement Using Data Envelopment Analysis

Data Envelopment Analysis (Charnes *et al.*, 1978; Färe *et al.*, 1985, 1994) is used to derive technical, scale, allocative and economic efficiency measures. DEA approach to frontier estimation has been developed almost independently of the stochastic frontier literature in the late 1970s. Only a small percentage of agricultural frontier applications have used the 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 the advantage of removing the necessity to make arbitrary assumptions regarding the functional form of the frontier and the distributional form of the u_i.

8.3.1 Input-Oriented DEA Model

Charnes, Cooper and Rhodes (1978) propose a model, which has input orientation and assumes constant returns to scale (CRS). Later on, Banker, Charnes, and Cooper (1984) have considered alternative sets of assumptions, and proposed a variable returns to scale (VRS) DEA model.

8.3.1.1 The Constant Returns to Scale (CRS) Model

Data envelopment analysis involves the use of linear programming methods to construct a non-parametric piece-wise frontier or surface over data. A comprehensive reviews of the methodology is provided by Seiford and Thrall (1990), Lovell (1993), Ali and Seiford (1993), Lovell (1995), Charnes *et. al.*, (1995) and Seiford (1996).

The piece-wise-linear convex hull (Figure 8.2) approach to frontier estimation, propose by Farrell (1957), is considered by only a few authors in the last decade following Farrell's paper. Boles (1966) and Afriat (1972) suggest mathematical programming methods which achieve the task, but the method does not receive wide attention until the paper of Charnes *et. al.*, (1978), in which the term *data envelopment analysis* is first used. Since then there have been a number of papers which have extended and applied the DEA methodology.

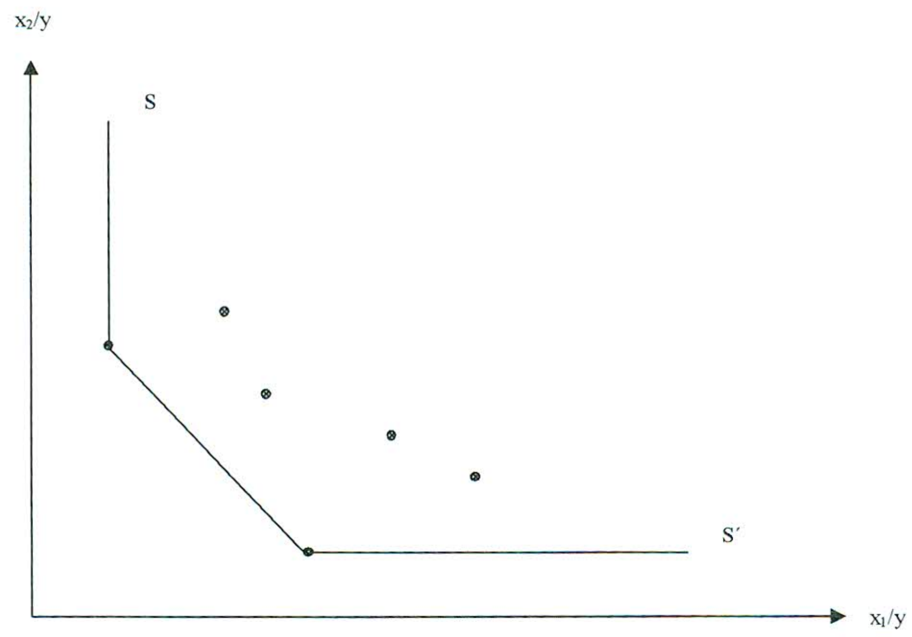


Figure 8.2: Piece-wise Linear Convex Unit Iso-quant

It is best to begin by defining some notation. Assume there are data on K inputs and M outputs on each of N farms. For the *i-th* farm these are represented by the vectors x_i and y_i, respectively. The $K \times N$ input matrix, X, and the $M \times N$ output matrix, Y, represent data of all N farms. The purpose of DEA is to construct a non-parametric envelopment frontier over data points such that all observed points lie on or below the production frontier.

The best way to introduce DEA is via the ratio form. For each farm we would like 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. To select optimal weights (for the *i-th* farm) we specify the mathematical programming problem:

$$\max_{u,v}(u'y_i / v'x_i) \tag{8.1}$$

subject to,

$$u'y_j / v'x_j \leq 1, \; j = 1,2,\ldots,N$$

$$u, v \geq 0$$

This involves finding values for u and v, such that the 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:

$$\max_{\mu,v}(\mu'y_i) \tag{8.2}$$

subject to,

$$v'x_i = 1,$$

$$\mu' y_j - v' x_j \leq 1, \; j = 1,2,\ldots,N$$

$$\mu, v \geq 0$$

where the notation changes from u and v to μ and ν respectively to reflect the transformation. This form is known as the multiplier form of the linear programming problem.

The technical efficiency (TE) measure under constant returns to scale (CRS) is obtained by solving the following DEA model:

$$\begin{aligned} & \min_{\theta,\lambda} \theta_i^{CRS} \\ \text{subject to,} \quad & -y_i + Y\lambda \geq 0 \\ & \theta x_i - X\lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \tag{8.3}$$

where θ is a scalar and λ is a $N \times 1$ vector of constants. This envelopment form involves fewer constraints than the multiplier form, and hence is generally the preferred form to solve. The value of θ obtained will be the efficiency score for the *i-th* farm. It will satisfy $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient farm, according to the Farrell (1957). The linear programming problem must be solved N times, one for each farm in the sample. A value of θ is then obtained for each farm.

In order to derive a measure of economic efficiency (EE) index, we can solve the following DEA model (Färe et. al., 1985, 1994)

$$\begin{aligned} & \min_{xi^*\lambda} p_i' X_i^* \\ \text{subject to} \quad & -y_i + Y\lambda \geq 0 \\ & X_i^* \geq X\lambda \\ & \lambda \geq 0 \end{aligned} \tag{8.4}$$

where X_i^* is the cost-minimizing or economically efficient input vector for the *i-th* farm, given its input price vector, p_i, and the output level, Y_i. The overall economic efficiency (EE) index for the *i-th* farm is then computed as

$$EE_i = p_i'X_i^* / p_i'X_i \quad (8.5)$$

which is the ratio of minimum cost to the observed cost.

The allocative efficiency (AE) index, derived from equations (8.3) and (8.5), is given by

$$\begin{aligned} AE_i &= (EE_i)/(\theta_i^{CRS}) \\ &= (p_i'X_i^*)/\, p_i'(\theta_i^{CRS} X_i) \end{aligned} \quad (8.6)$$

where, $0 \leq AE \leq 1, \quad 0 \leq EE \leq 1$

8.3.1.2 The Variable Returns to Scale (VRS) Model

The CRS assumption is only appropriate when all farms are operating at an optimal scale. Imperfect competition, constraints on finance, etc., may cause a farm to be not operating at optimal scale. Given that many farms are not perfectly competitive, the CRS assumption is often not appropriate, Banker, Charnes and Cooper (1984) suggest an extension of the CRS DEA model to account for variable returns to scale (VRS) situations. The CRS linear programming problem can be easily modified to account for VRS by adding the convexity constraint: $NI'\lambda = 1$ to equation (8.3) as:

$$\min_{\theta,\lambda} \theta_i^{VRS} \quad (8.7)$$

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

where NI is an $N \times I$ vector of ones. This approach forms a convex hull of intersecting planes which envelope data points more tightly than the CRS conical hull and thus provides technical efficiency scores, which are less than, or equal to those obtained using the CRS model. The VRS specification has been the most commonly used specification over the years.

The convexity constraint ($NI'\lambda = 1$), essentially ensures that an inefficient farm is only "benchmarked" against farms of a similar size. That is, the projected point (for that farm) on the DEA frontier will be a convex combination of observed farms. This convexity restriction is not imposed in the CRS case. Hence, in the CRS DEA, a farm may be benchmarked against farms which are substantially larger (smaller) than it. In this instance, the λ-weights will sum to a value greater (smaller) than (less than) one.

8.3.1.3 Calculation of Scale Efficiencies

Given that the technology of VRS, then one may obtain a scale efficiency measure for each farm. This is done by conducting both a CRS and a VRS DEA. One then decomposes TI scores obtained from the CRS DEA into two components, one due to scale inefficiency and one due to "pure" technical inefficiency. If there is a difference in CRS and VRS technical efficiency scores for a particular farm, then this indicates that the farm has scale inefficiency, and that scale inefficiency can be calculated from the difference between VRS and CRS technical efficiency scores.

In Figure 8.3, scale inefficiency is illustrated by using a one-input and one-output example. The CRS and VRS DEA frontiers are indicated in Figure 8.3.

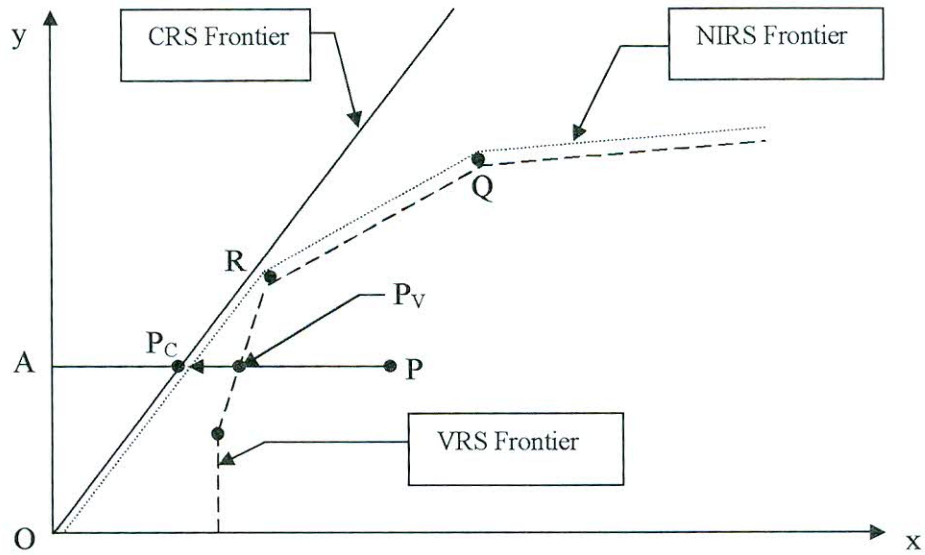


Figure 8.3: Calculation of Scale Economies in DEA

Under CRS, the input-oriented technical inefficiency of the point P is the distance PP_C. However, under VRS, the technical inefficiency would be PP_V. The difference between this two TE measures, P_CP_V, is due to scale inefficiency. These concepts can be expressed in ratio form as:

$$TE_{CRS} = AP_C / AP$$

$$TE_{VRS} = AP_V / AP$$

$$SE = AP_C / AP_V$$

where all of these measures are bounded between zero and one.

And also we have

$$TE_{CRS} = TE_{VRS} / SE$$

because, $AP_C / AP = (AP_V / AP) \times (AP_C / AP_V)$

Thus, the CRS technical efficiency measure is decomposed into "pure" technical efficiency and scale efficiency. This scale efficiency measure can be roughly interpreted as the ratio of the average product of a farm operating at the point P_V to the average product of the farm operating at a point of (technically) optimal scale (point R).

One shortcoming of this measure of scale efficiency is that the value does not indicate whether the farm is operating in the area of increasing or decreasing returns to scale. This latter issue can be solved by adding an additional DEA problem with non-increasing returns to scale (*NIRS*) imposed. This is done by altering the DEA model in equation 8.7 by substituting $NI'\lambda = 1$ restriction by $NI'\lambda \leq 1$, to provide:

$$\min_{\theta,\lambda} \theta_i^{VRS} \tag{8.8}$$

subject to,

$$-y_i + Y\lambda \geq 0,$$

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

$$NI'\lambda \leq 1, \ \lambda \geq 0,$$

The NIRS DEA frontier is also plotted in Figure 8.3. The nature of the scale inefficiencies (i.e., due to increasing or decreasing returns to scale) for a particular farm can be determined by seeing whether NIRS TE score is equal to the VRS TE score. If they are unequal (as in the case for the point P in Figure 8.3), then the increasing returns to scale exists for the farm. If they are equal (as in the case for the point Q in Figure 8.3) then decreasing returns to scale apply. Färe, Grosskopf, and Logan (1985) applied this approach to evaluate the performance of international airlines and electricity.

8.3.2 Output-Oriented Models

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 appeared 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).

8.3.2.1 Output-Oriented CRS Models

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:

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

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

$$\vartheta_m \geq 0 \text{ for } m = 1,2,\ldots,r$$

$$v_k \geq 0\text{, for } k = 1,2,\ldots,q$$

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

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

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

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

In matrix notation,

$$\underset{\theta'\vartheta}{Minimise} \quad \theta' x_i$$

$$\text{subject to} \quad \vartheta y_i = 1$$

$$\theta_i' x_j - \vartheta y_j \geq 0$$

$$\vartheta \geq 0 \text{ and } \theta_i' \geq 0$$

The corresponding dual function may be written as follows:

$$\underset{\varphi_i^{O,CRS},\omega}{Maximise} \quad \varphi_i^{O,CRS}$$

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

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

8.3.2.2 Output-Oriented VRS Models

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

$$\max_{\phi,\lambda} \quad \phi_i^{VRS}$$

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

where ϕ is the proportional increase in outputs that could be achieved by the i-th 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.

8.3.3 Efficiency Measurement and Slacks

The piece-wise linear form of the non-parametric frontier in DEA can cause a few difficulties in efficiency measurement. The problem arises because of selections of the piece-wise linear frontier which runs parallel to the axes (Figure 8.4) which do not occur in the most parametric functions.

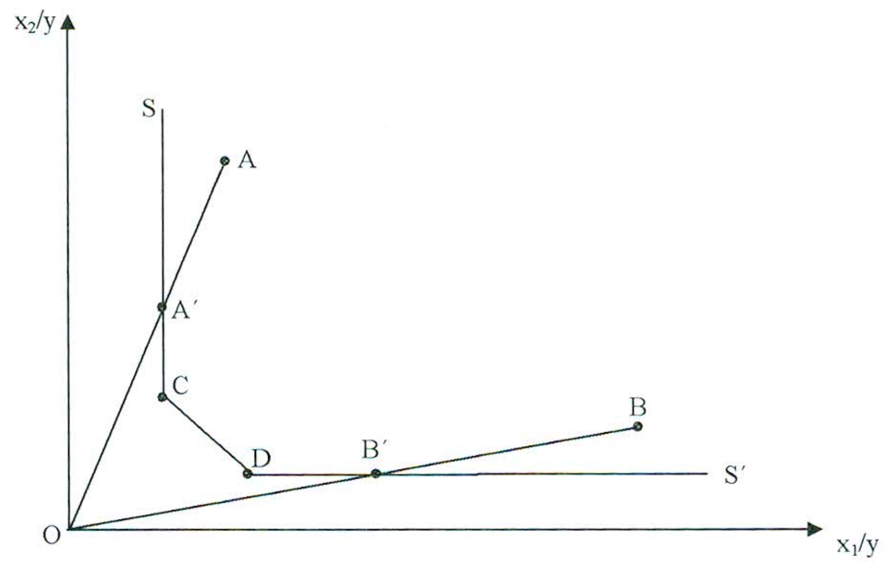


Figure 8.4: Efficiency Measurement and Input Slacks

To illustrate the problem, we refer to Figure 8.4 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 *0A′/0A* and *0B′/0B*, 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 produce 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 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 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 8.5. 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 onto those parts of the curve by a radial expansion in outputs.

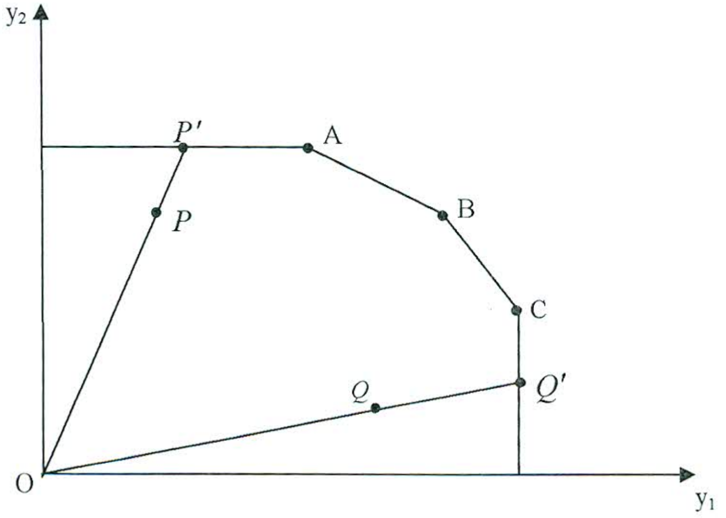


Figure 8.5: Output-Oriented DEA and Output Slacks

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 input use. This is simply known as output slack in DEA model. In the present context, there is output slack in this case 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 DEA model with slacks

$$\underset{\varphi_i^{I,VRS},\omega}{Minimise} \quad \varphi_i^{I,VRS}$$

$$\text{subject to,} \quad y_i + Y\omega - S_o = 0$$

$$\varphi_i^{I,VRS} x_i - X\omega - S_I = 0$$

$$\Omega'\omega = 1$$

$$\omega \geq 0$$

Output-oriented DEA model with slacks

$$\underset{\varphi_i^{O,VRS},\omega}{Minimise} \quad \varphi_i^{O,VRS}$$

$$\text{subject to,} \quad \varphi_i^{O,VRS} y_i + Y\omega - S_o = 0$$

$$x_i - X\omega - S_o = 0$$

$$\Omega'\omega = 1$$

$$\omega \geq 0$$

where S_I and S_o are $(k \times 1)$ and $(m \times 1)$ vectors of input and output slacks respectively.

8.3.4 Estimating the Determinants of Inefficiency

Nonparametric linear programming 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 and w_i is a $(k \times 1)$ vector of residuals that are independently and normally distributed with mean zero.

Tobit (1958) developed the regression model which can be specified as follows:

$IE_i = \delta' z_i + w_i$ if $(\delta' z_i + w_i) > 0$, i.e., inefficiency is not zero and

$IE_i = 0$ otherwise, i.e., inefficiency is zero.

We use Tobit inefficiency regression model because the estimation of δ and σ_w^2 using OLS produces biased and inconsistent estimates.

8.4 Conclusion

Data Envelopment Analysis and Stochastic Frontier Analysis are major methods of estimating production efficiency. DEA is first introduced in 1978 by Charnes, Cooper and Rhodes. They actually extend Farrell's idea of estimation of technical efficiency and production frontiers.

DEA involves two types of orientation - input-oriented method and output-oriented method. Both input-oriented and output-oriented DEA have two types: Constant Returns to Scale DEA and Variable Returns to Scale DEA. The CRS assumption is only appropriate when all farms are operating at an optimal scale. There are some 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.

In the input-oriented models, generally, we estimate technical inefficiency as a proportional reduction in input usage, given that output level is constant. This corresponds to Farrell's input-based measures of technical inefficiency. But in the output-oriented case, we measure technical inefficiency as a proportional increase in output, with input levels held constant. It is important to know that which orientation (input-orientation or output-orientation) should be selected depends on to which quantities managers 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

DEA Results and Comparison with SFA Results

CHAPTER 9	DEA RESULTS AND COMPARISON WITH SFA RESULTS

9.1 Introduction

In chapter 8, we have done a detailed theoretical discussion about DEA model. On the basis of the theoretical model we have got some empirical results using data obtained from the field level survey. In the middle section of this chapter, we have done some analysis, comments and implications of the results obtained from the empirical model. In chapter 7, we have obtained results of stochastic frontier model and in this chapter we have shown data envelopment analysis results.

We have given some comparison between results of DEA and SF models in this chapter also. From both models we have got some mixed results. But it is interesting to see what kind of different results have been found as far as technical, allocative and economic efficiency are concerned.

9.2 Input- and Output Oriented DEA Frontier Results

The DEA models are estimated for the same number of farmers, output and input variables as SF models. We have got DEA results by using the program DEAP, version 2.1 (Coelli, 1996). Constant returns to scale (CRS) and variable returns to scale (VRS) input- and output-oriented DEA frontiers are estimated. Scale efficiency is obtained by the ratio of CRS and VRS DEA efficiency estimates. Input-oriented CRS and VRS DEA results of technical efficiency and scale efficiency for aman and boro seasons are presented in Table 9.1 and Table 9.2 respectively. On the other hand, output-oriented CRS and VRS DEA results of technical efficiency and scale efficiency for aman and boro seasons are given in Table 9.3 and Table 9.4 respectively.

Table 9.1: Frequency Distribution of TE and SE from DEA Frontiers at Aman Season

Efficiency Index (%)	Input Orientation					
	CRS		VRS		SE	
	No. of Farms	% of Farms	No. of Farms	% of Farms	No. of Farms	% of Farms
1-40	4	1.95	2	0.98	1	0.49
40-45	2	0.98	1	0.49	0	0
45-50	8	3.9	3	1.46	1	0.49
50-55	4	1.95	6	2.93	3	1.46
55-60	12	5.85	8	3.9	1	0.49
60-65	13	6.34	6	2.93	0	0
65-70	13	6.34	10	4.88	3	1.46
70-75	32	15.6	21	10.2	7	3.41
75-80	38	18.5	29	14.1	5	2.44
80-85	25	12.2	16	7.8	11	5.37
85-90	11	5.37	17	8.29	24	11.7
90-95	7	3.41	18	8.78	30	14.6
95-100	36	17.6	68	33.2	119	58
Total	205	100	205	100	205	100

Table 9.2: Frequency Distribution of TE and SE from DEA Frontiers at Boro Season

Efficiency Index (%)	Input Orientation					
	CRS		VRS		SE	
	No. of Farms	% of Farms	No. of Farms	% of Farms	No. of Farms	% of Farms
1-40	0	0	0	0	0	0
40-45	0	0	0	0	0	0
45-50	0	0	0	0	0	0
50-55	5	2.44	3	1.46	0	0
55-60	11	5.37	8	3.9	1	0.49
60-65	36	17.6	22	10.7	3	1.46
65-70	40	19.5	31	15.1	6	2.93
70-75	24	11.7	21	10.2	6	2.93
75-80	26	12.7	14	6.83	5	2.44
80-85	15	7.32	24	11.7	9	4.39
85-90	11	5.37	12	5.85	13	6.34
90-95	6	2.93	5	2.44	31	15.1
95-100	31	15.1	65	31.7	131	63.9
Total	205	100	205	100	205	100

Table 9.3: Frequency Distribution of TE and SE from DEA Frontiers at Aman Season

Efficiency Index (%)	Output Orientation					
	CRS		VRS		SE	
	No. of Farms	% of Farms	No. of Farms	% of Farms	No. of Farms	% of Farms
1-40	4	1.95	2	0.98	1	0.49
40-45	2	0.98	1	0.49	0	0
45-50	8	3.9	3	1.46	1	0.49
50-55	4	1.95	6	2.93	3	1.46
55-60	12	5.85	8	3.9	1	0.49
60-65	13	6.34	6	2.93	0	0
65-70	13	6.34	10	4.88	3	1.46
70-75	32	15.6	21	10.2	7	3.41
75-80	38	18.5	29	14.1	5	2.44
80-85	25	12.2	16	7.8	11	5.37
85-90	11	5.37	17	8.29	24	11.7
90-95	7	3.41	18	8.78	30	14.6
95-100	36	17.6	68	33.2	119	58
Total	205	100	205	100	205	100

Table 9.4: Frequency Distribution of TE and SE from DEA Frontiers at Boro Season

Efficiency Index (%)	Output Orientation					
	CRS		VRS		SE	
	No. of Farms	% of Farms	No. of Farms	% of Farms	No. of Farms	% of Farms
1-40	0	0	0	0	0	0
40-45	0	0	0	0	0	0
45-50	0	0	0	0	0	0
50-55	5	2.44	0	0	0	0
55-60	11	5.37	2	0.98	1	0.49
60-65	36	17.6	11	5.37	0	0
65-70	40	19.5	24	11.7	1	0.49
70-75	24	11.7	42	20.5	0	0
75-80	26	12.7	25	12.2	7	3.41
80-85	15	7.32	20	9.76	25	12.2
85-90	11	5.37	22	10.7	34	16.6
90-95	6	2.93	11	5.37	61	29.8
95-100	31	15.1	48	23.4	76	37.1
Total	205	100	205	100	205	100

In our study, the sample size is 205 farms; they produce rice using six inputs- land, labour, irrigation, fertilizer, pesticides and seeds. Table 9.1, 9.2, 9.3 and 9.4 show that input- and output-oriented measures have little differences. In aman season, input- and output-oriented results are exactly same. But in boro season, there are some differences in input- and output-oriented results. Both input- and output-oriented CRS DEA results for aman season show that 39 per cent farms are over 80 per cent technically efficient and VRS DEA shows 58 per cent farms are over 80 per cent technically efficient. Only 7 per cent farms are less than 50 per cent efficient in case of input oriented CRS DEA in aman season and only 3 per cent are less than 50 per cent efficient in case of input oriented VRS DEA in aman season. Input- and output-oriented CRS and VRS DEA model show that there are no farms less than 50 per cent efficient in boro season.

Summary statistics of efficiency estimates from DEA model in aman and boro seasons are presented at Table 9.5 and 9.6. Mean technical efficiency of both input- and output-oriented method for CRS DEA model in aman and boro seasons are 76.7 and 75.2 per cent respectively. On the other hand, mean technical efficiency for VRS DEA model is 83.4 per cent from both orientations in aman season, and 81.2 and 81.9 per cent respectively from input- and output-oriented method in boro season. Overall technical efficiency rating range for aman season from both input- and output oriented methods give same results. Overall technical efficiency rating for CRS DEA method ranges from 37.8 to 100 per cent and for VRS DEA from 38.2 to 100 per cent with standard deviations of 15.4 and 15.5 per cent respectively. In boro season, technical efficiency rating for input- and output oriented CRS models ranges from 50 to 100 per cent with standard deviation of 13.3 per cent. VRS input oriented model shows a range from 52.1 to 100 per cent with same standard deviation and VRS output model shows a range from 55.9 to 100 per cent with standard deviation of 12.3 per cent. Scale efficiency estimates range from 39.6 to 100 per cent in aman season for both input- and output orientations with standard deviation of 10.6. Scale efficiency estimates for VRS input- and output-oriented models in boro season range from 55 to 100 per cent in both cases but with different standard deviations of 9.1 and 6.9 per cent respectively.

Table 9.5: Summary Statistics of Efficiency Estimates from DEA Model at Aman Season

Statistics	Input Orientation			Output Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	**76.7**	**83.4**	**92.5**	**76.7**	**83.4**	**92.5**
Minimum	37.8	38.2	39.6	37.8	38.2	39.6
Maximum	100	100	100	100	100	100
Standard deviation	15.4	15.5	10.6	15.4	15.5	10.6

Table 9.6: Summary Statistics of Efficiency Estimates from DEA Model at Boro Season

Statistics	Input Orientation			Output Orientation		
	CRS	VRS	SE	CRS	VRS	SE
Mean	**75.2**	**81.2**	**93.4**	**75.2**	**81.9**	**91.8**
Minimum	50	52.1	55	50	55.9	55
Maximum	100	100	100	100	100	100
Standard deviation	13.3	15	9.1	13.3	12.3	6.9

Graphical presentation of technical efficiency scores and scale efficiency estimates for CRS and VRS DEA from input- and output orientation in aman and boro seasons are given from Figure 9.1 to Figure 9.9. In aman season, input- and output oriented methods show exactly the same results. So, we are showing input oriented figures only.

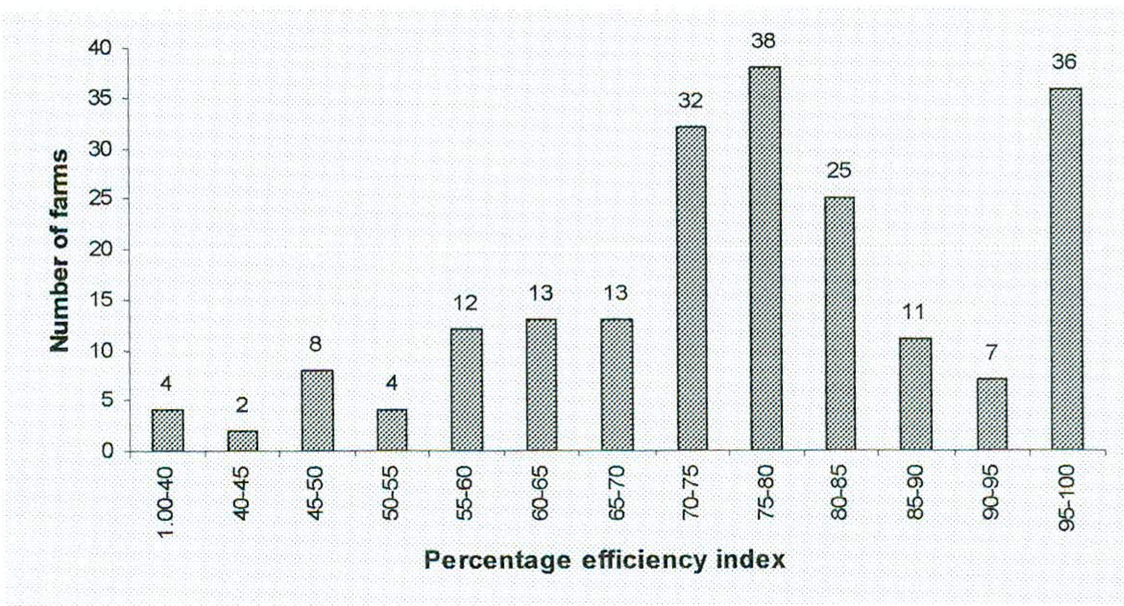


Figure 9.1: TE from Input Oriented CRS DEA Frontier Method for Aman Season

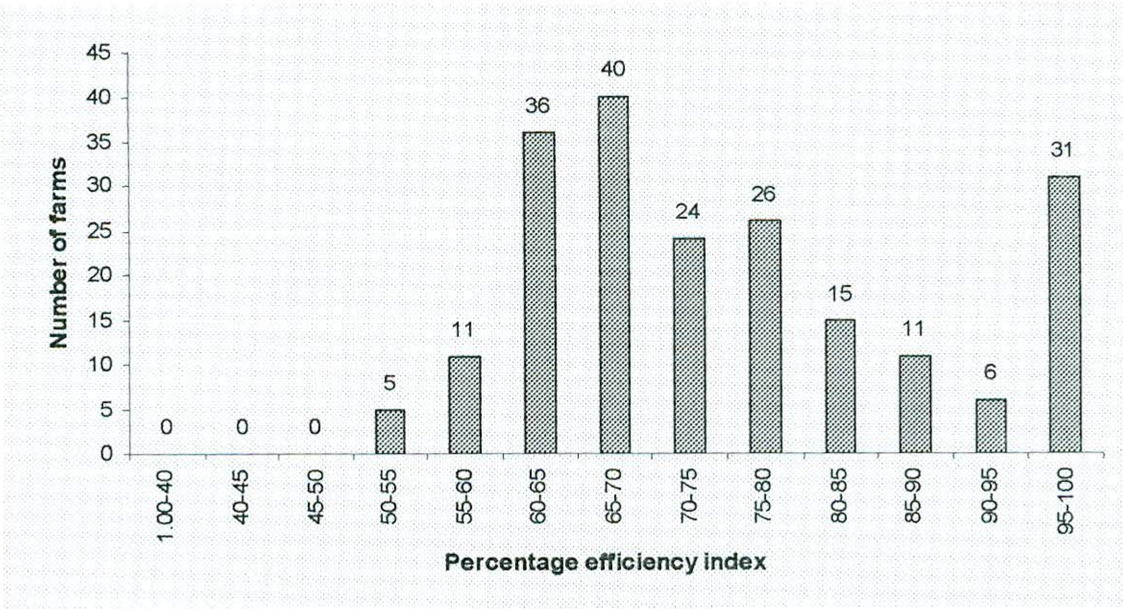


Figure 9.2: TE from Input Orientation CRS DEA Frontier Method for Boro Season

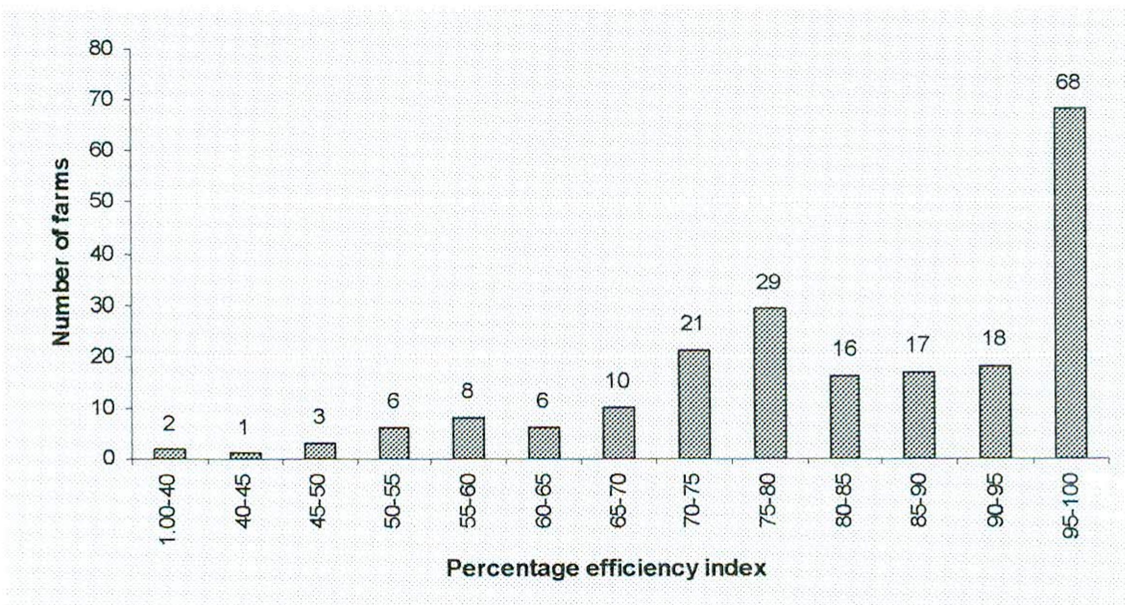


Figure 9.3: TE from Input Oriented VRS DEA Frontier Method for Aman Season

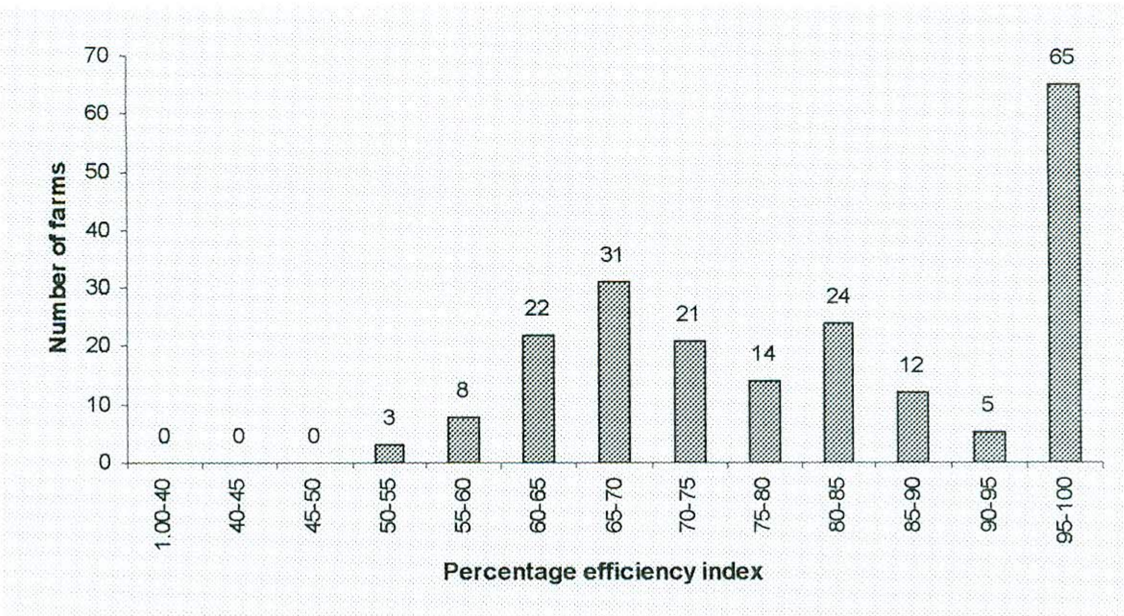


Figure 9.4: TE from Input Oriented VRS DEA Frontier Method for Boro Season

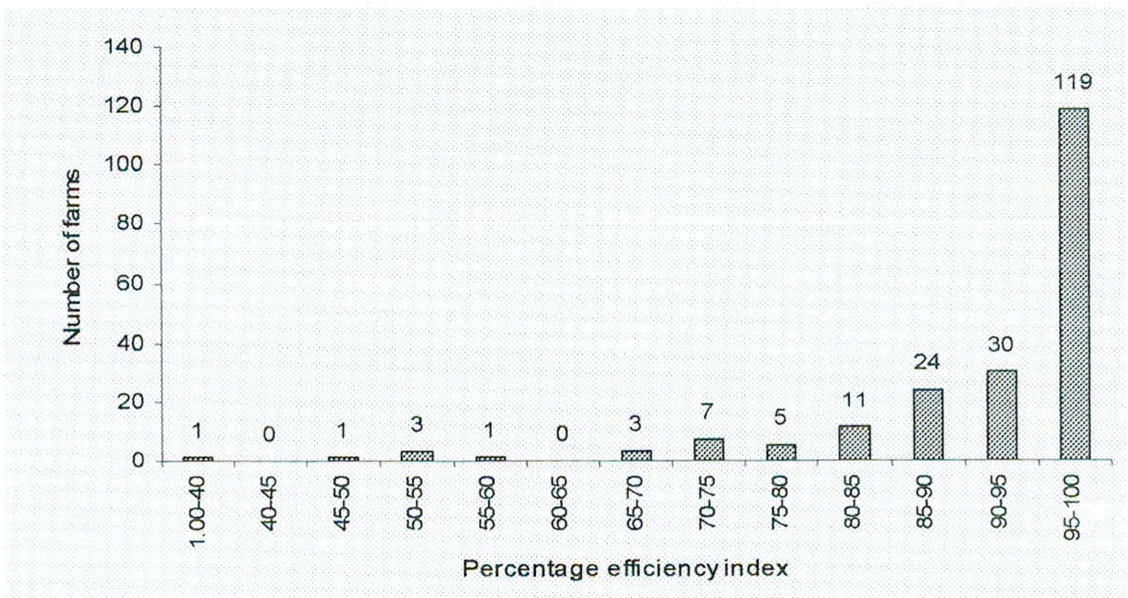


Figure 9.5: SE from Input Oriented DEA Frontier Method at Aman Season

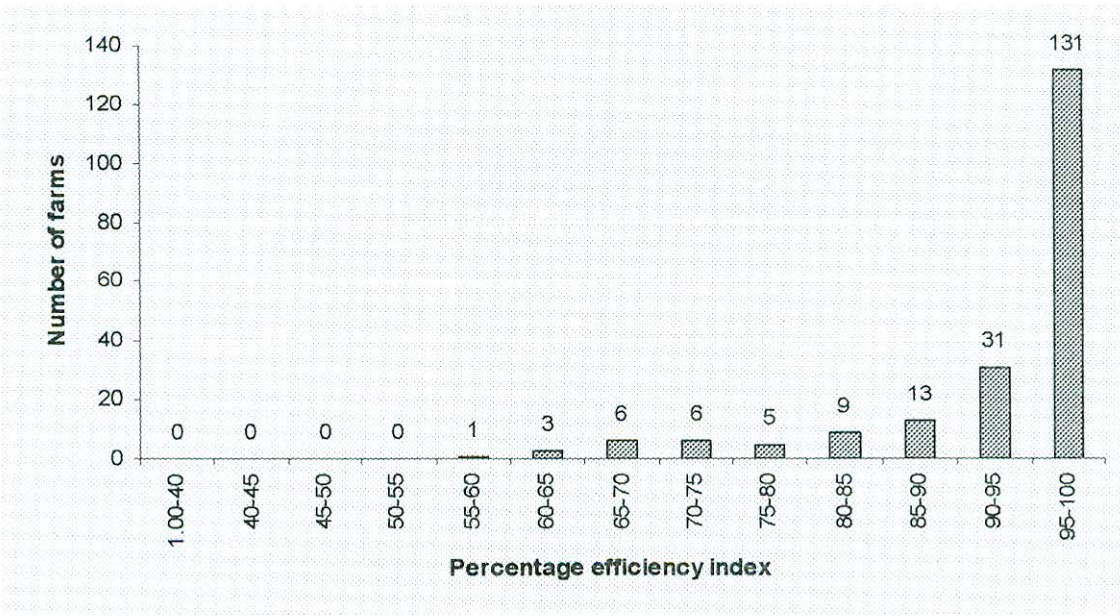


Figure 9.6: SE from Input Oriented DEA Frontier Method at Boro Season

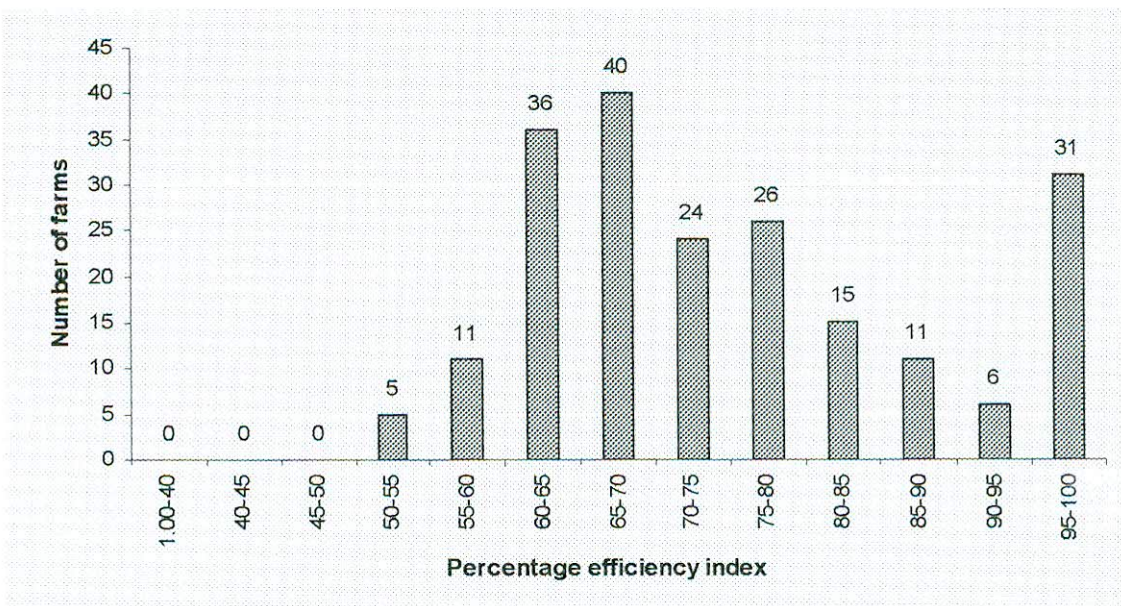


Figure 9.7: TE from Output Oriented CRS DEA Frontier Method for Boro Season

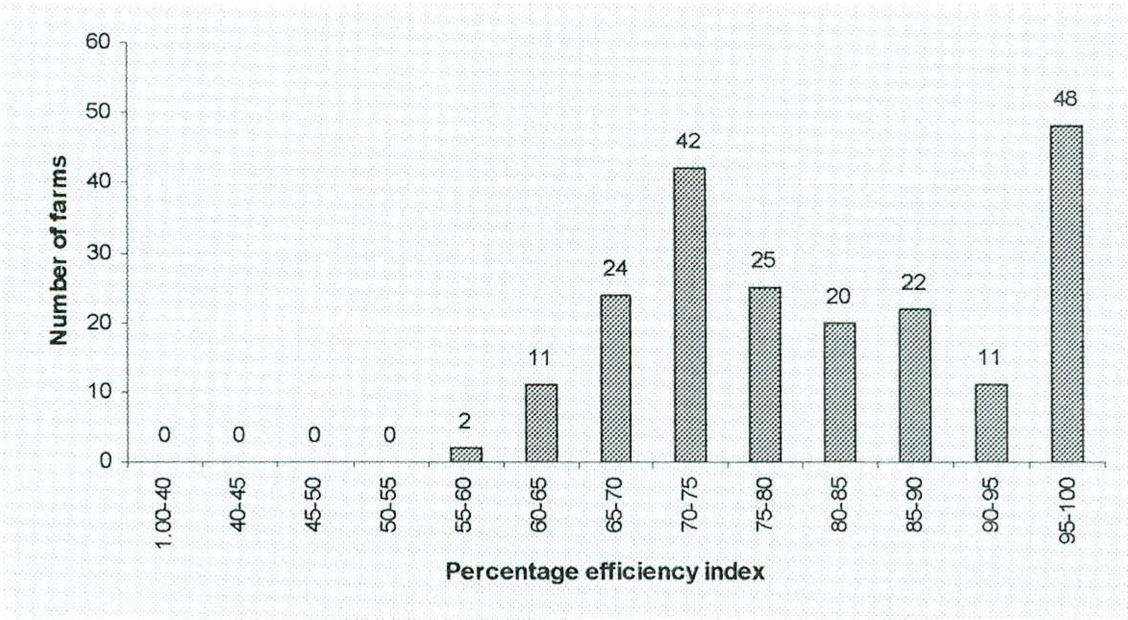


Figure 9.8: TE from Output Oriented VRS DEA Frontier Method for Boro Season

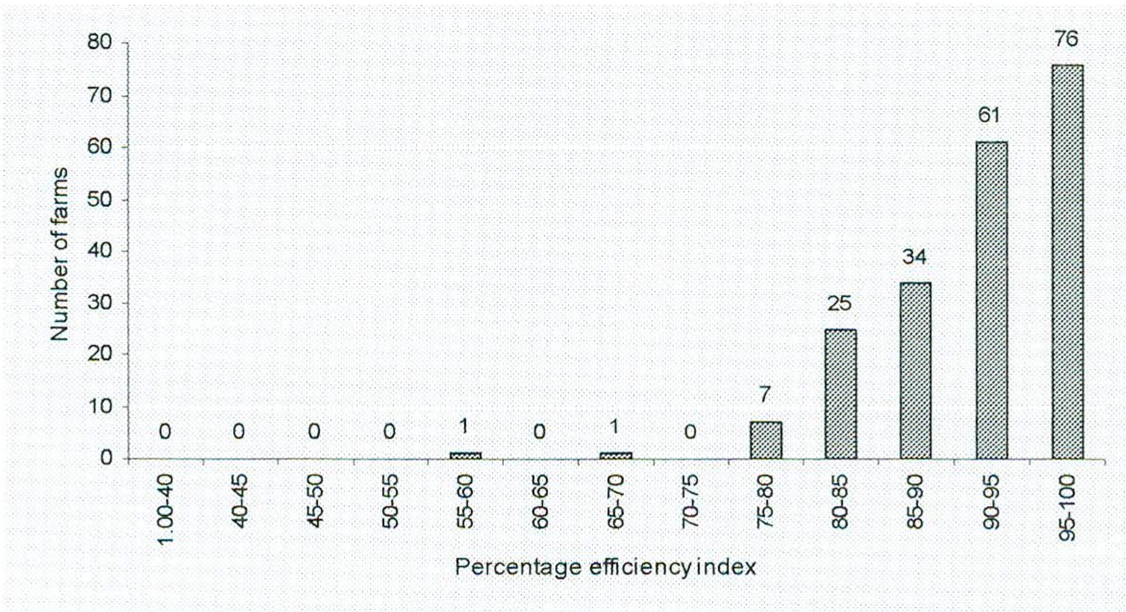


Figure 9.9: SE from Output Oriented DEA Frontier Method for Boro Season

9.3 DEA Results for Estimates of Technical, Allocative and Economic Efficiency

We use input oriented DEA model to estimate technical, allocative and economic efficiency scores. These measures are estimated by using DEAP, version 2.1 (Coelli, 1996). The frequency distribution of TE, AE, and EE measures under CRS and VRS frontier method are reported in Table 9.7 and 9.8 and their summery statistics for aman and boro season are separately presented in Table 9.9 and 9.10.

Table 9.7 Frequency Distribution of Efficiency Estimates from DEA Frontier for Aman Season

Efficiency Index (%)	DEA Frontier					
	Number of Farms					
	CRS			VRS		
	TE	AE	EE	TE	AE	EE
1.00-40	4	0	10	2	0	5
40-45	2	0	2	1	0	1
45-50	8	0	11	3	0	10
50-55	4	2	8	6	2	6
55-60	12	1	15	8	3	9
60-65	13	2	17	6	1	17
65-70	13	8	36	10	5	28
70-75	32	8	40	21	13	31
75-80	38	12	28	29	17	31
80-85	25	22	19	16	16	16
85-90	11	24	12	17	25	14
90-95	7	36	1	18	34	5
95-100	36	90	6	68	89	32
Total	205	205	205	205	205	205

Table 9.8 Frequency Distribution of Efficiency Estimates from DEA Frontier for Boro Season

Efficiency Index (%)	DEA Frontier					
	Number of Farms					
	CRS			VRS		
	TE	AE	EE	TE	AE	EE
1.00-40	0	0	0	0	0	0
40-45	0	0	2	0	0	1
45-50	0	0	4	0	0	4
50-55	5	0	23	3	0	14
55-60	11	2	61	8	2	40
60-65	36	3	40	22	2	27
65-70	40	6	37	31	5	27
70-75	24	25	19	21	14	22
75-80	26	16	8	14	8	19
80-85	15	33	8	24	19	4
85-90	11	64	1	12	61	3
90-95	6	54	1	5	36	1
95-100	31	2	1	65	58	43
Total	205	205	205	205	205	205

Table 9.9 Summary Statistics of Efficiency Estimates from DEA Frontier for Aman Season (in percentage)

Statistics	CRS DEA Frontier			VRS DEA Frontier		
	TE	AE	EE	TE	AE	EE
Mean	**76.7**	**90.1**	**68.8**	**83.4**	**89.5**	**74.5**
Minimum	37.8	50	29.6	38.2	52.3	31
Maximum	100	100	100	100	100	100
Standard deviation	15.42	10.50	14.21	15.49	10.89	16.02

Table 9.10 Summary Statistics of Efficiency Estimates from DEA Frontier for Boro Season (in percentage)

Statistics	CRS DEA Frontier			VRS DEA Frontier		
	TE	AE	EE	TE	AE	EE
Mean	**75.19**	**84.49**	**62.85**	**81.18**	**88.92**	**72.24**
Minimum	50	56.2	42.3	52.1	59.5	44.7
Maximum	100	100	100	100	100	100
Standard deviation	13.31	8.371	8.950	15.05	9.388	16.37

The average estimated technical, allocative and economic efficiencies in aman season are 76, 90 and 69 per cent respectively for CRS DEA frontier and those are 83, 90 and 75 for VRS DEA frontier respectively. Therefore, it is clear from results of DEA frontier analysis that there is a scope for comprehensive improvement in production as far as efficiency is concerned.

On the other hand, the average estimated technical, allocative and economic efficiencies in boro season are 75, 84 and 63 per cent respectively for CRS DEA frontier and those are 81, 89 and 72 per cent for VRS DEA frontier respectively. In both seasons we have got almost similar result, but more opportunity to improve efficiency in boro season than aman season. Therefore, these results clearly indicate that farmers can reduce production cost and hence can get more output gain through improving efficiency without introducing new or more improved technologies in production process.

In terms of scale economies, 81 farms are characterized by increasing returns to scale, 34 farms having constant returns to scale and the rest 90 farms are characterized by decreasing returns to scale in aman season. On the other hand, in contrast, 84 farms are characterized by increasing to scale, 30 farms have constant returns to scale and the rest 91 farms show decreasing returns to scale technology in 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 presentation of TE, AE and EE measures under CRS and VRS frontier technology for aman and boro seasons are given in Figure 9.10 to 9.21.

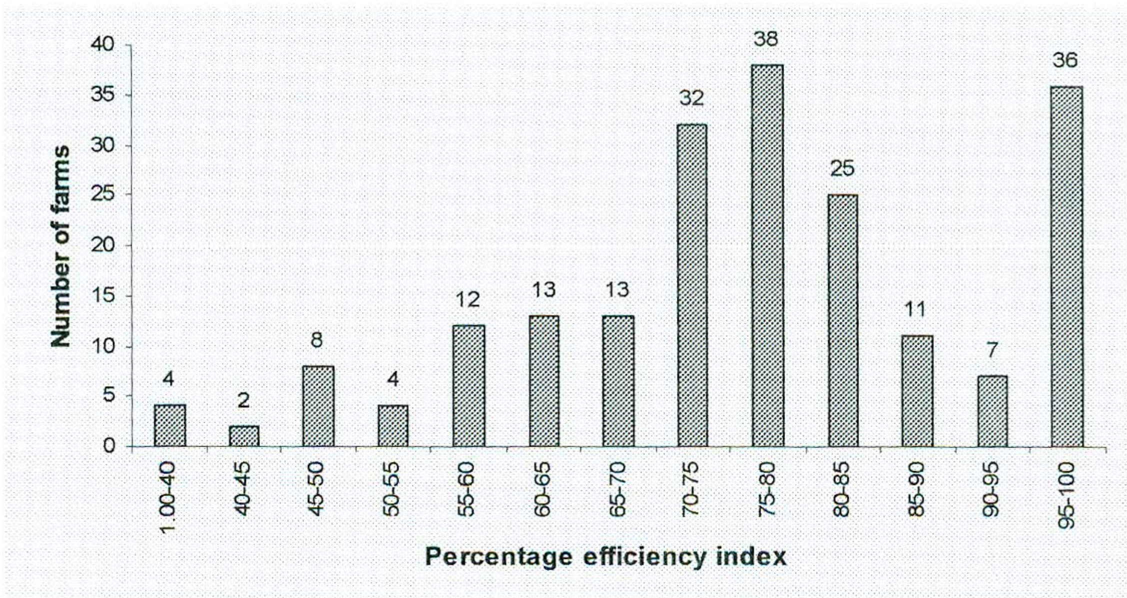


Figure 9.10: TE from CRS DEA Frontier for Aman Season

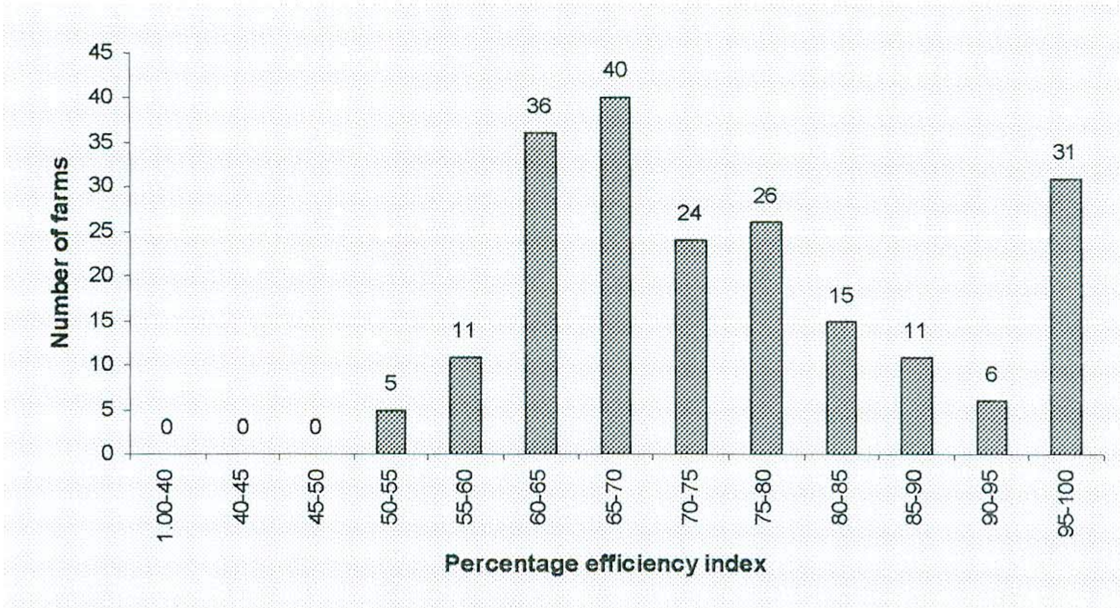


Figure 9.11: TE from CRS DEA Frontier for Boro Season

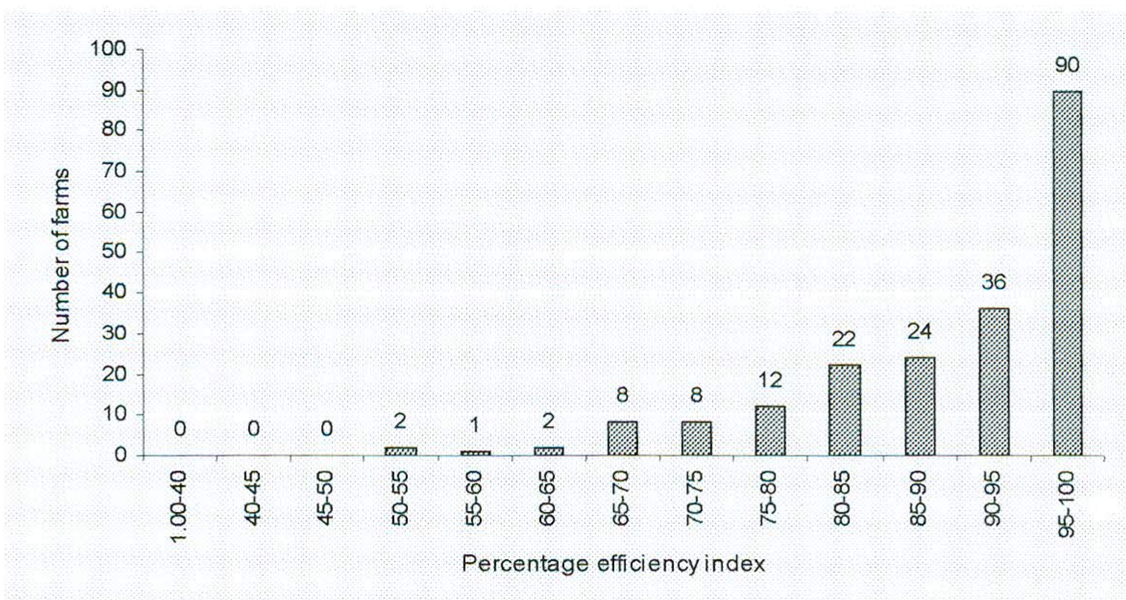


Figure 9.12: AE from CRS DEA Frontier for Aman Season

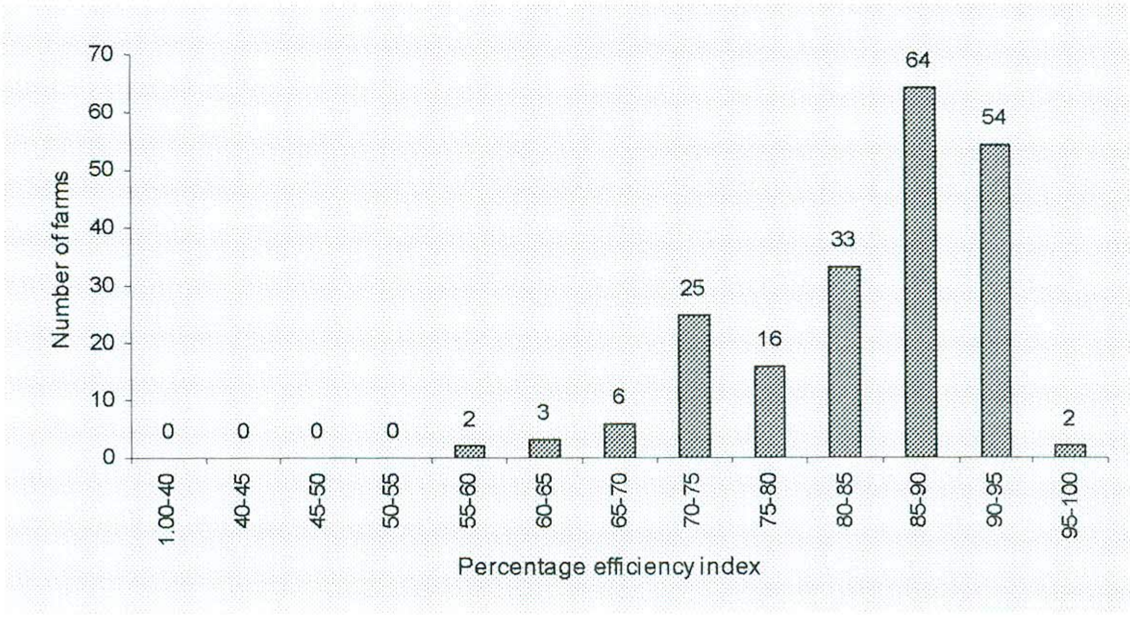


Figure 9.13: AE from CRS DEA Frontier for Boro Season

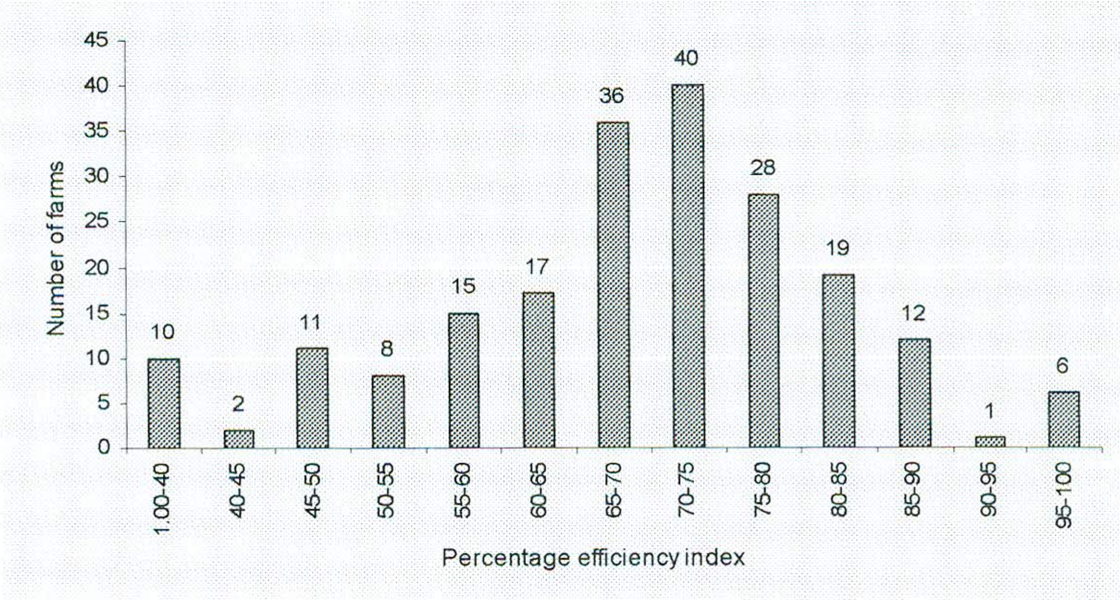


Figure 9.14: EE from CRS DEA Frontier for Aman Season

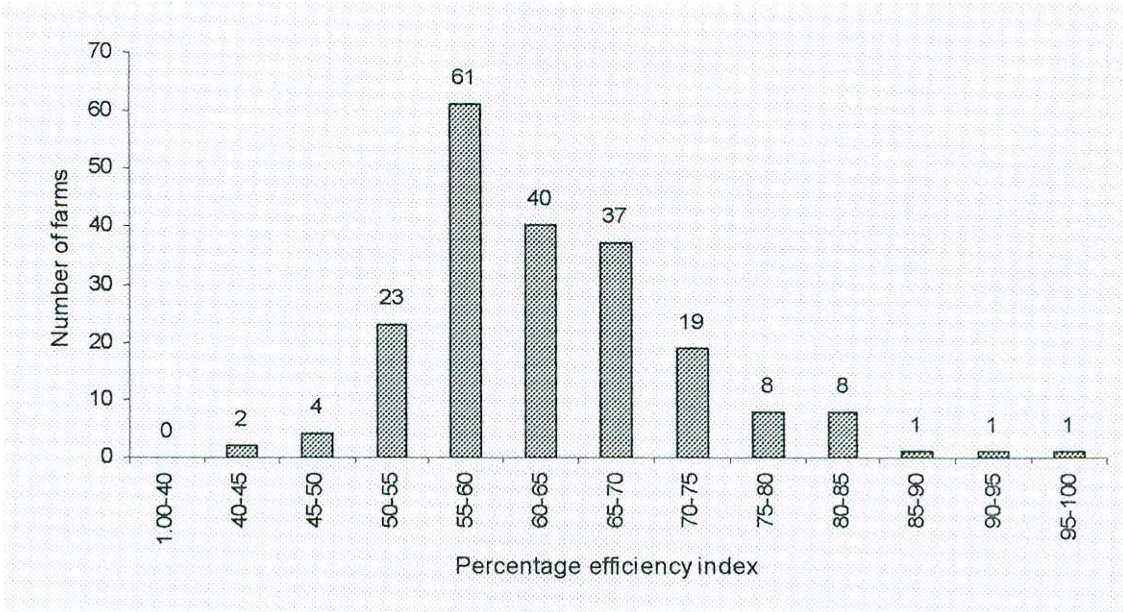


Figure 9.15: EE from CRS DEA Frontier for Boro Season

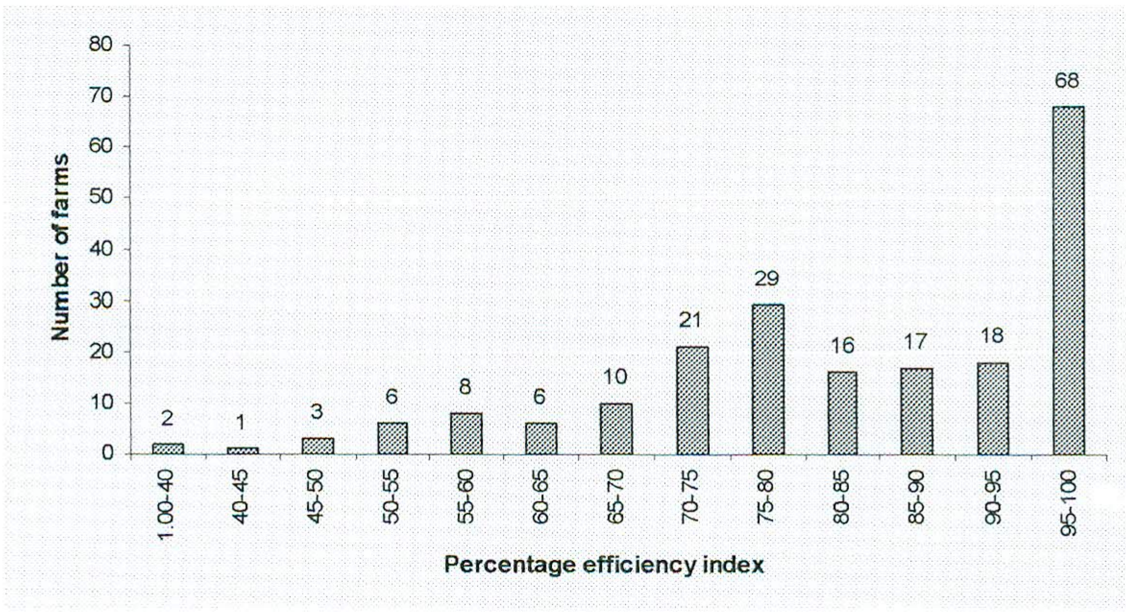


Figure 9.16: TE from VRS DEA Frontier for Aman Season

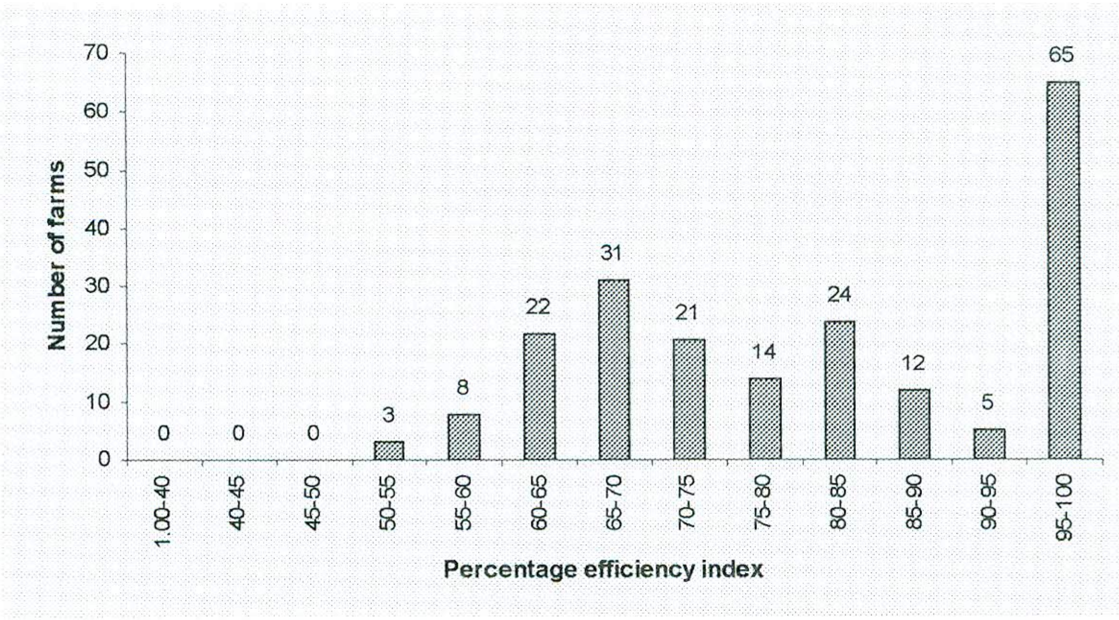


Figure 9.17: TE from VRS DEA Frontier for Boro Season

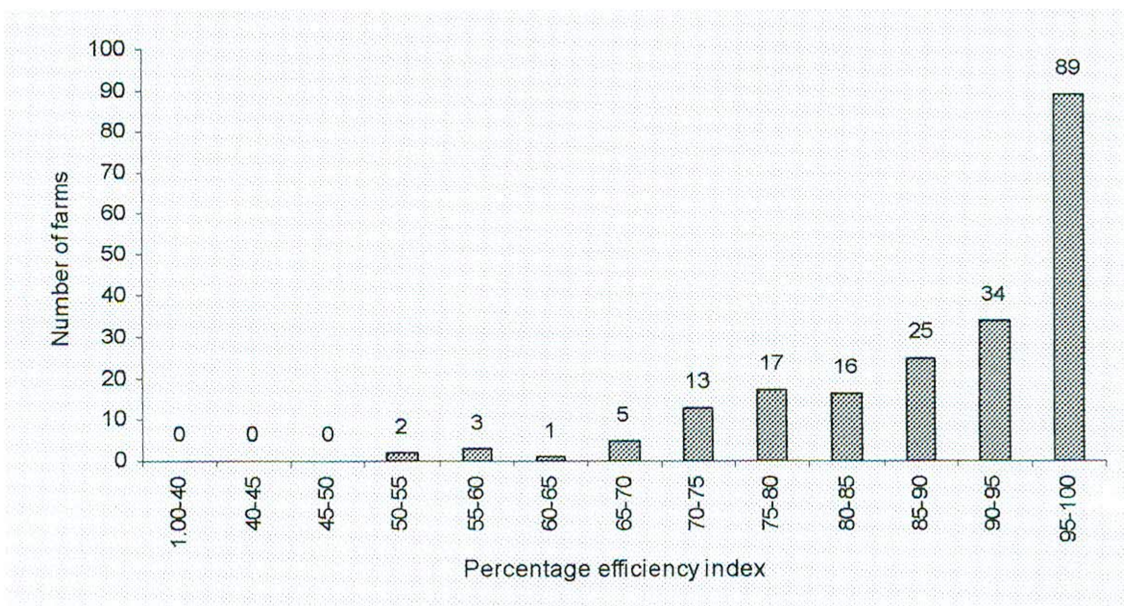


Figure 9.18: AE from VRS DEA Frontier for Aman Season

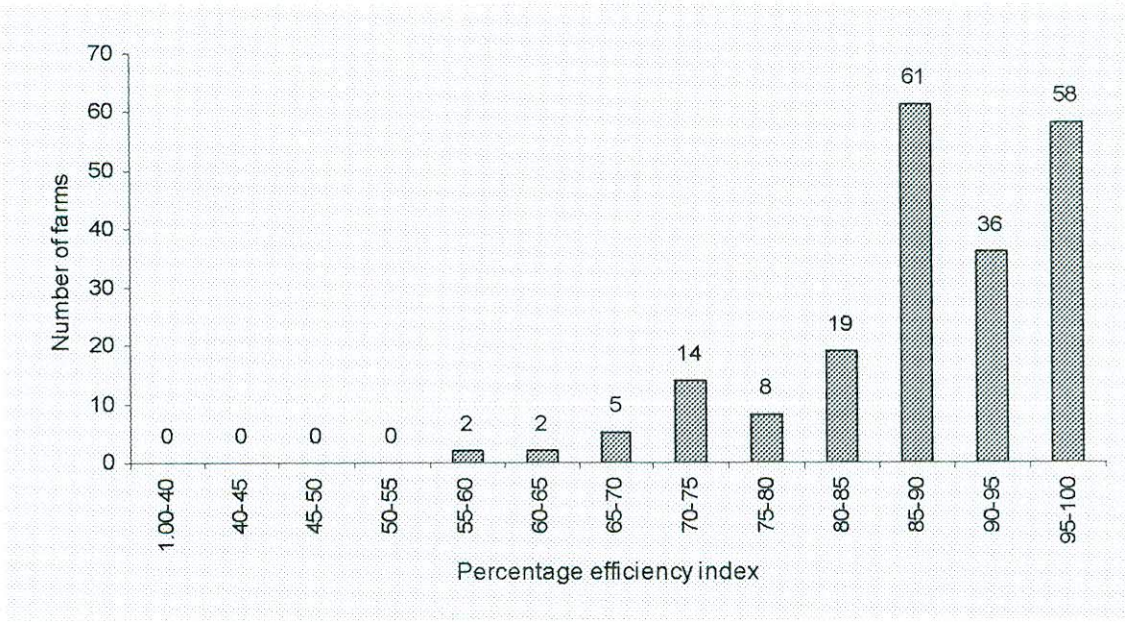


Figure 9.19: AE from VRS DEA Frontier for Boro Season

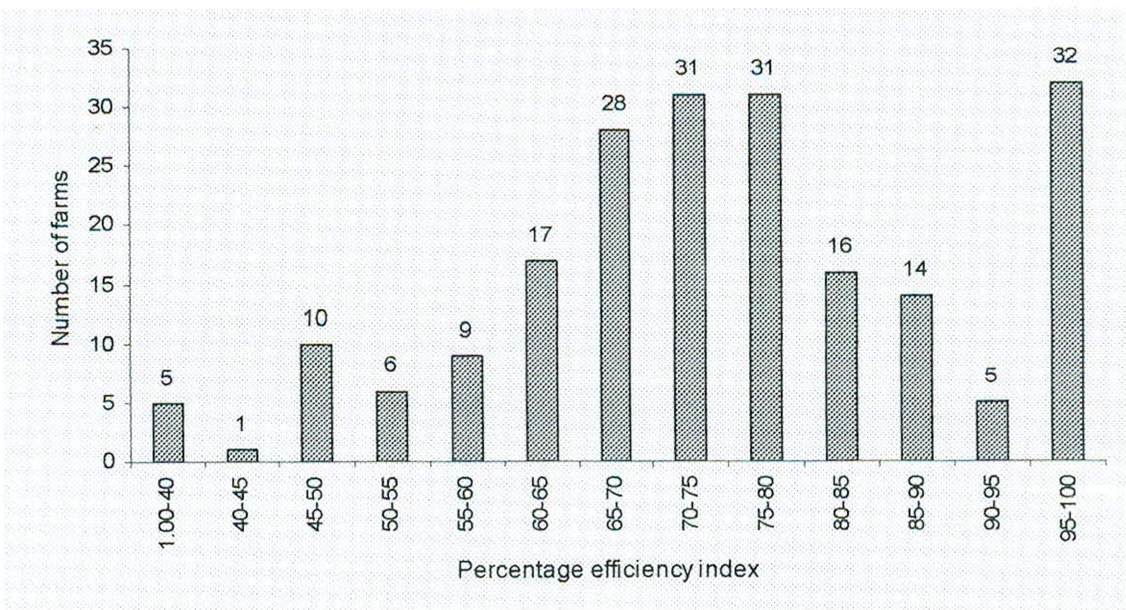


Figure 9.20: EE from VRS DEA Frontier for Aman Season

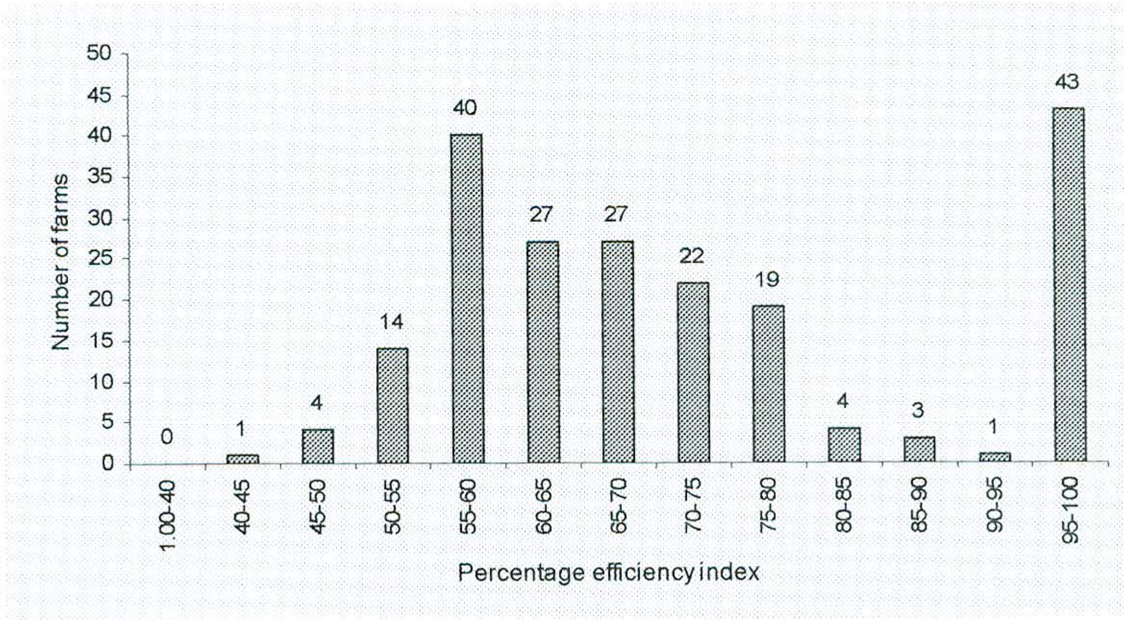


Figure 9.21: EE from VRS DEA Frontier for Boro Season

9.4 Factors Associated with Technical, Allocative and Economic Inefficiency

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

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

where z_i are socio-economic and infrastructural variables which affect efficiency of farmers. The variable z_{i1} denotes year of schooling of farmer; z_{i2} denotes year of rice cultivation experience of farmer; the variable z_{i3} represents land fragmentation; z_{i4}

denotes extension services dummy which assumes the value one if the farmer takes extension services from related officials and zero otherwise; 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, and z_{i6} denotes degradation dummy which takes the value one if land is un-degraded and zero otherwise. The value one for z_{i6} implies that most of lands 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 σ_w^2 . The Tobit model is used as inefficiency, IE_i, is a limited dependent variable. 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), CRS allocative inefficiency (CRS AI), VRS allocative inefficiency (VRS AI), CRS economic inefficiency (CRS EI), VRS economic inefficiency (VRS EI) by subtracting corresponding efficiencies from 100.

Results of the Tobit model for technical, allocative and economic inefficiencies for aman and boro seasons are given in Table 9.11 and 9.12 respectively. The estimated coefficient of years of schooling of farmers for CRS TI, AI, EI and VRS TI, AI and EI are positive and significant for both seasons. This means that as farmers are more educated they have higher levels of technical, allocative and economic efficiency. The estimated coefficient of rice cultivation experience of farmers for CRS and VRS AI are positive and significant. This implies that experienced farmers can allocate the inputs more efficiently as expected. On the other hand, the estimated coefficients of land fragmentation for CRS and VRS TI, AI and EI for both seasons are negative as expected, which implies that smaller plot size is associated with higher level of TI, AI and EI. The exceptions are CRS and VRS EI where coefficient is positive but insignificant. Extension services dummy coefficients are positive for CRS and VRS AI for aman and boro seasons. This shows that as farmers are provided more quality extension services they can allocate inputs more efficiently.

Table 9.11: Tobit Regression Results of Factors Affecting Inefficiencies for Aman Season

Factors						
CRS	TI		AI		EI	
	Co-efficients	t-ratios	Co-efficients	t-ratios	Co-efficients	t-ratios
Constant	0.25	7.821	0.0302	1.448	0.271	9.463
Yrs. of Schooling	0.00282	2.161	0.00472	2.979	0.00679	3.121
Exp. of the Farmers	-0.00045	-0.427	0.00281	4.077	0.0018	1.903
Land Fragmentation	-0.00407	-2.22	-0.00244	-2.038	-0.00562	-3.42
Extension Service Dummy	-0.17	-1.084	0.11	1.074	-0.0752	-0.53
Credit Facilities Dummy	0.197	4.268	-0.134	-1.327	0.08055	0.579
Land Degradation Dummy	-0.00408	-2.18	0.00651	0.441	-0.00008	-0.004
Log Likelihood	122.02		152.45		147.42	
VRS						
Constant	0.16	5.013	0.01041	0.483	0.167	5.2
Yrs. of Schooling	0.00468	1.927	0.005841	3.569	0.00971	3.976
Exp. of the Farmers	-0.00145	-0.137	0.0031	4.355	0.00245	2.305
Land Fragmentation	-0.00382	-2.087	-0.00106	-0.851	-0.00426	-2.31
Extension Service Dummy	-0.223	-1.428	0.125	1.189	-0.107	-0.68
Credit Facilities Dummy	0.249	3.603	-0.141	-1.349	0.118	0.755
Land Degradation Dummy	-0.00106	-3.047	0.00024	0.016	-0.00329	-2.14
Log Likelihood	178.04		140.3		102.6	

Table 9.12 Tobit Regression Results of Factors Affecting Inefficiencies for Boro Season

Factors						
CRS	TI		AI		EI	
	Co-efficients	t-ratios	Co-efficients	t-ratios	Co-efficients	t-ratios
Constant	0.211	7.587	0.156	8.956	0.34	8.269
Yrs. of Schooling	0.00389	2.843	0.00045	0.340	0.00368	2.609
Exp. of the Farmers	-0.0001	-0.116	0.00074	3.283	0.00048	0.79
Land Fragmentation	-0.00227	-1.426	-0.00229	-2.296	0.00029	0.273
Extension Service Dummy	0.0276	0.203	0.0691	0.813	0.08235	0.906
Credit Facilities Dummy	0.0421	0.313	-0.0535	-0.634	0.0847	0.94
Land Degradation Dummy	-0.00871	-0.442	-0.00905	-0.733	-0.0147	-1.116
Log Likelihood	112.02		118.24		107.22	
VRS						
Constant	0.102	3.347	0.04159	2.204	0.136	4.263
Yrs. of Schooling	0.00633	2.727	0.00612	4.271	0.0112	4.629
Exp. of the Farmers	0.0004	0.39	0.00109	2.749	0.00131	1.243
Land Fragmentation	0.00463	2.649	0.00068	0.635	0.00528	1.893
Extension Service Dummy	0.02893	0.194	0.01851	0.201	0.04053	0.260
Credit Facilities Dummy	0.0479	2.323	-0.0186	-0.204	0.0612	0.396
Land Degradation Dummy	-0.00517	-2.238	-0.00805	-0.602	-0.0127	-2.563
Log Likelihood	170.04		130.38		142.65	

As far as coefficients of credit facilities dummy are concerned, CRS and VRS TI and EI are positive and significant. It can be explained that as we provide more credit facilities to farmers they can be able more to cope technical facilities of cultivation and hence economic efficiency will be enhanced. The estimated coefficients of land degradation dummy for CRS and VRS TI, AI and EI for aman and boro seasons are negative, as expected. This implies that environment degradation creates problems for applying new technology in cultivation and also restricts to use cost minimizing input combination in production process in Barind area of Bangladesh. The coefficients for CRS, VRS TI, VRS EI are significant, but CRS and VRS AI and CRS EI are insignificant.

9.5 Comparison between Results from SF and DEA Models

In chapter 7 and early section of this chapter, we have given all efficiency results for both SF 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 the model provide as far as technical, allocative and economic efficiencies are concerned. In this purpose, we first present comparison of efficiency scores and then results of the inefficiency effects models.

9.5.1 Comparison of Efficiency Scores

The average efficiency measures based on CRS and VRS DEA frontiers for allocative and economic efficiency are higher than those based on SF model. But in case of technical efficiency, scores from SF model are greater than both CRS and VRS DEA model. In both aman and boro seasons we have similar results.

Few studies compared results obtained from two types of models. Ferrier and Lovell (1990), based on the US banking analysis, report higher technical, but lower economic efficiency for SF 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 allocative and economic efficiency from VRS DEA frontier and lower levels of other mean efficiencies than results of the stochastic frontier. In our study, we have higher allocative and economic efficiencies than SF 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 SF model. For the swine industry in Hawaii, Sharma *et. al.*, (1997) report a higher mean technical efficiency obtained from the stochastic frontier than those obtained from both CRS DEA and VRS DEA, which is similar to our results. Hjalmarson, Kumbhakar and Heshmati (1996) reported both similar and dissimilar results obtained from the SF model and DEA frontier model.

Percentage cumulative frequency distribution of technical, allocative and economic efficiency from stochastic frontier and CRS and VRS DEA models for aman and boro seasons are presented in Figure 9.22 to Figure 9.27.

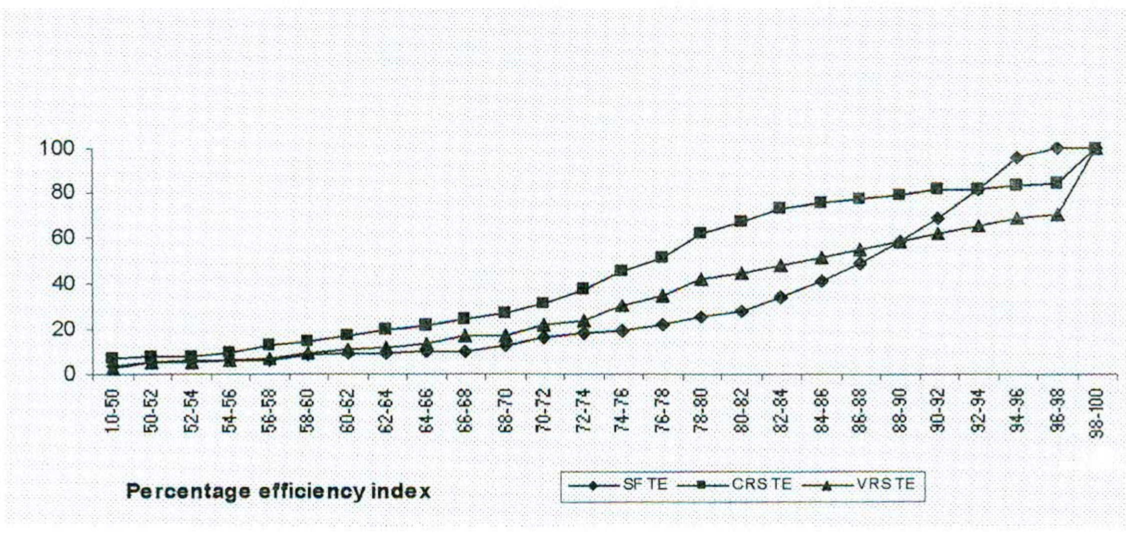


Figure 9.22: Percentage Cumulative Frequency Distribution of TE from SF and DEA for Aman Season

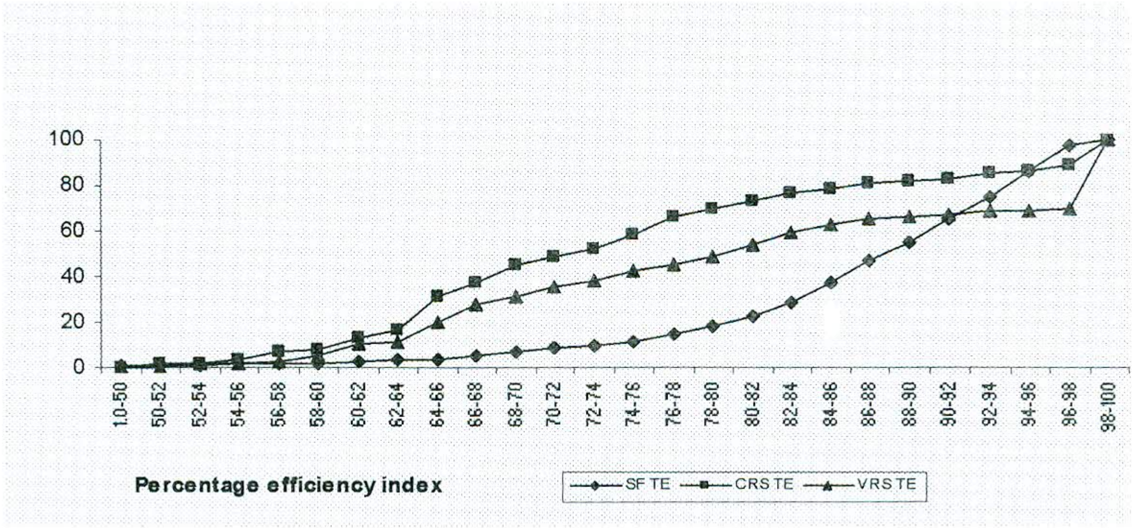


Figure 9.23: Percentage Cumulative Frequency Distribution of TE from SF and DEA for Boro Season

Cumulative frequency distribution curve of technical efficiency for aman season shows similar trends, but more variability in case of CRS DEA method. In boro season, technical efficiency scores from different methods give similar results as in aman season.

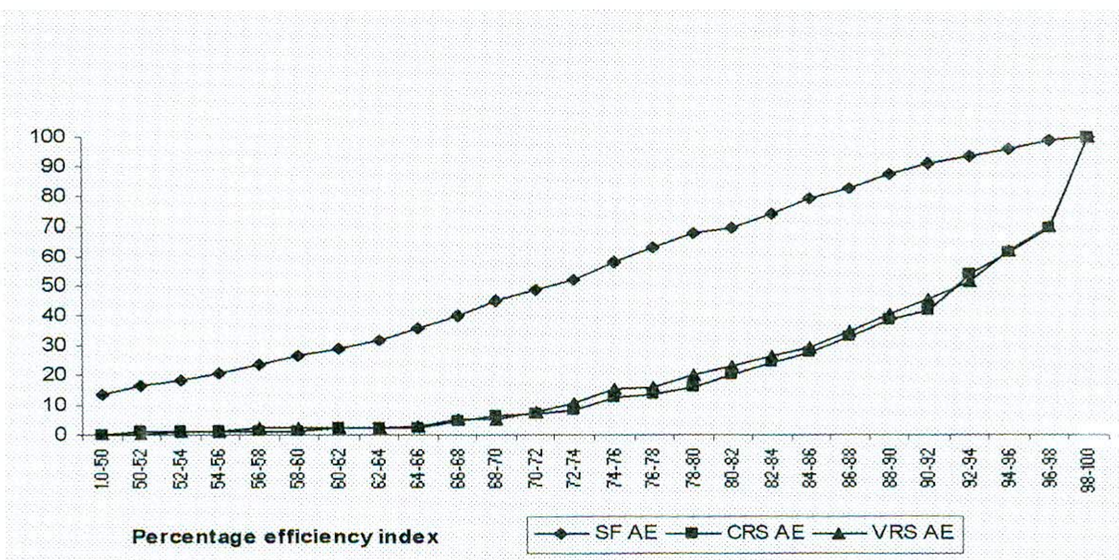


Figure 9.24: Percentage Cumulative Frequency Distribution of AE from SF and DEA for Aman Season

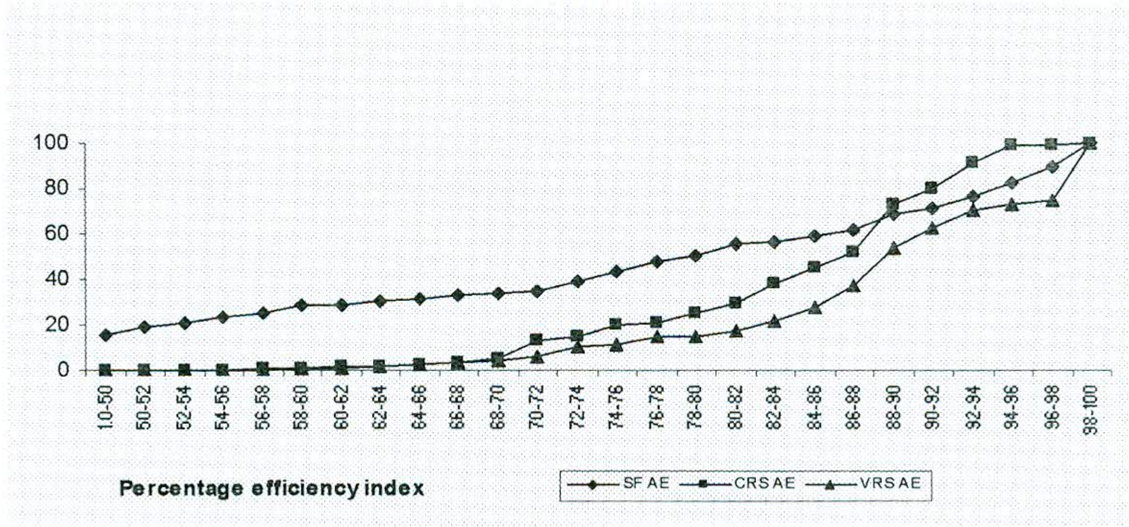


Figure 9.25: Percentage Cumulative Frequency Distribution of AE from SF and DEA for Boro Season

Allocative efficiency of farms in aman season for CRS and VRS DEA gives almost similar trend but SF method allocates more farms to low efficiency groups (0-70 per cent). About 45 per cent farms are placed in this group while only 7 per cent farms are placed in this group by the DEA method. On the other hand, in boro season, SF model places 35 per cent farms in this low efficiency group (0-70 per cent) and only 9 per cent farms are placed in this group by DEA method.

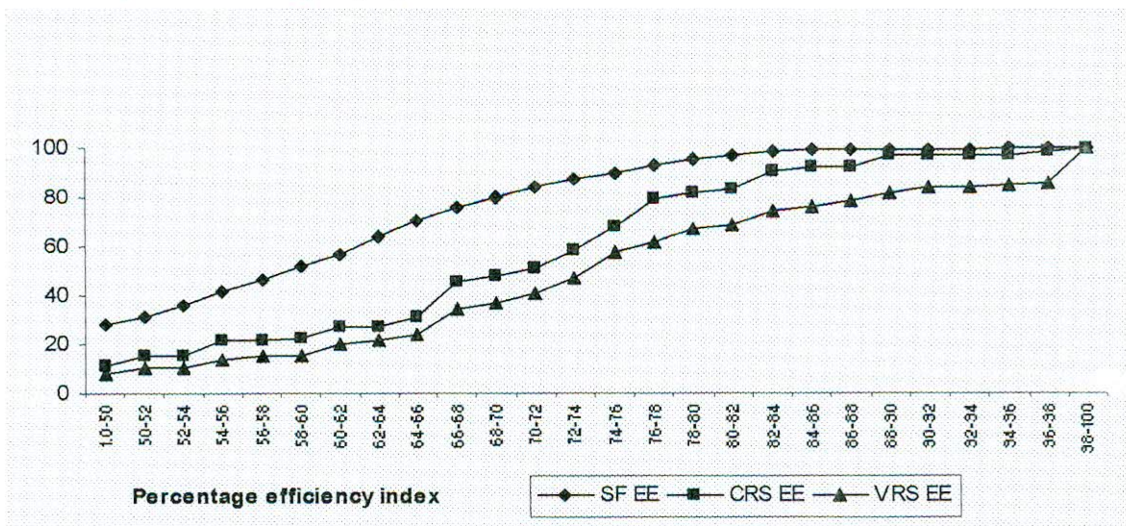


Figure 9.26: Percentage Cumulative Frequency Distribution of EE from SF and DEA for Aman Season

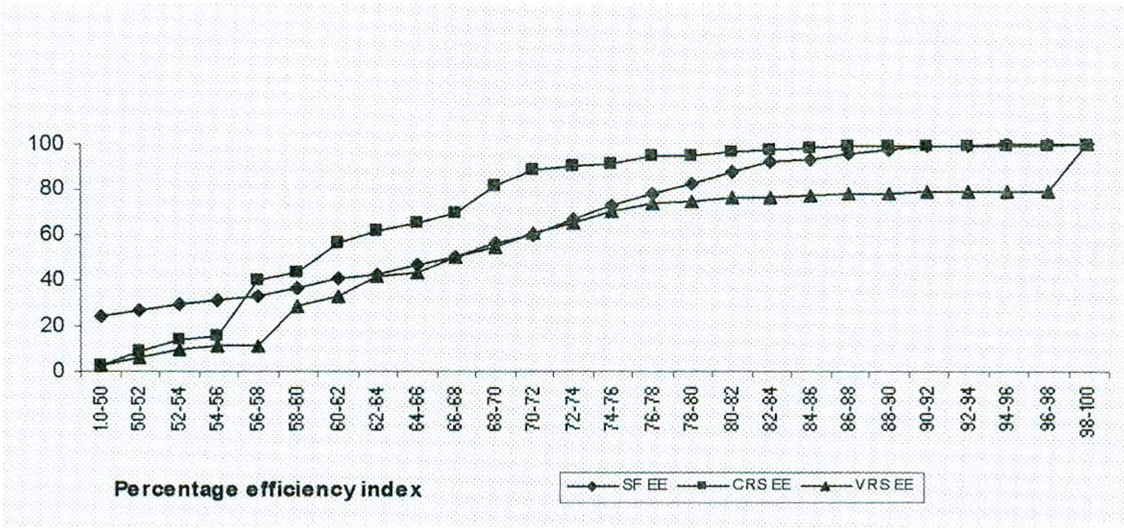


Figure 9.27: Percentage Cumulative Frequency Distribution of EE from SF and DEA for Boro Season

In case of economic efficiency for aman season, cumulative frequency distribution curve shows similar trends as allocative efficiency. But different results are found for boro season. Up to 50 per cent efficiency group, 24 per cent farmers are included by SF model, whereas DEA CRS and VRS models show only 3 and 2 per cent farmers respectively are in this group. According to SF model, 12 per cent boro farmers are 80 per cent or more economically efficient; whereas according to CRS DEA model, only 3.5 per cent farmers are in this group. VRS DEA shows 24 per cent farmers have 80 per cent or more efficiency in boro season.

Thus we may conclude from these results that SF model implies more room for production gain through improvement of technical and allocative efficiency than DEA method. But there are similar opportunities to get production gain by improving economic efficiency for both SF model and DEA method.

9.5.2 Comparison of Result of Inefficiency Effects Model

The inefficiency effect models are estimated using Tobit Regression Analysis. We have discussed these results of inefficiency effect model for SF model in Table 7.1 and 7.2 for aman and boro seasons respectively in chapter 7. On the other hand, inefficiency effect model for DEA frontier is presented in early section in Table 9.11 and 9.12 of this chapter. These show that estimated coefficient of duration of schooling for TI is positive in every model in aman and boro seasons. This result conforms to results obtained for Kanzara village by Coelli and Battese (1996). However, schooling is negatively associated with AI and EI SF model. This is expected and it implies that more educated farmers allocate the inputs more efficiently with changing input prices.

The estimated coefficients for experience of farmers for TI from both models give positive, which suggests that relatively new farmers are more technically efficient than their older counterparts. This result is similar to results obtained by Coelli and Battese (1996), Ajibefun *et. al.*, (1996) and Seyoum *et. al.*, (1998). The coefficient of experience of farmers for CRS AI and CRS EI both give positive results. 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 coefficient of experience (in terms of length of cultivation period) for SF AI and EI, and VRS AI and EI are negative. This indicates that relatively more experienced farmers are more efficient in allocating cost-minimizing input combinations.

The estimated coefficients of land fragmentation, i.e., plot size, except SF AI, are all negative, as expected for both frontiers. This result shows that farmers on average with greater plot size, i.e., less land fragmentation, operate at high level of technical, allocative and economic efficiency.

The estimated coefficient on extension services dummy in aman season for AI from both frontiers is found to be positive, but coefficients on TI and EI are found to be negatively related.

On the other hand, in boro season, the coefficient on extension services for TI is found to be positive but all other coefficients for AI and EI are found to be negative from both frontiers.

The estimated coefficients on credit facilities dummy are positive for aman season. But for boro season, all estimated coefficients on credit facilities except SF AI are negatively related.

The estimated coefficients on land degradation dummy for both aman and boro season from both frontiers give negative results. So, land degradation situation has a huge impact on all kinds of efficiency scores.

9.6 Conclusion

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 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 method show that there are small differences between VRS input- and output-oriented method. The average estimated technical, allocative and economic efficiencies in aman season are 76, 90 and 69 per cent respectively for CRS DEA frontier and those are 83, 90 and 75 for VRS DEA frontier respectively. Efficiency scores for aman season are little less than for boro season. This implies that farmers have more opportunity to improve production in aman season than in boro season.

Like SF model, the DEA frontier model results show that there is a room to improve efficiency levels of farms without improving technologies for both aman and boro seasons. More specifically, CRS DEA and VRS DEA frontier results show that 24 per cent and 17 per cent TE respectively for aman season and 25 per cent and 19 per cent TE respectively for boro season could be improved if the farmers would operate at full efficiency level. Similarly, CRS DEA and VRS DEA frontier results show that 10 per cent AE from both method for aman season and and 16 per cent and 11 per cent AE respectively for boro season could be improved at the same way. Again, CRS DEA and VRS DEA frontier results show that 31 per cent and 25 per cent EE respectively for aman season and 37 per cent and 28 per cent EE respectively for boro season could be improved if farmers would operate in the optimal efficiency scale.

We have discussed human capital and other factors as the sources of inefficiencies in production process. Some of the inefficiency factors are discussed with their effects. Age of farmers, experience for cultivation, credit facilities, land fragmentation, environmental degradation are most important in determining the sources of inefficiencies. Quality extension services can also have played a vital role to improve the efficiency of farmers.

Comparison of results from SF and DEA frontier for aman and boro seasons are produced in this chapter. Cumulative frequency distribution curve of technical efficiency for aman season shows similar trends, but more variability in case of CRS DEA method. In boro season, technical efficiency scores from different methods give similar results as in aman season.

Allocative efficiency of farms in aman season for CRS and VRS DEA gives almost similar trend but SF method allocates more farms to low efficiency groups (0-70 per cent). In boro season, SF model places 35 per cent farms in this low efficiency group (0-70 per cent) and only 9 per cent farms are placed in this group by DEA method.

In case of economic efficiency for aman season, cumulative frequency distribution curve shows similar trends as allocative efficiency. But different results are found for boro season.

Thus we may conclude from these results that SF model implies more room for production gain through improvement of technical and allocative efficiency than DEA method. But there are similar opportunities to get production gain by improving economic efficiency for both SF model and DEA method.

Chapter 10

Conclusions and Recommendations

10.1 Introduction

10.2 Summary

10.3 Conclusion and Recommendation

10.4 Further Research

CHAPTER 10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

This study examines the pattern and sources of technical, allocative and economic efficiency of rice farms in Bangladesh. We apply the stochastic frontier (SF) and data envelopment analysis (DEA) approach to obtain estimates of technical, allocative and economic efficiency. We make some comparison of efficiency estimates obtained from two approaches. We estimate technical, allocative and economic efficiencies following a cost decomposition technique by specifying a self-dual 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 return 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 previous chapters. Conclusion and some recommendations are discussed in the final section.

10.2 Summary of Results

In second chapter, we have reviewed in detail the literature related to both stochastic frontier and data envelopment analysis. Farrell (1957) presents a very outstanding and pioneer article on efficiency measurement which is based on production frontiers. 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 a input-saving or output-augmenting interpretation.

In chapter three, we have discussed location of the study area and its socio-economic, 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 Barind 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 1971 mm. per year. The clay of the region is reddish brown in colour, oxidized, sticky and compact. The major constraints for agriculture in this area, specially for cultivation of dry land are unstable silty topsoils and strongly developed ploughpans which make the soil quickly wet and quickly dry.

Field level survey and methodology of collecting data are discussed in chapter four. 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. Aman season data are collected from June to September in 2002 and boro season data from November to February in 2003-2004.

Before collecting data from farmers, we have done a pilot survey among respondents. About 47 per cent farmers among respondents are between ages of 30 years to 45 years, 36 per cent have secondary school to graduation level formal education. Most of farmers are marginal. Only two per cent farmers have cultivated 10 acres or more land in a season. Most of lands of the study are fragmented. About 63 per cent farmers have an average plot size less than half an acre and 51 per cent farmer's cost of production per acre during aman season is between Tk. 4500 to Tk. 5500. In boro season, 71 per cent farmers have an expense per acre between Tk. 7000 Tk. 8000. Around 65 per cent farmers' rice production per acre is between 25 to 40 mounds.

In chapter 5, we have discussed different issues relating production function and efficiencies. According Farrell (1957), efficiency of a farm consists of two components – one is technical and another is allocative efficiency. Technical efficiency represents the ability of a farm to obtain maximum output from a given set of inputs, or ability to minimize input use in the production of a given vector. Allocative efficiency means the ability of a farm to use inputs in optimal proportions given their respective prices. Input- and output orientation methods of efficiency estimation are also described in this chapter.

Stochastic frontier analysis is discussed theoretically in chapter 6. Stochastic frontier analysis originated by simultaneously by Meeusen and van den Broeck (1977), and Aigner, Lovell and Schmidt (1977). We have used maximum-likelihood (ML) estimation technique to estimate stochastic frontier production function and efficiency of farmers. The average function provides a picture of the shape of technology of an average farm, while estimating a frontier function are most heavily influenced by the best performing farms and hence reflect the technology they are using. In this chapter, we examine the cost decomposition method to obtain the estimates of technical, allocative and economic efficiency using the self-dual Cobb-Douglas stochastic frontier. We derive the observed output of farms adjusted for the stochastic random noise and then explain the dual approach for analytically obtaining the dual frontier cost function from the stochastic frontier production function and hence economically efficient input vector. From the primal stochastic frontier production function model and dual stochastic frontier cost function, we can obtain technically efficient input vectors. These technically and economically efficient input vectors and the observed input vectors along the corresponding price vectors provide technically, economically and observed cost vectors which produce the measures of technical and economic efficiency estimate, and finally allocative efficiency estimate is obtained from the ratio of two estimates.

Another method for estimating efficiencies is the data envelopment analysis (DEA). DEA is theoretically discussed in chapter 8. DEA methodology has some basic differences from the simple regression methodology. A parametric approach has the objective to optimize a single regression plan through data, but DEA optimizes each individual's observation with an objective of calculating a discrete piece-wise frontier determined by DMUs.

10.3 Conclusion and recommendations

The stochastic frontier results show that sign of the 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 seeds in the production process.

Mean scores of technical, allocative and economic efficiency for aman season are 84, 71 and 58 per cent respectively. In boro season, the respective efficiency scores are 87, 75 and 64 per cent. So, there is an opportunity to increase technical efficiency of farmers by 13 to 16 per cent, allocative efficiency by 25 to 29 per cent and economic efficiency by 36 to 42 per cent without any change or improvement in cultivation technologies if farmers operate at full efficiency scale.

On the other hand, mean efficiency scores from the CRS DEA shows technical, allocative and economic efficiencies are 77, 90 and 69 per cent respectively for aman season. At the same season, VRS DEA methodology gives technical, allocative and economic efficiency of 84, 90 and 76 per cent respectively. Similar results are obtained from boro season. CRS DEA gives technical, allocative and economic efficiency of 75, 84 and 63 per cent for boro season. VRS DEA shows that technical, allocative and economic efficiencies are 81, 89 and 72 per cent respectively. These results imply that there are rooms to improve efficiency level of farmers without any change in production process or without introducing any modern technology. Therefore, farmers can get more output gain without applying new improved technology.

The estimates of allocative efficiency in stochastic frontier show greater variability than those of DEA frontier, but the estimates of technical and economic efficiency in DEA frontier show greater variability than those in stochastic frontier. On the other hand, in boro season mixed results have been found. Technical and allocative efficiency estimates in boro season show similar results as those are in the aman season, but economic efficiency estimates have mixed results.

Results of inefficiency effects model from both the stochastic and DEA frontier approach imply that inefficiency effects in production are influenced by many factors. Results suggest that land fragmentation, extension services, credit facilities, land degradation and irrigation infrastructure are statistically most significantly associated with technical, allocative and economic inefficiency.

One of the major inefficiency effect factors in production is land fragmentation, that is, smaller plot sizes. So policies should be targeted in such way that the existing land tenure and land management system can reduce land fragmentation.

Results show that extension services are directly related to efficiency of the farmers. Both SF 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 farmers. So, if the proper authority gives appropriate effort to improve the extension services, it would be expected that farmer's efficiency in rice cultivation will improve. Therefore, policies should be targeted to increase quality extension services for the grassroots and marginal farmers.

Credit facility is one of the important factors which is related to efficiency of farmers. Credit facility particularly agriculture credit facility in this study area as well as in Bangladesh is not so organized. Results from both methodologies suggest that credit facility factor is directly related to efficiency. At the same time during the field level survey we observe that there are lots of difficulties faced by the farmers to get agriculture credit. For example, government financial institutions like Bangladesh Krishi Bank (Bangladesh Agriculture Bank), Rajshahi Krishi Unnayan Bank (Agriculture Development Bank of Rajshahi) and other institutions have lots of formalities and processes which discourage rural and low educated farmers to go there for loans. 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. Sometimes local chairman and members are not helped them. On the other hand, non-government organizations and other institutions, which have credit programs especially micro credit programs, 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 sale 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. It is one of the major obstacles for the farmers to operate at the maximum level of efficiency. 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 target people can get credit as easiest way as possible.

Irrigation infrastructure is another prime factor to influence efficiency of the farmers in Bangladesh. Irrigation infrastructure has developed sufficiently in the Barind region 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, and should supply electricity to the Deep Tube-wells.

Land degradation is considered as an environmental factor. Results show that it decreases technical, allocative and economic efficiency. So, it implies that land degradation decreases farmers' 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 the both frontier for both aman and boro seasons indicate that human factors such as, age and cultivation experience of farmers and duration of formal education i.e., years of schooling are more or less affect the efficiency of the farmers. So, policies which aim to reduce land degradation could be applied and also policies related to agricultural education and training could be taken to improve practical knowledge and experience 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, from Tk. 100 crore to Tk. 1200 crore (10 million to 120 million). The government should strictly supervise whether benefits of subsidized money have gone to the targeted marginal 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 program should be extended by the Thana (sub-district) 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 proper 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 pesticide will decrease technical, allocative and economic 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, allocative and economic inefficiency among the sample farm households in this study is found. Therefore, there is a substantial potential for increasing rice production through the improvement of technical, allocative and economic efficiency without any remarkable change in production process or existing technology. More specifically, the sample farmers, on average, could increase their production by 10 to 42 per cent depending on frontier methodology, season variation and scale assumption if they could operate at full technical, allocative and economic efficiency levels, given the existing technology. If efficiencies of farmers are increased, that resulting cost of production will be decreased. In other words, farmers have not to pay extra-expenditure for their improve 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 agricultural 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. Benefits go to the middle-man and business man 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.

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 50 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, rural infrastructure and marketing facilities. The securities for the marginal 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 able to use inputs in appropriate proportion and minimize the misuse of input use.

Land fragmentation or small size of land is one of 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.

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. 10 million in 2001-2002 to Tk. 120 million in 2005-2006. But government should be ensured that this allocated money for subsidy goes to benefits of the targeted people. So, 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 are used surface water 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 cultivation and cost minimizing input use. Thus, farmers could improve allocative efficiency performance by using cost minimizing input combinations. So, government should take initiative to provide this kind of formal and informal education facilities to the poor marginal farmers.

To avoid the excessive use or misuse of seeds, farmers can use dram seeder, a new technique of seeding, in their cultivation process. So, that will reduce the cost of seeds and will improve efficiency performance of farmers.

10.4 Further Research

We have taken a sample size of 205 farms in our study. Collected data and information based on a larger sample size would have been better. We have collected data from individual farm by interviewing method. Most of marginal farmers are not habituated to keep necessary information in systematic written form. Moreover, some of them are reluctant to provide information. A research with motivated written information can be a further research. As far as the methodology is concerned, we have used a self-dual (such as Cobb-Douglas) functional form of production frontier to estimate technical, allocative and economic efficiency. Thus, examining the effects of other functional form (such as translog) on efficiency estimates can be a further research.

Now the question is how the policy makers would interprete the different efficiency results on their decisions and how the farm-households are capable to adjust with the new training and education related programmes. Also the question is how these numerical results of the efficiency effects model can improve the infrastructure of the rural rice production area? Similarly, how farm-households could improve their education and experience to achieve the maximum efficiency level?

To find answers all of these questions, further research and investigation are required.

Appendix

Annexure

Bibliography

Appendix 1: Maximum Likelihood Estimators

The principle of maximum likelihood estimation is illustrated in the context of the linear regression which is defined by:

$$y_i = X\beta + u \qquad \text{A1.1}$$

where X is a fixed nonstochastic matrix. This model then defines a transformation form u to y. The assumption of 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:

$$\begin{bmatrix} \partial u_1/\partial y_1 & \partial u_1/\partial y_2 & \dots & \partial u_1/\partial y_n \\ \partial u_2/\partial y_1 & \partial u_2/\partial y_2 & \dots & \partial u_2/\partial y_n \\ \dots & \dots & \dots & \dots \\ \partial u_n/\partial y_1 & \partial u_n/\partial y_2 & \dots & \partial u_n/\partial y_n \end{bmatrix}$$

This matrix appears to be the identity matrix whose determinant is unity in case of (A1.1). 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:

$$f(u) = \frac{1}{\left(\sigma\sqrt{2\pi}\right)^n} e^{-\frac{1}{2\sigma^2}u'u}$$

And so:

$$f(y) = \frac{1}{\left(\sigma\sqrt{2\pi}\right)^n} e^{-\frac{1}{2\sigma^2}(y-X\beta)'(y-X\beta)} \qquad \text{(A1.2)}$$

Equation (A1.2) 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 (A1.2) is termed the likelihood function denoted by L. Taking natural log of the likelihood function in (A1.2) yields:

$$\ln L = -\frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln(\sigma^2) - \frac{1}{2\sigma^2}(y - X\beta)'(y - X\beta) \qquad \text{(A1.3)}$$

The maximum Likelihood (ML) principle consists in estimating the unknown parameters with the values which maximize the likelihood function, given the sample data y. Differentiating (A1.3) partially with respect to β and σ^2 and seting equal to zero gives:

$$\frac{\partial(\ln L)}{\partial\beta} = -\frac{1}{2\hat{\sigma}^2}\left(-2X'y + 2X'X\hat{\beta}\right) = 0$$

or, $$\frac{1}{\hat{\sigma}^2}\left(X'y - X'X\hat{\beta}\right) = 0$$

and: $$\frac{\partial(\ln L)}{\partial\sigma^2} = -\frac{1}{2\hat{\sigma}^2} + \frac{1}{2\hat{\sigma}^4}(y - X\hat{\beta})'(y - X\hat{\beta}) = 0$$

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 estimator of $\hat{\sigma}^2$ is asymptotically unbiased.

Appendix 2: Derivation of the Cost Function

We now explain the mathematical model from which the cost functions for profit maximizing farms are derived:

Minimize $C = \sum_{i=1}^{q} p_i x_i$

Subject to: $y = f(x_1, x_2, \ldots, x_q)$, $x_i > 0$ and $y > 0$

where the p_i's are input prices, y is a parametric output value, $f(x_1, x_2, \ldots, x_q)$ is the production function of the farm. Assume that the farm minimizes the total cost of producing any specific output level. For simplicity, we begin with the three variable cases and the production function of the Cobb-Douglas type. Hence the Lagrangian function is constructed as follows:

$$\underset{x,\lambda}{L}(p, y) = p_1 x_1 + p_2 x_2 + p_3 x_3 + \lambda\left(y - \beta_0 x_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_3} e^{-u}\right)$$

where λ is the Lagrange multiplier.

The first-order conditions of this function are written as:

$$p_1 = \lambda \beta_0 \beta_1 x_1^{\beta_1 - 1} x_2^{\beta_2} x_3^{\beta_3} \quad \text{(A2.1)}$$

$$p_2 = \lambda \beta_0 \beta_2 x_1^{\beta_1} x_2^{\beta_2 - 1} x_3^{\beta_3} \quad \text{(A2.2)}$$

$$p_3 = \lambda \beta_0 \beta_3 x_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_3 - 1} \quad \text{(A2.3)}$$

$$y = \beta_0 x_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_3} \quad \text{(A2.4)}$$

From (A2.1) and (A2.2) we get:

$$\frac{p_1}{p_2} = \frac{\lambda\beta_0\beta_1 x_1^{\beta_1-1}x_2^{\beta_2}x_3^{\beta_3}}{\lambda\beta_0\beta_2 x_1^{\beta_1}x_2^{\beta_2-1}x_3^{\beta_3}} = \frac{\beta_1 x_2^{\beta_2}}{\beta_2 x_1^{\beta_1}}$$

$$\therefore \qquad x_2 = \frac{p_1\beta_2}{p_2\beta_1}x_1$$

And from (A2.2) and (A2.3) we derive that:

$$\frac{p_3}{p_2} = \frac{\lambda\beta_0\beta_3 x_1^{\beta_1}x_2^{\beta_2}x_3^{\beta_3-1}}{\lambda\beta_0\beta_2 x_1^{\beta_1}x_2^{\beta_2-1}x_3^{\beta_3}} = \frac{\beta_3 x_2^{\beta_2}}{\beta_2 x_3^{\beta_3}}$$

$$\therefore \qquad x_3 = \frac{p_2\beta_3}{p_3\beta_2}x_2$$

Substituting the value of x_2 and x_3 into (A2.4) yields:

$$y = \beta_0 x_1^{\beta_1}\left(\frac{p_1\beta_2}{p_2\beta_1}x_1\right)^{\beta_2}\left(\frac{p_2\beta_3}{p_3\beta_2}x_2\right)^{\beta_3}$$

$$y = \beta_0 x_1^{\beta_1}x_1^{\beta_2}\left(\frac{p_1\beta_2}{p_2\beta_1}\right)^{\beta_2}\left(\frac{p_2\beta_3}{p_3\beta_2}\right)^{\beta_3}x_2^{\beta_3}$$

$$y = \beta_0 x_1^{\beta_1+\beta_2+\beta_3}\left(\frac{\beta_2}{\beta_1}\right)^{\beta_2}\left(\frac{\beta_3}{\beta_1}\right)^{\beta_3}\left(\frac{p_1}{p_2}\right)^{\beta_2}\left(\frac{p_1}{p_3}\right)^{\beta_3}$$

$$x_1 = \frac{1}{\beta_0^{\frac{1}{\beta_1+\beta_2+\beta_3}}}\frac{1}{\left(\frac{\beta_2}{\beta_1}\right)^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}}\left(\frac{\beta_3}{\beta_1}\right)^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}}\frac{1}{\left(\frac{p_1}{p_2}\right)^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}}\left(\frac{p_1}{p_3}\right)^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}}y^{\frac{1}{\beta_1+\beta_2+\beta_3}}$$

$$x_1 = \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_1 \beta_1^{-\frac{\beta_1}{\sum_{i=1}^{3}\beta_i}}}{(\beta_2)^{\beta_2 / \sum_{i=1}^{3}\beta_i} (\beta_3)^{\beta_2 / \sum_{i=1}^{3}\beta_i}{}^{\beta_3 / \sum_{i=1}^{3}\beta_i}} \frac{p_2^{\beta_2 / \sum_{i=1}^{3}\beta_i} \; p_3^{\beta_3 / \sum_{i=1}^{3}\beta_i}}{(p_1)^{\beta_2 / \sum_{i=1}^{3}\beta_i} \; (p_1)^{\beta_3 / \sum_{i=1}^{3}\beta_i}} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$x_1 = \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_1}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

Similarly we can get the input demand functions for x_2 and x_3 as:

$$x_2 = \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_2}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_2}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

And

$$x_3 = \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_3}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_3}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

In general, the input demand functions are:

$$x_i = \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{n}\beta_i}}} \frac{\beta_i}{\prod_{i=1}^{n}\beta_i^{\beta_i / \sum_{i=1}^{n}\beta_i}} \prod_{j=2}^{n}\left(\frac{p_j}{p_i}\right)^{\beta_j / \sum_{i=1}^{n}\beta_i} y^{\frac{1}{\sum_{i=1}^{n}\beta_i}}$$

Now the cost function is derived on the basis of the production function as follows:

$$C(p,y) = p_1 x_1 + p_2 x_2 + p_3 x_3$$

$$= p_1 \cdot \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_1}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}} + p_2 \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_2}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_2}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$+ p_3 \frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{3}\beta_i}}} \frac{\beta_3}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \prod_{j=2}^{3}\left(\frac{p_j}{p_3}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$= \frac{1}{\beta_0^{1/\sum_{i=1}^{3}\beta_i}} \frac{1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \left[\beta_1 p_1 \prod_{j=2}^{3}\left(\frac{p_j}{p_1}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} + \beta_2 p_2 \prod_{j=2}^{3}\left(\frac{p_j}{p_2}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i} + \beta_3 p_3 \prod_{j=2}^{3}\left(\frac{p_j}{p_3}\right)^{\beta_j / \sum_{i=1}^{3}\beta_i}\right] y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$= \frac{1}{\beta_0^{1/\sum_{i=1}^{3}\beta_i}} \frac{1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \left[\frac{\beta_1 p_1 p_2^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}} p_3^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}}{p_1^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}} p_1^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}} + \frac{\beta_2 p_2 p_1^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_3^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}}{p_2^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_2^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}} + \frac{\beta_3 p_3 p_1^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_2^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}}}{p_3^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_3^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}}}\right] y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$= \frac{1}{\beta_0^{1/\sum_{i=1}^{3}\beta_i}} \frac{1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \left[\frac{\beta_1 p_1 p_2 p_3 + \beta_2 p_1 p_2 p_3 + \beta_3 p_1 p_2 p_3}{p_1^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}} p_1^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}} p_2^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_2^{\frac{\beta_3}{\beta_1+\beta_2+\beta_3}} p_3^{\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_3^{\frac{\beta_2}{\beta_1+\beta_2+\beta_3}}}\right] y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

$$= \frac{1}{\beta_0^{1/\sum_{i=1}^{3}\beta_i}} \frac{1}{\prod_{i=1}^{3}\beta_i^{\beta_i / \sum_{i=1}^{3}\beta_i}} \left[\frac{(\beta_1 + \beta_2 + \beta_3) p_1 p_2 p_3}{p_1 p_1^{-\frac{\beta_1}{\beta_1+\beta_2+\beta_3}} p_2 p_2^{-\frac{\beta_2}{\beta_1+\beta_2+\beta_3}} p_3 p_3^{-\frac{\beta_3}{\beta_1+\beta_2+\beta_3}}}\right] y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

Therefore the derived cost function which is a function of factor prices and output is:

$$C(p,y)=\frac{1}{\beta_0^{1/\sum_{i=1}^{3}\beta_i}}\frac{\sum_{i=1}^{3}\beta_i}{\prod_{i=1}^{3}\beta_i^{\beta_i/\sum_{i=1}^{3}\beta_i}}\prod_{i=1}^{3}p_i^{\beta_i/\sum_{i=1}^{3}\beta_i}\,y^{\frac{1}{\sum_{i=1}^{3}\beta_i}}$$

In a similar fashion, we obtain the input demand functions and the cost function for our six input case as follows:

The input demand functions: $$x_i=\frac{1}{\beta_0^{\frac{1}{\sum_{i=1}^{6}\beta_i}}}\frac{\beta_i}{\prod_{i=1}^{6}\beta_i^{\beta_i/\sum_{i=1}^{6}\beta_i}}\prod_{j=2}^{6}\left(\frac{p_j}{p_i}\right)^{\beta_j/\sum_{i=1}^{6}\beta_i}y^{\frac{1}{\sum_{i=1}^{6}\beta_i}}$$

The cost function: $$C(p,y)=\frac{1}{\beta_0^{1/\sum_{i=1}^{6}\beta_i}}\frac{\sum_{i=1}^{6}\beta_i}{\prod_{i=1}^{6}\beta_i^{\beta_i/\sum_{i=1}^{6}\beta_i}}\prod_{i=1}^{6}p_i^{\beta_i/\sum_{i=1}^{6}\beta_i}\,y^{\frac{1}{\sum_{i=1}^{6}\beta_i}}$$

These functions can easily be generalized for n inputs.

Annexure-1

Questionnaire

Personal Information

1. Name of the Farmer : ______________________
2. Village : ______________________
3. Thana : ______________________
4. District : ______________________
5. Sex : (i) Male ☐ (ii) Female ☐
6. Age : ______________________
7. Experience : ______________________
8. Marital Status : (i) Single ☐

   (ii) Married ☐ No. of Wives _____

   (iii) Others ☐ Divorced / Separated / Widowed
9. Local Government Area :

Formal Education

Years of schooling

10. (i) Never attended school ☐ ______________

    (ii) Below class five ☐ ______________

    (iii) Above class five but below SSC certificate ☐ ______________

(iv) SSC certificate ☐ ____________________

(v) HSC certificate ☐ ____________________

(vi) Commercial schooling ☐ ____________________

(vii) First university degree and above ☐ ____________________

(viii) Technical degree and other training ☐ ____________________

(ix) Total no. of years of education ☐ ____________________

Household Characteristics

11. Number of children of the household : ____________________

12. Number of people living in the household : ____________________

13. Names, age, sex, education, income and relationship of the members of the household (children and others):

Name	Age	Sex	Education	Income	Relationship
(i)					
(ii)					
(iii)					
(iv)					
(v)					
(vi)					
(vii)					
(viii)					
(ix)					
(x)					

Occupation

14. Main occupation of the household : ______________________

15. Others sources of income Time spent per year

(i) ______________ ______________

(ii) ______________ ______________

(iii) ______________ ______________

(iv) ______________ ______________

(v) ______________ ______________

16. Duration of the occupation: ______________________

Special Status

17. The household: (i) Schoolteacher ☐ ____________

(ii) Official (govt./ non govt.) ☐ ____________

(iii) Union Parishad/ Ward member ☐ ____________

(iv) Ordinary member of the society ☐ ____________

18. Farm size of the household

(i) Total area owned : ____________

(a) Homestead area : ____________

(b) Forest area : ____________

(c) Fallow area : ____________________

(ii) Total cultivable land : ____________________

(iii) Total land cultivated (2002) : __________________

(iv) No. of plots : ____________________

(v) Plot size (average) : ____________________

(vi) Distance from one plot to another (avg.): ________

(vii) Distance from homestead (avg.): ______________

19. Have you got land for sharecropping? Yes ☐ No ☐

20. In case of sharecropping, what is the mode of payment?

(i) In cash ☐ please specify: ________________________

(ii) In kind ☐ please specify: ________________________

21. Do you think any major problem exist in sharecropping system?

____

____

22. Do you have any rented land? Yes ☐ No ☐

23. In case of rented land, what is the mode of payment?

(i) In cash ☐ please specify: ________________________

(ii) In kind ☐ please specify: ________________________

24. Land and Irrigation Information

Season	CL	FL	TCL	NCL	TIA	NIA	Problems
Aman							
Boro							

25. Production Side of the Household

(a) Homestead utilization

Crops (Aman Season)	No. of family labour			Hired labour		Total Hrs. of work (with family labour)	Total costs (with family labour)	Total revenue
	M	F	C	M	F			
a.								
b.								
c.								
d.								

Crops (Boro Season)	No. of family labour			Hired labour		Total Hrs. of work (with family labour)	Total costs (with family labour)	Total revenue
	M	F	C	M	F			
a.								
b.								
c.								
d.								

Farm activities

(b) Land Utilization

Crops Tilled land	season 1 (Aman)	season 2 (Boro)	season 3 (Aus)	Market price per Acre	Total value
a.					
b.					
c.					
d.					
e.					
Sharecropping					
Total					

(i) Do you think your land is degraded? Yes ☐ No ☐

(ii) If yes, please tell us what the reasons are.

(c) Labour Utilization (per acre)

Season	Family labour	Hired labour	Hrs. of work (per day)	Days of work	Wage rate	Costs of labour
Season1						
Season2						
Season3						
Total						

(i) Mention the peak period of farming : ______________________________

(d) Peak Period

	Months	Operation	Work Hrs.	Wage rate	Variation	L. Demand	Problems
Season1							
Season2							
Season3							
Pre. exp.							

(e) Irrigation

	C.A.	Irrigation Area			Price per acre(Tk.)			Total costs	Crops irrigated
		DTW	STW	others	DTW	STW	others		
Season1									
Season2									
Season3									
Prev.									

(i) Who owns the means of Irrigation?

(ii) Modes of payments for Irrigation?

(iii) Any fluctuations of Irrigation price?

(iv) Your idea about productivity due Irrigation?

(f) Water Sellers

	Water source	No. of customers	Price	Quantity	Length of time
Season1					
Season2					
Season3					

(i) Competition among other water seller: ______________________________

(ii) Basis of contract: ____

(iii) Controls over the irrigation project: ________________________________

(iv) Shortfall in water supply: ____

(v) Limitations in supplying water: ____________________________________

(g) Fertilizer Utilization(per acre)

Season1

Crop	Cow-dung	TSP	MP	Urea	Others
a.					
b.					
c.					
d.					
e.					

Season2

Crop	Cow-dung	TSP	MP	Urea	Others
a.					
b.					
c.					
d.					
e.					

Season3

Crop	Cow-dung	TSP	MP	Urea	Others
a.					
b.					
c.					
d.					
e.					

Crop	Cow-dung	TSP	MP	Urea	Others
a.					
b.					
c.					
d.					
e.					

(i) Is the supply of fertilizer sufficient? Yes ☐ No ☐

(ii) If not, what is the main reason for it? Please specify at your own opinion.

(iii) Do you think that the price of fertilizer is reasonable? Yes ☐ No ☐

(iv) If not, how much it should be.

(v)

(h) Pesticides Utilization(per acre)

Season1

Crop					Others
a.					
b.					
c.					
d.					
e.					

Season2

Crop					Others
a.					
b.					
c.					
d.					
e.					

Season3

Crop					Others
a.					
b.					
c.					
d.					
e.					

(i) Market prices of fertilizer

	Cow-dung per mound	TSP per kg.	MP per kg.	Urea per kg.	Others per kg.
Season1					
Season2					
Season3					

(j) Market prices of pesticides

Season1					
Season2					
Season3					

(i) Is there any fluctuation in price?

(ii) If yes, please specify the reason: ______________________________

(k) Capital Asset (Machinery) Utilization

	Crop	Traditional system used	Power Tiller or Tractor used	Others
Season1				
Season2				
Season3				

(i) Do you think that modern power tiller or tractor use is more beneficial than the traditional system? Yes ☐ No ☐

(ii) If yes, what is the reason not to use modern technology?

(iii) Do you have sufficient access to credit for buying modern equipment?

(iv) What are the main barriers to get credit?

(I) Yield and Revenue

	Yield per acre	Total	Market price	Revenue
Season1				
a. Rice				
b.				
c.				
d.				
e.				
f.				
Total				
Season2				
a. Rice				
b.				
c.				
d.				
e.				
f.				
Total				

Season3 a. *Rice* b. c. d. e. f.				
Total				

26. Non- Farm Activities

Activities	Hrs. of work/week	Days of work/month	Costs in this season	Income in this season	Is it easily available
Season1 a. Labourer b. Fishing c. Business d. Rickshaw pulling e. Others					
Season2 a. Labourer b. Fishing					

c. Business d. Rickshaw pulling e. Others					
Season3 a. Labourer b. Fishing c. Business d. Rickshaw pulling e. Others					
Total					

27. Livestocks

Types of Livestock	No. of livestock	Hrs. per week			Diseases	Costs =	Bought this year	Income
		M	F	C				
a. Bullock b. Cow c. Goat d. Chicken e. Others								

Rapid Rural Appraisal (RRA) Questions

1. Do you think that the water extraction capacity of the diesel-oriented pumps is lower?

   Yes ☐ No ☐

2. Do you think this affect production Yes ☐ No ☐
3. What is your suggestion regarding this aspect.
4. Are there any environmental problems due to irrigation? Yes ☐ No ☐

   Please specify: ____

5. Your suggestion to reduce the problem : ________________________
6. Any extension officials come to help you giving ideas about the different aspects of the production system? Yes ☐ No ☐
7. If yes, how many times in a season? ____________________________
8. Do you read any newspapers/ magazines or watch Television programmes about farming? Yes ☐ No ☐
9. Do you think land is degrading in this region? Yes ☐ No ☐
10. What are the main reasons for land degradation? ___________________________
11. D you think the following are causes of land degradation:

(i)	Use cow-dung for domestic fuel	Yes ☐	No ☐
(ii)	Use crop residues for domestic fuel	Yes ☐	No ☐
(iii)	Use leaves and twigs for domestic fuel	Yes ☐	No ☐
(iv)	Grazing domestic animal in the open field	Yes ☐	No ☐
(v)	Please specify any other reason (if any): ____________________________		

12. Is there any social conflict in this area about any aspect? Why?

____

13. (i) Do you have any comment about the labour market?

(iii) Any suggestions for improvements of the market?

(iv) Any socioeconomic problems relating to the labour market?

14. (i) Do you think that market prices of your products are seasonable?

Yes ☐ No ☐

(ii) If no, what is the problem with it? ______________________________

15. (i) Do you think non-farm income is reasonable? Yes ☐ No ☐

(ii) Why? ______________________________

16. Does lack of credit affect your use of produced inputs e.g., seeds, fertilizer, and water use? ______________________________

17. What are sources inputs? ______________________________

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