International Journal of Development and Sustainability
ISSN: 2186-8662 – www.isdsnet.com/ijds
Volume 7 Number 3 (2018): Pages 1072-1092
ISDS Article ID: IJDS18011003

Analysis of efficiency of trained, non-trained and control group of farmers: A case study of wheat farmers in north region of Bangladesh

Mohammad Earfan Ali Khondaker *

Department of Statistics, Hajee Mohammad Danesh Science and Technology University, P.O. Box 5200, Dinajpur, Bangladesh

Abstract

This paper is to examine the effect of farm size on economic efficiency among trained, non-trained and control group of wheat farmers so that we can detect ways to improve wheat production in the country. Moreover, the quest of the papers is to endeavor to spheres of technical, allocative, and economic efficiencies among sampled 600 large, medium and small scale wheat farmers in north region of Bangladesh. The socioeconomic factors that influence economic efficiency in wheat production in north region of Bangladesh have also been determined. Results indicate that the mean economic efficiency indices of trained, non-trained and control Group of wheat farmers are 81%, 78%, and 71%, respectively. The corresponding figures for the small, medium and large scale farmers are 77%, 77%, and 75%, respectively. The skill and efficiency levels of a farmer is also depending on the number of years of school for formal education, distance extension advice and how bigger the farm is which has a strong influence. The higher variation in economic efficiency implies that economic efficiency was somewhat unstable for the trained and non-trained farmers as well as for the control group of farmers in wheat production

Keywords: Efficiency; Farming; Frontier; Production; Bangladesh

Cite this article as: Khondaker, M.E.A. (2018), "Analysis of efficiency of trained, non-trained and control group of farmers: A case study of wheat farmers in north region of Bangladesh", *International Journal of Development and Sustainability*, Vol. 7 No. 3, pp. 1072-1092.

* Corresponding author. *E-mail address:* khondaker_dgvc@yahoo.com

1. Introduction

One of the reason failure of functioning properly or lacking of these markets will lead beneath resource allocation at the farm level indicating inefficiencies. In developing countries is labour supervision cost; as hired labour is assumed to be less motivated and effective, it takes more productive family labour to supervise hired labour which decreases overall labour productivity at farm level which is an important issues. The labour and farm productivity are lower on large farms, which require more hired labour. Studies (Assunção and Braido, 2007) and (Barrett et al., 2010) argue that the imperfect market hypotheses imply the presence of unobservable variation between households that leads to differences in the input intensity levels which are inter-correlated with farm area. So that, they add a set of specific characteristics such as household size, dependency ratio, and gender of the household head in testing the inverse relation between farm size and productivity. There is no evidence in previous study has shown that household characteristics completely explain land productivity, (Samuel Mburu et al., 2014).

Again the variation in soil productivity directly affect output with small farmers and they become more productive for their plot of better quality of the land has a close relationship with methodological factors. Moreover, farming practices and production methods might vary according to farm size which is leading to differences in yields and productivity. In these papers all are shows a decrease in the severity of land productivity when controlling for soil quality, but none has found that the land productivity decreases. Lipton (2010) used differentiation in farm management skills as an explanatory variable of farm productivity using panel data which allows for household-specific fixed effects. However, the evidence does not suggest that managerial skills explain land productivity.

Moreover, the productivity of land has a close relationship with methodological factors. Here clearly mention that those large farms cannot be considered linear replicas of small ones. Incentives to use inputs vary with production scale; that is, larger farms use different technologies than small farms. Usually what we find in our empirical study on the land productivity is based on cross-sectional data and econometric models can fail to capture nonlinearities and often impose common parameters for the whole sample. However, to measure scale effects and scale ranges that are allowed in the models may be too small.

1.1. Background of the study

Wheat is the second most important crop after rice in Bangladesh with regard to both production and consumption. Until the early 1970s Bangladesh was a net exporter of wheat but currently the country imports about 60% of the total domestic demand. Wheat is grown in the cooler and medium-rainfall regions covering the Rangpur, Thakugaon and Dinajpur districts in north region of Bangladesh and is mostly rain-fed. Production is carried out by small, medium, and large scale farmers numbering about 600. The industry, supported by about 20 millers, contributes 1.4% and 30% to overall and cereal GDP, respectively. The small scale farmers are the majority of the producers but their production accounts for only one-quarter of the total wheat produced, (Khondaker, 2016). A joint Bangladesh-FAO soil survey report indicated that 2.3 million hectares of land are physically suitable for wheat under rainfed condition and an additional 0.8 million hectares would be suitable, if irrigation could be provided (Begum, 1998). According to Bangladesh soil survey report, about 3.1 million hectares of land are physically suitable for wheat cultivation. Currently the net area available for wheat is about 1.5 million hectares after leaving land for other winter crops (Hossain, 1985). Wheat and its by-products have gained importance in the households' consumption patterns in the last decade.

Fast rising population, growing urbanization, development in incomes are the factors for accelerating requisition

And demand. This gives an opportunity in food performances from traditional grain towards wheat and wheat products. Also the country has the potential of increasing the production of wheat, the sector is faced by several challenges, notably: expensive inputs (chemicals, seeds, and fertilizers); insufficient farm machineries; high fuel prices; unstable producer prices; and subdivision of large scale farms into smaller units. The small scale farmers are the majority of the producers but they differ significantly in the use of inputs, agronomic practices, and productivity from the large scale farmers (Nyoro et al., 2005). The actual levels of efficiency and sources of inefficiencies among the different size categories are, however, unknown. Measuring economic efficiency in wheat production is important for a number of reasons: the significance of the subsector in terms of farm incomes to the rural economy is spawning higher levels of competition that require increased production and distribution efficiency; and the importance of the subsector to the country's strategies relating to achievement of broad food self-sufficiency, rural employment creation, and poverty reduction.

Several studies in other countries have shown that there is significant potential for raising agricultural output or profitability by improving productive (technical and allocative) efficiency using existing resources (Rahman, 2002). In these studies we have also indicated that there may be significant efficiency differentials across regions, Trained, Non-trained and Control Group of farmers and among farms as well. Understanding the determinants of economic inefficiency of wheat production is very important for both farmers and policy makers to increase the productivity and profitability of wheat production.

1.2. Objectives of the study

The disadvantages of the agricultural land is facing under stretch from other sources: odd weather destroys the already diminished fallow periods due to fragmentation in the more population and high rainfall potential regions which are the factors responsible for declining soil fertility; and the need for equality in land ownership that brings the large wheat farms into high elevation. This study is to examine general objective of the effect of farm size on economic efficiency among wheat farmers in Dinajpur and Thakurgaon District and to suggest ways to improve wheat production in the country. To identify and analyze the possibilities for improving productivity of wheat by increasing the productive efficiency of trained, non-trained and control group of wheat farmers of Bangladesh, the specific objectives of the study were:

1- to determine the level of farm-specific, farm-size-specific and location-specific technical, allocative and economic efficiency of the wheat producing farmers of Bangladesh;
2- to identify socio-economic factors affecting the level of efficiency of farmers;
3- to measure the productivity and profitability of wheat production;

4- to suggest some policies to increase productivity and efficiencies of wheat production in Bangladesh;

2. Farm size and efficiency

Different research in Bangladesh have completed some research works on various agronomic aspects of wheat productions but research work comprising agronomic as well as economic aspects have started only recently. Banik (1994) estimated technical efficiency of individual farms employing the stochastic frontier model with cross-sectional data for 99 farms from a village of Bangladesh. The MLE method was employed to Cobb-Douglas production frontier. He found a wide variation in the level of technical efficiencies across farms. The average technical efficiency was 0.78, indicating that there was considerable scope for increasing the technical efficiency. It was observed that the average technical efficiency of owner tenant/tenant farms was higher that of owner farms. In the case of the most efficient farm, it was common for the operator and his family to prepare firm plot seedbed to apply fertiliser and pesticides at appropriate time and to manage water efficiently. In contrast, the least efficient farm relied heavily on hired labour as the head of the farm was employed in some non-farm activities. Rahman et al. (1999) investigated the rice production of Bangladesh using a Cobb-Douglas stochastic production function which incorporates a model for the technical inefficiency effects. The mean farm specific technical efficiencies for Boro, Aus and Aman were 86%, 93% and 80%, respectively. The model for the technical efficiency effects in the Cobb-Douglas production frontiers included the farm-specific factors age, education, experience, and extension contact and farm size. It was found that older and more experienced farmers tended to have smaller efficiencies than the younger and less experienced farmers. Education has no impact, extension contact had a vital role and farm size had significantly positive effect on the technical efficiency effect of rice production Rahman, et al., 1999). Samad and Patwary (2002) have estimated technical efficiencies for the textile industry of Bangladesh from CMI panel data. This justifies use of the stochastic frontier model and the associated ML method of estimation. Their important result for the textile industry in Bangladesh that implies only 80% of the potential output is being realized in this sector. This research will be very helpful for future studies (Samad and Patwary, 2002). Baksh (2003) studied economic efficiency and sustainability of wheat production in Bangladesh by applying stochastic frontier production function of a Cobb-Douglas type functional form. He observed that farm-specific technical efficiency varied among farmer to farmer and ranged from 0.62 to 0.96 with a mean of 0.88 in Dinajpur district followed by efficiency that ranged from 0.51 to 0.96 with a mean of 0.69 in Rangpur district. The frontier farmers received higher yield by following optimum seeding time, using more urea, TSP, gypsum, manure and applying more frequently irrigation water with modest use of seed rate and human labour at both the sites (Baksh, 2003). Islam (2003) studied profitable and technical efficiency of wheat production in some selected areas of Bangladesh. He applied stochastic frontier production with Cobb-Douglas functional form and found mean technical efficiency level of 70 percent. The medium farmers were technically more efficient than small and large farmers. He found that co-efficient of farming experience and frequency of extension contact to be negative and significant implying that the farmers with more farming experience and more extension contact were technically less inefficient (Islam, 2003). Baksh et al. (2008) estimated technical efficiency and technical progress (change) with stochastic frontier production function model on wheat farmers in northern regions of Bangladesh. Panel data have been used for (2007-2008) years from a sample of 100 trained, non-trained and control group of farmers. The results showed that the average technical efficiency of trained, non-trained and control group of farmers are 77%, 68% and 64%, respectively obtained over the whole period of estimation. The small and medium trained farmers were technically more efficient than large farmers. He found that co-efficient of farming experience and frequency of extension contact to be negative and significant implying that the farmers with training and more extension contact were technically less inefficient. The evidence on the farm-size efficiency relationship is mixed. It is important to clearly define the terms and methodologies adopted in investigating the relationship among trained, non-trained and control group of farmers and the efficiency of farms based on the particular region. Most frontier studies have focused only on technical efficiency even though it is by improving overall economic efficiency that major gains in output could be achieved. The few studies reviewed above suggest there is still a gap in our understanding of the relationship among trained, non-trained and control group of farmers. This paper attempts to fill the gap by examining overall efficiency on wheat production (Khondaker, 2016).

2.1. Theoretical framework

The proportion of agricultural production, efficiency and how bigger the farm are always producing controversy in the regarding its management. This is an important factor for the individual farms gaining efficiency while they are facing financial stress. Efficient farms are more likely to generate higher incomes and thus stand a better chance of surviving and prospering.

This chapter is devoted to the theoretical and conceptual frameworks of efficiency measurement where technical, allocative, economic efficiency and profit efficiency and their measurement. This study uses the parametric stochastic efficiency technique that follows the (Kopp and Diewert, 1982) cost decomposition procedure to estimate technical, allocative, and economic efficiencies. Its advantage lies in the application of a stochastic frontier model with a disturbance term specification that captures noise, measurement error, and exogenous shocks beyond the farm.

Over fifty years ago (Farrell, 1957) introduced a methodology to measure economic efficiency (EE), technical efficiency (TE), and allocative efficiency (AE; by definition, EE is equal to the product of TE and AE). According to Farrell, TE is associated with the ability to produce on the frontier isoquant, while AE refers to the ability to produce at a given level of output using the cost-minimizing input ratios (Figure 1). Alternatively, technical inefficiency is related to deviations from the frontier isoquant, and allocative inefficiency reflects deviations from the minimum cost input ratios. Thus, EE is defined as the capacity of a firm to produce a predetermined quantity of output at minimum cost for a given level of technology. Productive units can be inefficient either by obtaining less than the maximum output available from a determined set of inputs (technical inefficiency) or by not purchasing the lowest priced package of inputs given their respective prices and marginal productivities (allocative efficiency). Efficiency measurement can be categorized as either input or output oriented: input-oriented technical efficiency evaluates how much input quantities can be reduced without changing the quantities produced while output-oriented measures of efficiency estimate the extent to which output quantities can be expanded without altering the input quantities used. Efficiency estimation can best be demonstrated by relating both allocative and technical efficiency; Farrell's methodology has been applied widely while undergoing many refinements.

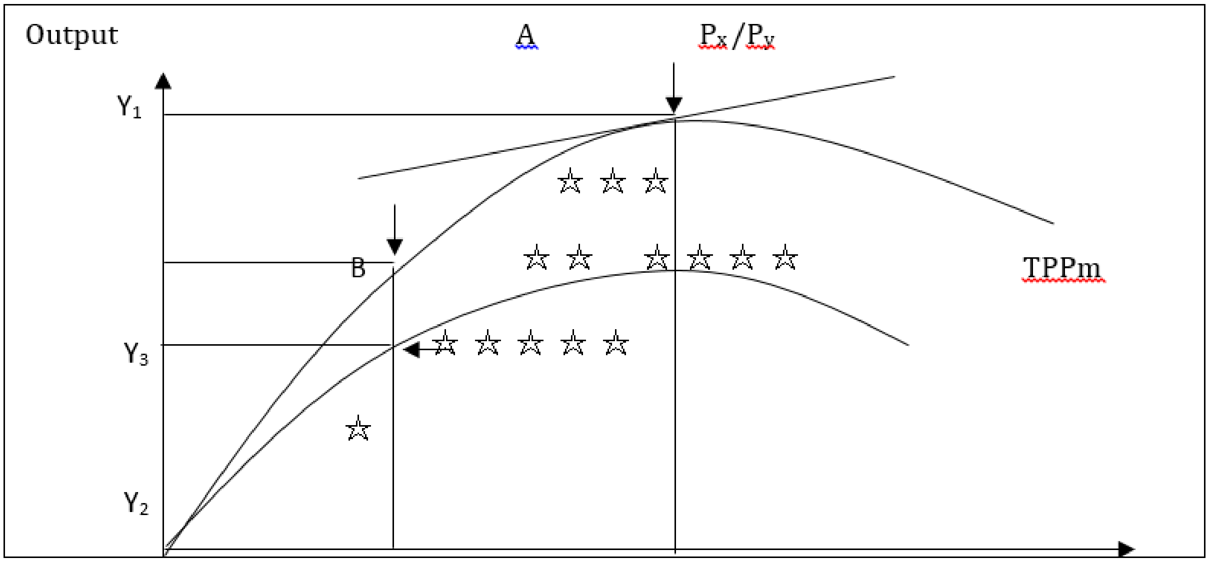

Figure 1. Graphical representation of observed and technically and economically efficient measures

3. Empirical framework: stochastic frontier production and cost functions

The parametric technique used in this study follows the (Kopp and Diewert, 1982) cost decomposition procedure to estimate technical, allocative, and economic efficiencies. The firm's technology is represented by the stochastic frontier production function as follows:

$$Yi = f(X_i; \beta) + e_i \qquad (1)$$

where Y_i = Yield of wheat of the i-th farmer, X_i = a vector of input quantities of the i-th farmer, and β = a vector of unknown parameters to be estimated. Consider the following:

$$e_i = V_i - U_i \qquad (2)$$

The V_i are assumed to be independent and identically distributed $N(0,\sigma_v^2)$ random errors independent of the U_i. The U_i are nonnegative technical inefficiency effects representing management factors and are assumed to be independently distributed with mean u_i and variance σ^2. i-th farm exploits the full technological production potential when the value of U_i comes out to be equal to zero, and the farmer is then producing at the production frontier beyond which he cannot produce. The greater of the magnitude of U_i from the production frontier, the higher the level of inefficiency of the farmer (Abdulai A. and R. Eberlin, 2001). The maximum likelihood estimation of (1) provides estimators for the beta coefficients. The variances of the random errors σ_v^2 and those of the technical and allocative inefficiency effects and overall variance of the model σ^2 are related; thus,

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \qquad (3)$$

The ratio $\gamma = \sigma_u^2 / \sigma_v^2$ measures the total variation of output from the frontier which can be attributed to technical or allocative inefficiency.

Subtracting v_i from both sides of (1) yields

$$Y_i^* = y_i - v_i = f(X_i; \beta) - U_i \qquad (4)$$

where Y_i^* is the observed output of the *i*-th firm, adjusted for the stochastic noise captured by v_i. Equation (4) is the basis for deriving the technically efficient input vectors and for analytically deriving the dual cost frontier of the production function represented by (1). For a given level of output Y_i^*, the technically efficient input vector for the *i*-th firm, X_i^t, is derived by simultaneously solving (4) and the ratios $X_1 / X_i = k_i$ (i >1) where k_i is the ratio of observed inputs X_1 and X_i . Assuming that the production function in (1) is self-dual, the dual cost frontier can be derived algebraically and written in a general form as

$$C_i = f(P_i; \alpha, Y_i^*, \alpha) \qquad (5)$$

where C_i is the minimum cost of the *i*-th firm associated with output Y_i^*, P_i is a vector of input prices for the *i*-th firm, and is a vector of parameters. The economically efficient input vector for the *i*-th firm, X_i^e, is derived by applying Shephard's Lemma and substituting the firm's input prices and output level into the resulting system of input demand equations:

$$\frac{\partial C_i}{\partial P_i} = X_i^e(P_i Y_i^*; \beta) \qquad (6)$$

where β is a vector of estimated parameters.

The observed, technically efficient, and economically efficient costs of production of the th firm are equal to $P_i' X_i, P_i' X_i^t$, and $P_i' X_i^e$ respectively. These cost measures are used to compute technical efficiency (TE) and economic efficiency (EE) indices for the *i*-th firm as follows:

$$TE_i = \frac{P_i' X_i^t}{P_i' X_i}, \qquad (7a)$$

$$EE_i = \frac{P_i' X_i^t}{P_i' X_i} \qquad (7b)$$

Following Farrell (1957), the allocative efficiency (AE) index can be derived from (7a) and (7b) as follows:

$$TE_i = \frac{P_i' X_i^e}{P_i' X_i} \qquad (8)$$

Thus the total cost or economic efficiency of the i-th firm ($P_i'X_i - P_i'X_i^e$) can be decomposed into its technical ($P_i'X_i - P_i'X_i^t$) and allocative ($P_i' - P_i'X_i^e$) components.

3.1. Cobb-Douglas frontier production function

Generally $Y = f(X_i)$ is a production function where Y is output level per unit of time and X_i denote quantities of different inputs. Here, labor (L) and capital (K) and other factors of production held constant (in the short run), we have $Y= f(X_i)$. Ultimately, labor units can be changed at a short notice but it takes more time to install machinery or equipment represented here by K. So the production functions can be explained in different forms depending on the technological relationship between Y and X; indeed, the functional relationship between output and inputs is referred to as the firm's technology. Due to duality, knowledge of a firm's technology automatically reveals a firm's cost function (the relationship between Y and total cost of all inputs including fixed costs). One of the most commonly used production function specifications for agricultural production relationships is the Cobb-Douglas function generally expressed as follows in the case of two inputs:

$$Y = f(L, K) = A L^a K^b \tag{9}$$

where A is a scale parameter (constant) and a and b are elasticity of output response due to changes in L and K, respectively; the coefficients a and b are generally restricted to ensure that the technology exhibits decreasing returns to scale, thus allowing for a profit maximum.

A variation of the Cobb-Douglas function applied in this study is the stochastic frontier model defined in (10). (The Cobb-Douglas production form is chosen because its practicality and ease in the interpretation of its estimated coefficients. Despite its limitations of constant elasticity of substitution, the Cobb-Douglas is found to be an adequate representation of our data.) The empirical Cobb-Douglas frontier production function with double log form can be expressed as:

$$l_n Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + v_i - u_i \tag{10}$$

where l_n = natural logarithm; Y_i = wheat output (in kg per acre) of the i-th farmer ; X_1= quantity of fertilizer used in kg per acre; X_2 = quantity of seeds used in kg per acre; X_3= quantity chemicals used in kg per acre; X_4= quantity of foliar used in liters per acre; X_5 = cost of hired labor per acre; X_6 = imputed cost of family labor per acre; v_i=random error; u_i = inefficiency measure; and β_i = parameters to be estimated. The u_i is the nonnegative truncation (at zero) of the normal distribution with mean, μ_i , and variance σ^2 . The variables specified in the model were subjected to a correlation test that showed that all the variables were not highly correlated.

3.2. The Empirical Cobb-Douglas frontier cost function cost function

An input is the minimum payment required to keep the input in its present employment from the economic cost. It is the payment the input would receive in its best alternative employment. The corresponding dual stochastic Cobb-Douglas frontier cost function which is the basis of estimating the allocative efficiencies of the farmers is specified as follows:

$C_i = f\,(f\,(P_i;\alpha, Y_i^*, \alpha),\ i=1,2,3,\ \ldots\ldots, N$ (11)

where C_i = minimum cost of the th firm associated with output, Y_i; f = Cobb-Douglas functional form; P = input prices employed by i-th farm in wheat production; α = parameter to be estimated; Y_i^* = the observed wheat output per acre of the i-th firm adjusted for the statistical noise captured by V_i; and U_i provides information on the levels of allocative efficiency of the i-th farm. The empirical Cobb-Douglas frontier cost function with double log form can be written by normalizing with labour wage rate as:

$ln\ C_i = \alpha_0 + \alpha_1\, ln\ Y_i^* + \alpha_2\, ln\ W_2 + \alpha_3\, ln\ W_3 + \alpha_4\, ln\ W_4 + \alpha_5\, ln\ W_5 + \alpha_6\, ln\ W_6 + \alpha_7 ln\ W_7 + v_i - u_i$ (12)

where C_i = total cost of production of i-th farm per acre; Y_i^* = observed wheat output per acre adjusted for statistical noise; W_2 = price of fertilizer per kg; W_3 = price of seeds per kg; W_4 = price per liter of chemical; W_5= price per liter of chemical; W_6 = wage rate per day; and W_7 = imputed family labor per day.

3.3. Estimates of factors influencing efficiency

It is from different investigators who inquired the association between efficiency using two choices (for a review of several of these papers (Bravo-Ureta and Rieger, 1997). To calculate is one of it to handle other simple non-parametric analysis. One approach is to compute correlation coefficients to conduct other simple nonparametric analyses. The second way, usually referred to as a two-step procedure, is to first measure farm level efficiency and then to estimate a regression model where efficiency is expressed as a function of socioeconomic attributes. Kalirajan (1991) observed that socioeconomic attributes have roundabout effects on production and hence should be incorporated into the analysis directly while (Ray, 1988) argued that the two-step procedure is justifiable if one assumes that production function is multiplicatively separable in what he calls discretionary (included in production function) and nondiscretionary (used to explain variations in efficiency) inputs. Analysis of the effects of firm-specific factors on economic efficiency has generated considerable debate in frontier studies. In this study, the two-step procedure has been adopted to analyze the effects of socioeconomic factors in the economic efficiency of the wheat farmers. The economic efficiency estimates obtained are regressed on some socioeconomic factors using the Tobit model. This use of a second stage regression model of determining the socioeconomic attributes in explaining inefficiency has been suggested in a number of studies. Consider the theoretical Tobit model, which takes the following form:

$Y_k^* = X_k\,\beta + U_k$ (13)

where Y_k is the latent (hidden) independent variable for the k-th farm; X_k is the vector of independent variables which have been postulated to affect efficiency. The vector β comprises the unknown parameters associated with the independent variables for the k-th farm and U_k is an independently distributed error term assumed to be normally distributed with zero mean and constant variance. Dummy variables were added to represent the various socioeconomic factors such as age, gender, and level of education of the head of household among others. Because the dependent variable in (13) is a measure of efficiency, the variables with a negative (positive) coefficient will have a positive (negative) effect on efficiency levels.

3.4. Section of sample and sample size

The study was carried out in Dinajpur, Thakurgaon and Panchagarh districts where a representative sample of 200 trained, 200 non-trained and 200 control farmers, respectively, using information by purposive sampling method for primary data collection. Two districts, Dinajpur and Thakurgaon from (Trained and non-trained farmers) higher intensity and another districts, Panchagarh (control group of farmers) from medium intensity areas were chosen considering the intensity of wheat area coverage among different regions. The low intensity wheat growing areas were not included in the study because it was assumed that these areas had limited potential for wheat production. The three great regions represent two different Agro-Ecological Zone (AEZ) such as AEZ-1 (Takurgaon and Panchagarh) and AEZ-3 (Dinajpur), which cover (4.78 and 3.56 %) and (5.66%), respectively, of total area of the country. These three districts also produce about 14 percent of the total wheat crops in Bangladesh (BBS, 2008). The selection of these areas will be uniform on the spatial context of the wheat growing areas of the country. In the second stage, five upazilas are selected; these are Bochaganj, Birganj, Pirganj, Ranisankail and Boda from three districts consisting of 23 upazilas. One union from each upuzila was selected randomly. Finally from these five selected mouzas we collected 200 trained, 200 non-trained and 200 control farmers, respectively, using information by purposive sampling method for primary data collection. In the second stage, five upazilas are selected; these are Bochaganj, Birganj, Pirganj, Ranisankail and Boda from three districts consisting of 23 upazilas. One union from each upuzila was selected randomly. Finally from these five selected mouzas we collected 200 trained, 200 non-trained and 200 control farmers, respectively, using information by purposive sampling method for primary data collection.

Trained farmers refer to those who received training on wheat production and participated in the demonstration trials (Training arranged by the Wheat Research Center (WRC, Dinajpur, Bangladesh).

Non-trained farmers are those who visited demo field and participated in wheat field days residing near demonstrated farmers; and

Control farmers are those who never participated in any field days, discussion meeting, and house is far from demonstrated farmers.

In a complete sample survey, the required information is collected from each and every elements of the population. In this research statistical tools were applied to select representative sample numbers. For determining the sample size the variability of land holding of the farmers in the selected areas was considered. The series of data on size of land holding were plotted on a graph to observe the dispersion of the data. Distribution of data in a series happened to be distorted on the right side indicating a positive skewness. It was, however, ideal to choose samples from normal distribution. There was no safe general rule as to how large sample size must be for use of the normal approximation in computing confidence limit (Cochran, 1999). In order to normalize the data the following Fisher's measures of skewness (Fisher's,1958 and Karim,1996) formula was used and by applying this technique and optimum number of samples (Moser and Kaltons,1980); Cochran (1999) were chosen for this research. For population in which the principal deviation from normality consists of positives skewness, a crude rule that occasionally found useful is:

Sample size, $n \geq 25\ G_1^2$ (which says 95% confidence probability)

where Fisher's measures of skewness

$$G_1 = \frac{E(y_i - \bar{Y})^3}{\sigma^3} = \frac{1}{N\sigma^2}\sum_{i=1}^{N}(y_i - \bar{Y})^3$$

N = Population size

y_i = i-th number of the population

$\bar{Y}$ = Population mean

σ = Standard deviation

As the strata differ not only in size but also in variability and it was considered reasonable to take large samples from the more variable strata and smaller from the less variable strata, we can then account for both (differences in stratum size and differences in stratum variability) by using disproportionate sampling design. The Neyman Allocation Method, Neyman (1934) was used to determine the samples from different strata (Parel et al., 1973 and Kothari, 2001). By applying these techniques the number of samples for different locations and farm groups was estimated.

4. Key results and discussion

This section highlights the key results on the production systems, productivity, and efficiency levels.

4.1. Factors influencing production practices

Farm level yield of wheat is much lower than the yield obtained in on-station experiment and in farmer's field demonstration. This difference has resulted due to the variation in input use and poor management at farm level. To increase wheat yield, the existing production practices of wheat at farm level needs to be identified first. With this view, the present study deals with the level of technology employed and agronomic practices followed by the farmers at farm level in wheat production.

Adoption of modern technology and production practices vary among the group of farmers, farms and locations for various reasons. The factors of production are not maintained properly in the farmers' level. Variation in amounts of different factors of production and production environment different input used and other management varied from one farmer to another. Thus the potential yield level at farmers' field is not achieved in many cases. The management practices and input use are likely to be influenced by various socio-agro-economic factors.

A required number of the farmers (both small scale and large scale) were growing wheat on rented land. Some farmers are high cost of renting land had implications on the area that farmers were able to put under production. The latest technology was highly mechanized with most of the farm activities being carried out by use of tractors. The large scale trained farmers reported high use of inputs such as certified seeds and fertilizers while most small scale farmers used recycled seeds during planting. The main reason for the use of recycled seeds was that they were cheaper than the purchased hybrid seeds. As a result, the productivity among the small scale farmers was lower than the large scale farmers. Wheat productivity in the district was below the normal yields mainly due to inadequate rainfall during the 2007 cropping season. The use of inputs such as certified seeds was quite low and farmers relied on recycled seeds. Fertilizer use was also low especially among the small scale farmers. Chemicals, land preparation costs, and fertilizer and seed costs consider the main cost components.

Moreover, most of the farmers had achieved the primary level of education. The literacy level determines the rate and extent of technology adoption and, with such level of education, the uptake of technology can be enhanced. Majority of the farmers were self-employed in agriculture implying that they were available on their farms most of the times. The results indicate that most farmers were not accessing extension services mainly due to unavailability of extension workers and farmers had to travel long distances to access extension advice. Similarly, few farmers accessed credit facilities mainly due to lack of collateral and very strict conditions of accessing credit. All other costs held constant; the gross margins looks attractive for both categories of farmers. This indicates that wheat production can be a profitable enterprise among the small scale farmers. With the supply of labor in the rural areas, the small scale farmers would manage to produce wheat in a cost-effective manner. This argument is supported by maize sector Bangladesh where majority of the farmers are small scale farmers practicing labor-intensive farming techniques and they supply the bulk of maize produced in the country.

4.2. Technical, allocative, and economic efficiencies

The maximum-likelihood (ML) estimates of the parameters of the stochastic production frontier were obtained using the program (FRONTIER 4.1, 1994). These results are presented in Table 1 which also presents the OLS results of the average production function for comparison. The signs of the slope coefficients of both OLS and ML estimates are positive except for family labor that has a negative coefficient implying that increasing the family labor affects wheat production negatively. ML estimated coefficients such as seeds, fertilizers, and chemicals are significant while for OLS only chemicals coefficient is statistically significant. The estimate of the variance parameter gamma is also significantly different from zero, which implies that the inefficiency effects are significant in determining the levels of wheat output of the sampled farmers. The estimated production function is given as

Table1. Maximum likelihood estimates for parameters of farm-size-specific Cobb-Douglas stochastic normalized cost frontier and economic inefficiency effect model

Independent Variables	Parameters	Farmer Category		
		Trained farmers	Non-trained farmers	Control farmers
***Stochastic frontier*:**				
Constant	β_0	5.316**(0.41)	3.321**(1.00)	3.482**(0.83)
Ln Human labour (man-days/ha)	β_1	-0.052(0.033)	0.055 (0.530)	0.075(0.044)
Ln Powr tiler/Animal power (hour/ha)	β_2	0.010*(0.004)	0.146*(0.072)	0.005(0.005)
Ln Seed (kg/ha)	β_3	-0.066(0.035)	0.096 (0.168)	0.046(0.092)
Ln Fertiliser (kg/ha)	β_4	0.182 (0.035)	0.128*(0.066)	0.187**(0.04)
Ln FYM (kg/ha)	β_5	0.004**(0.00)	0.006*(0.003)	0.003*(0.014)
Ln Irrigation cost (Tk./ha)	β_6	0.104**(0.01)	0.023*(0.012)	0.148**(0.02)

Ln Weedicides cost (Tk./ha)	β_7	0.007(0.0023)	0.008(0.005)	0.004(0.003)
Dummy for sowing date (1=Optimum, = otherwise)	η_1	0.015*(0.007)	0.045*(0.022)	0.062**(0.01)
Dummy for variety (1= *Shatabdi*, 0=otherwise)	η_2	-0.028(0.029)	0.004 (0.025)	0.023(0.044)
Dummy for seed source (1=Own, 0=otherwise)	η_3	0.002 (0.008)	-0.022(0.030)	0.006(0.014)
Dummy for locations (1= Dinajpur, 0=otherwise)	η_4	0.036**(0.05)	0.015 (0.030)	2.43(0.014)
Technical inefficiency effect model:				
Constant	δ_0	0.134**(0.04)	0.262*(0.125)	0.214*(0.110)
Ln cultivated land (in ha)	δ_1	-0.000091	0.006 (0.115)	0.010(0.012)
Farmers age (years)	δ_2	0.0004(0.000)	-0.003(0.002)	-0.001(0.001)
Farmers education (year of schooling)	δ_3	- 0.004**(0.001)	-0.000008	-0.007**(0.002)
Wheat farming experience (years)	δ_4	-0.0008(.0013)	-0.000002	-0.002(0.001)
Household size (persions/hh)	δ_5	-0.002(0.003)	-0.003(0.043)	-0.004(0.004)
Dummy for Extension (1=Yes, 0=otherwise)	δ_6	0.013 (0.009)	0.019 (0.049)	-0.012(0.022)
Dummy for wheat training (1=Yes, 0=otherwise)	δ_7	-0.001(0.016)	-0.223(0.143)	-0.00036
Variance parameters:				
Sigma-squared	σ^2	.001**(.0004)	.005**(0.002)	0.004**(.001)
Gamma	g	1.000**(.037)	0.996**(0.08)	1.00* (0.455)
Log likelihood function			137.667	146.161

*[** and * indicate significant at 1% and 5% level of probability, respectively. *Figures in the parentheses indicate standard error, Source: Own estimation.]*

4.3. Maximum likelihood estimates of farm-specific Cobb-Douglas stochastic frontier production function and technical inefficiency effect model:

Using stochastic frontier production function described were estimated by maximum likelihood estimate (MLE) method using a computer software, FRONTIER 4.1 programme which also provides other variance parameters such as sigma squared (σ^2), gamma (γ) and log likelihood function. To generate farm-specific technical efficiency indices for wheat production in the study areas, the stochastic frontier production function with yield as dependent variable was estimated in which all variables were standardized on the basis of per hectare cultivated land area. The ML estimates of the co-efficients of stochastic Cobb-Douglas production frontier and technical inefficiency effect model which show the best practice performance, *i.e.*, efficient use of the variable technology are presented in table 2. The empirical results indicate that the co-efficients of human labour, power tiller and animal power fertiliser of NPKGs, FYM and irrigation cost were positive and significant, while that of seed and weedicides cost were positive but insignificant. It indicated that human labour, power tiller and animal power, FYM and irrigation cost had significant and positive impacts on wheat production. The estimated co-efficients of the explanatory variables in the model for the technical inefficiency effects are of interest and have important implications. The co-efficients of FYM and irrigation cost were positive. In other words, the elasticities of FYM and irrigation cost were 0.005 and 0.059, respectively. It implies that FYM and irrigation cost had a significant and positive impact on wheat yield. The yield of wheat increases by 0.005 and

0.059 percent if farmers apply 1 percent additional FYM and irrigation, respectively. Moreover, the co-efficients of dummy variables such as sowing date and location were found positive and significant. On the other hand, the co-efficients of dummies for variety and seed source were negative and insignificant.

Table 2. Maximum likelihood estimates of the stochastic Cobb-Douglas frontier production function and technical inefficiency effect model for wheat

Independent variables	Parameters	Co-efficient	Standard error	t-ratio
Stochastic frontier:				
Constant	β_0	3.766	0.389	9.68
Ln Human labour (man-days/ha)	β_1	0.063*	0.029	2.19
Ln Power tiller/animal power (hour/ha)	β_2	0.008*	0.003	2.43
Ln Seed (kg/ha)	β_3	0.07	0.037	1.91
Ln Fertiliser (kg/ha)	β_4	0.203**	0.024	8.4
Ln FYM (kg/ha)	β_5	0.005**	0.001	7.28
Ln Irrigation cost (Tk./ha)	β_6	0.059**	0.006	10.6
Ln Weedicides cost (Tk./ha)	β_7	0.002	0.003	0.84
Dummy for sowing date (1=Optimum, 0=otherwise)	η_1	0.063**	0.009	6.73
Dummy for variety (1= *shatabdi*, 0=otherwise)	η_2	-0.004	0.017	-0.22
Dummy for seed source (1=Own, 0=otherwise)	η_3	-0.001	0.008	-0.13
Dummy for locations (1=Dinajpur, 0=otherwise)	η_4	0.036**	0.015	2.43
Technical inefficiency efect model:				
Constant	δ_0	0.173	0.068	2.56
Ln Cultivated land (ha)	δ_1	0.0002	0.012	0.22
Farmers age (years)	δ_2	-0.0005	0.0006	-1.18
Farmers education (year of schooling)	δ_3	-0.005**	0.002	-2.81
Wheat farming experience (years)	δ_4	-0.002*	0.001	-1.98
Household size (pp/hh)	δ_5	-0.003	0.004	-1.5
Dummy for Extension (1=Yes, 0=otherwise)	δ_6	0.007	0.008	1.04
Dummy for wheat training (1=Yes, 0=otherwise)	δ_7	-0.006	0.026	-0.45
Variance parameters:				
Sigma-squared	σ^2	0.005**	0.001	8.746
Gamma	Γ	1.000**	0.006	175.03
Log likelihood function			371.148	

*[** and * indicate significant at 1% and 5% level of probability, respectively. Source: Own estimation.]*

The parameter estimates of the dummy for sowing date had the larger positive co-efficient compared to other dummy variables. In other words, the elasticity of dummy for sowing date (0.063) was the biggest among all dummy variables used, implying that the level of wheat production was higher in medium high lands and in optimum sowing date. This was because of better suitability of medium high land for wheat cultivation. On the other hand, wheat production is much sensitive to sowing date, sowing of seeds beyond optimum date

(November 16-25) cause yield loss due to heat stress in the booting stage. At 1% level of significance, dummy for locations had positive co-efficient. This implies that in general wheat production was higher among the trained farmers in Dinajpur than other group of farmers and locations. This is because there are advantages of loamy soil in respect of moisture holding and that of Dinajpur location in respect of suitable weather for wheat production. The sign of the co-efficients of the stochastic frontier is as expected, with the expectation of the negative estimate of the animal labour variable. The negative elasticity for animal power may be due to the fact that it is used extensivly more years of poorer rainfall (for weed control, levy bank improvements, etc) when yields are lower. Thus the animal labour may be an inverse proxy for rainfall. The co-efficient of hired labour ratio is positive, which indicates that the farm operations of hired labour tend to be more efficient. The human labour, power tiller and animal power was also positive. It indicated that the elasticities of human labour, power tiller and animal power were 0.063 and 0.008, respectively, which were playing a significant positive role on wheat yield. It further implies that holding other things constant, the yield of wheat would increase by 0.063 and 0.008 percent, as farmers would apply 1 percent additional human labour, power tiller and animal power, respectively. The estimated values of variance parameters (σ^2 and γ) were large and significantly different from zero, which indicated a good fit, and correctness of the specified distributional assumptions. The significant value of γ also indicated that there were significant technical inefficiency effects in the production of wheat.

4.4. Maximum likelihood estimates of farm-size-specific Cobb-Douglas stochastic normalized cost frontier and economic inefficiency effect model:

The co-efficients of per hectare irrigation cost, dummy for sowing date, seed source and location were found to be positive but insignificant. On the other hand, the co-efficient of fertiliser price were negative and significant, which implies that an increase in the use of urea and TSP would result in the decrease of cost of producing wheat for the large farmers. The co-efficients of power tiller/animal power price per hectare mechanical, weedicides cost, land rent, and dummy for were found to be negative and but statistically insignificant for the large farmers. The co-efficients of output, FYM price per hectare weedicides cost and land rent, and dummy for seed source were positive and significant which imply that an increase in the magnitudes of these variables would result in the corresponding increase of cost of producing wheat for the medium farms.

The co-efficients of power tiller/animal power price, per hectare irrigation cost, dummy for sowing date and variety were found to be positive but statistically insignificant. On the other hand, the co-efficient of per hectare mechanical cost were negative and significant which imply that an increase in the magnitudes of these variables would result in the corresponding increase of cost of producing wheat for the medium farmers. The co-efficients of seed price, fertiliser and dummy for location were found to be negative but insignificant. For the small farm category, the co-efficients of output and per hectare land rent were positive and significant which imply that an increase in the magnitudes of output and land rent would result in the corresponding increase of cost of producing wheat. The co-efficients of seed price, per hectare weedicides cost and dummy for location were found to be negative but insignificant. On the other hand, the co-efficients FYM price, per hectare mechanical cost and dummy for sowing date were negative and significant which imply that an increase in the magnitudes of these variables would decrease the cost of producing wheat for small farms. The co-efficients of power tiller, price, per hectare irrigation cost, dummy for variety and seed source were found to be negative but statistically insignificant. The γ-parameter associated with the variances in the stochastic frontier is estimated to be greater than 0.9 in all the three groups of farmer. Although this parameter cannot be interpreted as the proportion of the variance of the inefficiency effects relative to the sum of the variance of the inefficiencies effects and random variation, it indicates that the random component of the inefficiency effects does make a significant contribution in the analysis of agricultural production in the different farmers of Bangladesh involved.

Table 3. Maximum likelihood estimates for parameters of farm-size-specific Cobb-Douglas stochastic normalized cost frontier and economic inefficiency effect model

Independent variables	Farm category			
	Parameters	Large	Medium	Small
Stochastic frontier:				
Constant	α_0	3.18 (0.998)	15.14 (0.991)	-9.00 (3.06)
Ln Output (kg)	α_1	0.590**(0.291)	0.358**(0.16)	0.619**(0.293)
Ln Power tiller/Animal power (Tk./h)	α_2	-0.974(0.999)	0.487 (1.05)	-0.853 (1.07)
Ln Seed price (Tk./kg)	α_3	0.331**(0.145)	-0.635 (0.472)	0.531 (0.325)
Ln Fertiliser price (Tk./kg)	α_4	-0.12544	-0.721**(0.32)	-0.507 (0.867)
Ln FYM price (Tk./kg)	α_5	-0.025 (0.023)	-.029**(0.01)	-0.10971
Ln Mechanical cost (Tk./h)	α_6	-.025**(0.023)	-029**(0.004)	0.021**(0.005)
Ln Weedicides cost (Tk./h)	α_7	-0.002 (0.069)	0.024(0.006)	0.017 (0.025)
Ln Land rent (Tk./ha)	α_8	-0.080 (0.965)	0.806* (0.334)	0.163**(0.045)
Ln Irrigation cost (Tk./ha)	α_9	0.108 (0.460)	0.014 (0.008)	-0.018 (0.010)
Dummy for sowing date (1=*Optimum*, 0=otherwise)	μ_1	0.0003(0.0009)	.0003(0.0002)	-0.005**(0.001)
Dummy for variety (1= *Shatabdi*, 0=otherwise)	μ_2	0.242*(0.222)	0.0001(0.083)	-0.182(0.241)
Dummy for seed source (1=*Own*, 0=otherwise)	μ_3	0.305(0.952)	0.476*(0.212)	-0.264(0.397)
Dummy for locations (1=*Dinajpur*, 0=otherwise)	μ_4	0.018(0.025)	-0.008(0.019)	0.026(0.021)
Inefficient effect model:				
Constant	δ_0	0.005 (0.999)	0.476 (0.651)	0.372 (0.544)
Ln Cultivated land (in ha)	δ_1	-0.026 (0.272)	0.015(0.037)	0.071 (0.043)
Farmers age (years)	δ_2	-0.006 (0.156)	-0.064(0.035)	0.047* (0.034)
Farmers education (years of schooling)	δ_3	-0.041 (0.021)	-0.095(0.047)	-0.00312
Farming experience (years)	δ_4	0.190(0.998)	0.190 (0.953)	0.149 (0.942)
Household size (persons/hh)	δ_5	-0.00000008	0.001**(0.0004)	0.0001(0.0003)
Dummy for Extension (1=Yes, 0 = otherwise)	δ_6	-0.0002(0.0007)	0.0003(0.0008)	0.0005 (0.003)
Dummy for wheat training (1=Yes, 0 = otherwise)	δ_7	0.000059(0.0006)	-0.0000025	-0.0047(0.0026)
Variance parameters:				
Sigma-squared	σ^2	0.109 (0.011)	0.936**(0.001)	0.638**(0.793)
Gamma	γ	0.995 (0.938)	0.971**(0.212)	0.993**(0.107)
Log likelihood function		81.26	93.82	178.27

*[** and * indicate significant at 1% and 5% level of probability, respectively. Source: Own estimation.]*

4.5. Farm-specific indices of technical allocative and economic efficiency

The frequency distribution of technical, allocative and economic efficiency indices of wheat producers in the study areas are shown in Table.4 and Fig. 2. It is evident that the technical efficiency of the farms varied from 0.60 to 0.99, with the mean technical efficiency of 0.83. This implies that, on an average, the farmers were producing wheat to about 83 percent of the potential frontier levels and 17 percent technical inefficiency existed with the farms.

Table 4. Frequency distribution of farm-specific technical, allocative and economic efficiency estimates of wheat farmers

Efficiency Level (%)	Technical efficiency		Allocative efficiency		Economic efficiency	
	No. of farms	Total farms (%)	No.of farms	Total farms (%)	No. of farms	Total farms (%)
≤ 60	4	0.7	-	-	36	6
61 – 70	87	14.5	1	0.2	142	23.7
71 – 80	141	23.5	53	8.8	165	27.5
81 – 90	256	42.7	68	11.3	212	35.3
91 – 100	112	18.7	478	79.7	45	7.5
Total	600	100	600	100	600	100
Mean	0.83		0.93		0.77	
Maximum	0.99		1.00		0.97	
Minimum	0.6		0.67		0.44	
Standard deviation	0.09		0.06		0.10	

Source: Own estimation

It is evident that only 18.7 percent of the sample farmers achieved technical efficiencies greater than 90 percent and thus obtained maximum output estimated through the frontier. On the other hand, 23.5 percent of the sample farmers were running their farms with technical efficiency levels up to 80 percent.

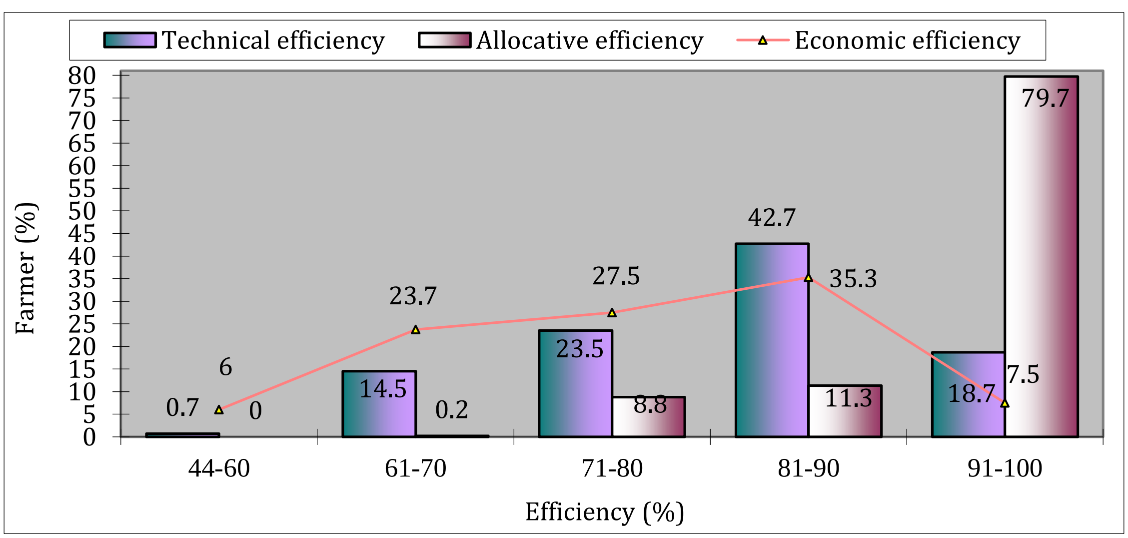

Figure 2. Technical, allocative and economic efficiency of wheat farmers

This indicates that there were some farmers who were quite poor in their technical efficiency performance. The average levels estimated for allocative and economic efficiency were 0.93 and 0.77, respectively indicating that their existed an allocative inefficiency of 7.0 percent and an average cost saving of 23.0 percent was achievable. Only 79.7 percent of the sample farmers could optimally allocate their inputs for wheat production and their allocative efficiency levels exceeded 90 percent. On the other hand, only 7.5 percent of the farmers were able to achieve economic efficiency level (frontier minimum cost) greater than 90 percent. There were a large number of farmers (20.5%) whose economic efficiency was less than 70 percent and thus their cost of saving of 30 percent was achievable.

4.6. Findings on factors influencing efficiency

The findings on factors influencing efficiency of the study indicated that the measuring efficiency of wheat between best practice and farmers can be reduced inefficiency of wheat production and can be increased significantly by adopting. In thesis cases, the parameters technical efficiency (TE), allocative efficiency (AE), and economic efficiency (EE) indices were estimated censured Tobit procedure for the following socioeconomic characteristics☹1)farm size, equal to zero for small scale and equal to one for large scale;(2)age, given by age of the household head;(3)gender, equal to zero for female head and one for male head;(4)marital status, equal zero for single, one for married, and two for widowed;(5)level of education of head, equal to zero for no education, one for primary education, and two for post primary education;(6)main occupation of household head, equal to zero for salaried and one for self-employed; (7) belonging to a farmer group, equal to zero for No and one for Yes; (8)distance to the nearest certified seed seller (km);(9)distance to nearest extension services (km);(10)land tenure, equals zero for owned land and one for rented land;(11)source of seed, equal to zero for recycled seed and one for purchased seed. The clearest pattern that emerges is that most of these social-economic characteristics were positively related to efficiency. The positive sign of farm size implies that technical efficiency increases with the size of the farm. The size of the farm is also significant with allocative efficiency. The negative sign for the age of the head implies that efficiency of production declined with the age of the head. The significant influence of education on farm efficiency is critical indicating that households headed by more educated heads were more educated compared with households headed by less educated heads. The interpretation is that farmers who had a higher level of training were more technically and economically efficient than those with low level of training.

The education level of household head and economic efficiency can be supported by similar results reported in studies which have focused on the association between formal education and technical efficiency has positive relationship. In general, more educated farmers are able to perceive and interpret and respond to new information and adopt improved technologies such as fertilizers, pesticides, and planting materials much faster than their counterparts. This result is consistent with the findings by Abdulai and Eberlin (2001) which established that an increase in human capital will augment the productivity of farmers since they will be better able to allocate family-supplied and purchased inputs and select and utilize the appropriate quantities of purchased inputs while applying available and acceptable techniques to achieve the portfolio of household pursuits such as income. The result that shorter distances to extension providers influenced farm efficiency is also consistent with findings (Seyoum et al., 1998) who found a 14% difference in technical efficiency between farmers who had access to extension services. Extension workers play a central role in informing, motivating, and educating farmers about available technology.

5. Conclusions

In the marginal analysis, the variables are measured functionally using stochastic frontiers. In this case, the parameters of respective variables are estimated using the statistical package (FRONTIER Version 4.1). The association between farm size and efficiency is one of the more persistent puzzles in development economics, even more so as many potential determinants have been put forward and tested without being able to provide a fully satisfying explanation. The findings from this study suggest that gains from improving technical efficiency exist in all farm categories but they appear to be much higher on large than on small farms. While small farms tend to use land more intensively in an attempt to alleviate land constraints, the study suggests that the relatively higher level of technical efficiency observed on small farms is largely attributable to the adoption of traditional land saving techniques rather than the use of modern land saving technologies. The higher variation in economic efficiency implies that economic efficiency was somewhat unstable for the trained and non-trained farmers as well as for the control group of farmers in wheat production. However, gains from improving allocative efficiency exist in more than 89% of the sample households. Accordingly, measures aimed at reducing labor congestion on the farms, relaxing liquidity constraints, and improving the functioning of land rental markets can significantly improve productive efficiency. While self-sufficiency in wheat remains a stated goal of the government, it has remained elusive over the years. Trained farmers adopted more recommended wheat technologies and got higher yield and profit than control farmers. Training of farmers on any particular crop is important because it can improve farmer's skill and knowledge regarding production practice and related aspects. Training and technology transfer activities hve tremendous positive effect on wheat yield and area increase (Baksh, 2008). Trained farmers have higher Technical efficiency level than non-trained farmers, meaning they have more efficiently managed inputs than non-trained farmers.

References

Abdulai, A. and Eberlin, R. (2001), "Technical efficiency during economic reform in Nicaragua: evidence from farm household survey data", *Economic Systems*, Vol. 25 No. 2, pp. 113-125.

Aigner, D.J., Lovell, C.A.K. and Schmidt, P.J. (1977), "Formulation and estimation of stochastic frontier production function models", *Journal of Econometrics*, Vol. 6 No. 1, pp. 21-37.

Assunção, J.J. and Braido, L.H.B. (2007), "Testing household-specific explanations for the inverse productivity relationship", *The American Journal of Agricultural Economics*, Vol. 89 No. 4, pp. 980-990.

Baksh, M.E. (2003), “Economic efficiency and sustainability of wheat production in wheat-based cropping systems in northwest Bangladesh”, *Ph.D. dissertation, Dept. of Agricultural Economics*, Bangladesh Agricultural University, Mymensingh-2202. Bangladesh.

Baksh, M.E., Kabir, M. and Mandal, M.S.N. (2008), “Socio-economic study on sustainability of wheat production in northern region of Bangladesh”, *Annual Report (2007–08)*, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur-5200, Bangladesh. pp. 129-134.

Banik, A. (1994), “Technical efficiency of irrigated farms in a village of Bangladesh”, *Indian Journal of Agricultural Economics*, Vol. 49 No.1, pp. 70-78.

Barrett, C.B., Bellemare, M.F. and Hou, J.Y. (2010), “Reconsidering conventional explanations of the inverse productivity-size relationship”, *World Development*, Vol. 38 No. 1, pp. 88-97.

BBS (2008), “Yearbook of Agricultural Statistics of Bangladesh. Bangladesh Bureau of statistics”, *Ministry of Planning, Government of the People's Republic of Bangladesh*, Dhaka, Bangladesh. P58.

Begum, R. (1998), “An economic study of wheat production and marketing in Bangladesh”, *Ph.D. Dissertation, the united graduate school of agricultural sciences*, Ehime University, Matsuyama, Japan, P-194.

Bravo-Ureta, B.E. and Rieger, L. (1997), “Dairy farm efficiency measurement using stochastic frontiers and neoclassical duality”, *American Journal of Agricultural Economic*, Vol. 73 No. 2, pp. 421-428.

Cochran W.G. (1999), *Sampling Techniques (3rd Edn)*, John Willey & Sons, New York, USA, pp. 39-44.

Coelli, T.J. (1994), “A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation”, *Department of econometrics*, *University of New England*, Armidale, Australia.

Farrell, M.I. (1957), “The measurement of productive efficiency”, *Journal of the Royal Statistical Society*, Vol. 120 No. 3, pp. 253-281.

Farrell, M.J. (1957), “The measurement of productive efficiency”, *Journal of the Royal Statistical Society Series A*, Vol. 120 No. 3, pp. 253-290.

Fisher, R.A. (1958), “Statistical Methods for Research Workers (Thirteenth edition)*”, Section 21. Oliver and Boyd*, Edinburgh, U.K., pp. 356.

Herdt, R.W. and Mandac A.M. (1981), “Modern technology and economic efficiency of Philippine rice farmers”, *Economic Development and Cultural Change*, Vol. 29 No. 2, pp. 375-399.

Hossain, A.B.S. (1985), “Wheat production in Bangladesh: Its constraints and research priorities. In: Wheat’s for more tropical environments proceedings of the *International symposium held September 24-28*, 1984 at CIMMYT, Mexico. D. F. pp. 59-62.

Islam, M.H. (2003), “Profitability and technical efficiency of wheat production in some selected areas of Dinajpur district”, *M.S. thesis, Dept. of Agricultural Economics*, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh.

Kalirajan, K.P. (1991), “The importance of efficient use in the adoption of technology: a micro panel data analysis”, *Journal of Productivity Analysis*, Vol. 2 No. 2, pp. 113-126.

Khondaker, M.E.A. (2016), "Measuring Efficiency of Wheat Production in North Region of Bangladesh: A Stochastic Frontier Function Analysis", *Book, ISBN*13 9783659951213, LAP Lambert Academic Publishing , German.

Kopp, R.J. and Diewert, W.E. (1982), "The decomposition of frontier cost function deviations into measures of technical and allocative efficiency", *Journal of Econometrics*, Vol. 19 No. 2-3, pp. 319-331.

Kothari, C.R. (2001), "Research methodology: methods and techniques (2nd edition)", *Wishwa Prakashan*, 4835/24 Ansari Road, Daryaganj, New Delhi 110002. pp. 468.

Lipton, M. (2010), "From policy aims and small-farm characteristics to farm science needs", *World Development*, Vol. 38 No. 10, pp. 1399-1412.

Moser, S.C. and Kaltons, J. (1980), "Survey Methods in Social Investigation (2nd edn.)", *Heinemann Educational Books Ltd*., London, WC1B 3HH, p. 146.

Neyman, J. (1934), "On the two different aspects of the representative method: The method of stratified sampling and the method of purposive selection", *Journal of the Royal Statistical Society*, Vol.97, pp. 558-606.

Nyoro, J., Muyanga, M. and Komo, I. (2005), "Wheat and wheat products trade in Kenya," *Tech. Rep., Cereal Growers Association*, Cereal Millers Association and Tegemeo Institute.

Parel, C.P., Caldito, G.C., Ferrer, P.L., De Guzman, G.G., Sinsioco, C.S. and Tan, R.H. (1973), "Sampling design and procedures", *The Agricultural Development Council*, 630 Fifth Avenue, NY 10020, USA.

Rahman, K.M.M. (2002). "Measuring efficiency of producing rice in Bangladesh: A stochastic frontier analysis", Ph.D. dissertation, *Institute of Agricultural Policy and Marketing Research*, Justus-iIiehig University,Giessen, Germany.

Rahman, K.M.M., Schmitz, P.M. and Wronka, T.C. (1999), "Impact of farm-specific factors on the technical-inefficiency of producing rice in Bangladesh", *Bangladesh Journal of Agricultural Economics*, Vol.22, No. 2, pp.19-41.

Ray, S.C. (1988), "Data envelopment analysis, nondiscretionary inputs and efficiency: an alternative interpretation", *Socio-Economic Planning Sciences*, Vol. 22 No. 4, pp. 167-176.

Samad, Q.A. and Patwary, F.K. (2002), "Technical efficiency in the textile industry of Bangladesh: An application of frontier production function", *Journal of Information and Management Sciences*, Vol. 14, No. 1, pp. 19-30.

Seyoum, M.J., Battese, G.E. and Fleming, E.M. (1998), "Technical efficiency and productivity of maize producers in eastern Ethiopia: a study of farmers within and outside the Sasakawa-Global 2000 project", *Agricultural Economics*, Vol. 19 No. 3, pp. 341-348.

Timmer, C.P. (1971), "Using a probabilistic frontier production function to measure technical efficiency", *Journal of Political Economy*, Vol. 79 No. 4, pp. 776-794.