Article

SciPap
scientific papers

Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration
2020, 28(2), 1069.

DOI: 10.46585/sp28021069
editorial.upce.cz/SciPap

The Technical Efficiency of Transplanted Aman Rice Farms in Bangladesh

Kanis Fatama Ferdushi

Shahjalal University of Science and Technology in Sylhet, Department of Statistics, Bangladesh

Anton Abdulbasah Kamil

Istanbul Gelisim University, Faculty of Economics, Administrative and Social Sciences, Turkey

Abstract

The comparison of technical efficiency scores has been estimated by the parametric and nonparametric production model for agricultural rice farms. This paper used a trans-log stochastic frontier model to explain the existing sources of inefficiency of rice farm due to socioeconomic and farm-specific variables in seven selected regions of Bangladesh based on agro-economic zone. The motivational point is to “start trade” in international rice market like other Asian countries. The results show that the estimated technical efficiency of Transplanted AMAN rice farms are vary from 45% to 92% in case of stochastic frontier analysis (SFA). In addition, the estimated technical efficiency is varying from 64% to 79% in case of data envelopment analysis (DEA). The farms’ distributed technical efficiency scores were found higher in the method of parametric SFA than nonparametric DEA in the regions of Dhaka, Khulna, Barisal and Rangpur. The graphical representation of the kernel density estimate indicates that inefficiency was among the farms in the all the selected regions. The results of kernel density estimate indicate that efficiency were negatively skewed in Dhaka, Rajshahi, Khulna, Barisal, Sylhet and Rangpur region. We can conclude that in some places, it can be possible to improve rice production using farmers existing input level. However, there is lot to subsidize for farmers which can be contributed by the local government. They should provide necessary supports for production for marginal farm owners such as training, credit, improved seed and fertilizers and also market facility.

Keywords
Technical Efficiency, Rice Farm, Trans-log Stochastic Frontier Production Model, Inefficiency, Kernel Density

JEL Classification
C51, E23, Q18

Introduction

Bangladesh had been the highest rice yielding nation during 1991 in South Asia. But after that time Bangladesh has been endured a sharp decline whereas India has revealed an increasing yield since 2001. Global paddy production has worsened substantially due to unfavourable weather conditions and also expected to result in falling output in major exported countries Indonesia, Cambodia, Nepal, Pakistan, Philippines, Sri Lanka and Thailand during 2014. ADB (2009) showed Southeast Asia is highly vulnerable to climate change. Asia accounts for more than 80 percent of global rice production and 75 percent of global consumption, and 70 percent of exports FAO (2017). Karunarathna & Wilson (2017) showed environmentally sustainable farming practices can help to maintain a sustainable agricultural sector. Although adverse climatic condition is affecting rice crop in Bangladesh but output is still increasing from year 2014 FAO (2014).

The present emerging picture shows that Bangladesh in door step to get self-sufficiency in food. Bangladesh is the world’s fourth largest rice producer among the rice producers’ countries (FAO, 2013; Hossain, Jaim, Parish, & Hardy, 2012). Rice farm is one of the major sectors to secure food for country’s population. Among other kinds of rice, Transplanted AMAN (T. AMAN) rice farm is vastly accepted due to transplantation of the crop through manual cultivation systems. Farm owners do not use supplementary irrigation for this type of rice due to wet seasonal rice. Aman rice is the predominant crop (72% of the net cultivable area) in the wet season Mainuddin et al. (2014). For less costly nature of AMAN production, marginal farmers are more interested in those types of cultivation. The results are day by day increasing production in 2016/2017 and goes up 13.656 metric tons and added value BBS (2017). However, the challenge remains to continue increasing production and maintain the current surplus of rice in the upcoming decades in order to sustain rice security in the country. By 2050, the annual demand for rice will hit around 44.6 million tons in Bangladesh. Total production of rice has been increased Mainuddin & Kirby (2015).

Corresponding author:
Anton Abdulbasah Kamil, Istanbul Gelisim University, Istanbul, Turkey.
Email: akamil@gelisim.edu.tr

To make food security for increasing population rice production and incentives for marginal farmers is imperative (Jalilov, Mainuddin, Alam, & Kabir, 2019; Uddin & Dhar, 2018). Bishwajit et al. (2013) showed self-sufficiency in rice production is paramount to its domestic food security also. Moreover, climate change will have a largely adverse impact on agricultural production in Asia and particularly in Bangladesh (Ferdushi, Ismail, & Kamil, 2019; Hijioka et al., 2014). Bangladesh takes fourth place among the thirteen main rice-producing (90% of the global rice production) with average annual rice production of 37 million tons which is 6.3% of the global share (FAO, 2018).

Efficiency measurement is important for developing countries, where resources (manpower, capitals, incomes and wealth) are insufficient and opportunities for developing and adopting better technologies are insufficient Jalilov et al. (2019). The research on efficiency can let Bangladesh to be fully self-sufficient and let to export to the other countries.

In this backdrop, the efficiency measurement should be continued to retain the position as before from the motivational point of “start trade” to international rice market like other Asian countries (e.g., India, Pakistan, Vietnam, Thailand etc.) on behalf of only being self-sufficient in rice. In 2015 Bangladesh exported 4103 ton rice and in 2014 it was 3059 ton (http://data.gov.bd/dataset/export-and-import-rice-data-bangladesh).

Moreover, in this study the objective is to compare “regional technical efficiency” which has not yet been accounted by the researcher in Bangladesh in the context of both stochastic frontier analysis (SFA) and data envelopment analysis (DEA) estimation approach. The purpose of this paper is not only to compare estimates of technical efficiency obtained from two different approaches, but also to explain the source of the inefficiency statistics which depends on socioeconomic factors about the farms considered, which may have suggestions for agricultural policy to improve rice production.

World widely, significant concern exists about the impact of socioeconomic factors and its variability on inefficiency of agricultural production. Specially, in developing countries like Bangladesh there exists an uneven social economic condition Khan, Huda, & Alam (2010). Uneven social economic condition is a barrier of higher efficiency in agriculture Uddin & Dhar (2018). He showed higher efficiency of rice farms and farmers training can help them to improve living standard. In this regards, this paper is designed to examine the source of inefficiency associated with individual farm of T. AMAN by using parametric efficiency approaches, with the aim to investigate to what extent rice production can be improved under existing technologies.

Materials

We had used a data set that contains on production related variable collected to fulfil the framework of the study. Data were extracted by the survey method of interview using a questionnaire on the year 2018 from T. AMAN rice cropping farm. Data were collected immediately after the harvest season of T. AMAN rice farm for minimizing errors. The weather was favourable during the sampling year which was supporting for sowing to harvesting for T. AMAN rice in all over the country. The study design was a multistage cluster sampling to select farm household. This survey was planned to select data randomly from each cluster.

The selection procedure of sample farm was carried out in three steps. The first step was selecting two districts purposively under each division. Bangladesh is divided into eight major administrative regions, called division. The second step was randomly selected clusters or Thana from these districts. The districts covered under AEZ according to (BBS, 2012b) are given in Table 1. Two Thana’s had been selected under each district. Third step is the selection of Union Parishads under each Thana. Finally, the data had been collected from village which is under union parishad. For the data collection, the sample size was calculated using the following formula given by (Islam, 2005) as:

$$n = z^2[P\,(1-P)/d^2] * D_{\text{eff}} \tag{1}$$

where

n is the size of the sample;

z is two-sided normal variate at 95% confidence level (1.96);

P is the percentage of indicator;

d denotes the precision;

D_{eff} is the design effect.

To obtain data on indicators at a 10% precision and 95% confidence interval, assuming a design effect of 2.20 and the most conservative estimate of indicator percentage (50%), the sample size required was 200. Therefore, 200 farm households were required to measure the efficiency of rice growing farms from each division. A total of 1400 data were collected from different farms of seven different divisions for this study.

Regional differences create inconsistency of production within farm. Regional differences vary from farm to farm due to different farm manager’s or owner’s personal qualification, farming practice, availability of irrigation facility, favourable climatic condition and definitely depend on soil quality also etc. Bangladesh comprises 30 agro-ecological zones (AEZ) which are overlapping with each other. A total number of 7 mutually exclusive regions under AEZ were considered in the data set which have been placed in Table 1. The description of the data set has been given in Table 2. The descriptive statistics of input, output, socio-economic and farm-specific variables has been specified in Table 3.

Table 1. Districts covered under AEZ

Agro Ecological Zone	Division Covered under AEZ	District Covered under AEZ
Brahmaputra-Jamuna Floodplain	Dhaka Division (DHR)	Manikganj & Kishoreganj.
Middle Meghna River Floodplain and Lower Meghna River and Estuarine Floodplain	Chittagong Division (CHR)	Brahmanbaria & Feni.
Karatoya Floodplain and Atrai Basin	Rajshahi Division (RAJR)	Naogaon & Jhalokhathi.
High Gaunges River Floodplain	Khulna Division (KHR)	Jhenaideh & Kustia.
Ganges Tidal Floodplain	Barisal Division (BAR)	Barguna & Patuakhali.
Sylhet Basin and Surma-Kusiyara Floodplain	Sylhet Division (SYR)	Sunamgonj & Gopalgonj.
Old Himalayan Piedmont Plain and Tista Floodplain	Rangpur Division (RANGR)	Gaibandah & Lalmonirhat.

Table 2. Description of the output, input, socio-economic and farm specific variables

Name of Variables	Symbols	Description of Variables
Production	(y)	Production was the output and represented by standard unit as kilogram. Total production of T. AMAN was considered during monsoon season year 2018.
Input Variables		
Area	(x_1)	The quantity of appropriate land was considered as area. Area was measured by standard unit as hectare. As a single crop, the area coverage of T. AMAN rice was highest.
Labor	(x_2)	The person worked as a labor for T. AMAN rice farm, included the owner of the farm, family members (unpaid) and hired man powers.
Seed	(x_3)	The quantities of seed which were produced by the owners themselves or from the government or from other organizations are considered.
Fertilizer	(x_4)	Fertilizers that were consumed by T. AMAN rice farm owners. Chemical and non-chemical fertilizers (cow dung) were considered for this study. Fertilizers were measured by kilogram. The chemical fertilizers were UREA, MP and GIPSAM. We considered the variable fertilizer as a combination of all fertilizers.
Pesticide	(x_5)	The amount (ml) of pesticide was considered as variable of pesticide.
Socio-economic Variables		
Status	(z_1)	Status is defined by the farmers' size of the farm. Size of the farm was categorized into three types: large farmer (>2 hectares), medium farmer (>1 hectare and ≤2 hectares), and small farmer/marginal farmer (≤1 hectare).
Member	(z_2)	The spouse and children were considered as family members.
Education	(z_3)	The number of schooling years of the farmers were considered for education.
Experience	(z_4)	The number of working years in farming were considered as variable of experience.
Contact with extension Officer (CWE)	(z_5)	CWE=1, if farmers had contacted with the agricultural officer; otherwise zero.
Training	(z_6)	Skilled worker=1, if farmers had taken training within 5 years; otherwise, zero.
Farm-specific Variables		
Plough System (PS)	(z_7)	If farm owner had used plough (machine and bullock) =1, otherwise = 0.
Seed Type (ST)	(z_8)	Different types of seed were used by farmers. ST=1, if improved seed (High Yielding Variety) supplied by Govt. were used by farmers; ST=0, improved seed (Traditional) supplied by own self or other organization were used by farmers.
Irrigation System (IS)	(z_9)	There are many traditional irrigation systems available in Bangladesh. Dummy variables had been defined for irrigation systems. If farmer's had accessed irrigation (power pump, deep tube-well etc.) during farming; then IS=1, Had not used any irrigation = 0.
Condition of Land (CL)	(z_{10})	Condition of land was a dummy variable. Before cultivation, if farm's land was degraded by any unusual circumstances. Then CL=1, not degraded CL=0.
Natural Calamity (NCL)	(z_{11})	Dummy variables that farmer's rice farms were affected by flood or others. NCL=1, if farm had been affected by natural calamity during production; NCL=0, if farm had not been faced natural calamity during production;
Disease (DSE)	(z_{12})	Disease was a dummy variable. DSE=1, if rice farm had been affected by the disease; DSE=0, if rice farm had not been affected.

Table 3. Descriptive statistics of the different variables

Variables	Dhaka Region	Chittagong Region	Rajshahi Region	Khulna Region
Production (Kg)	1288 (995.596)	1330.600 (1161.55)	2876.125 (4479.26)	1287.000 (1499.74)
Area (Ha)	0.470 (0.32)	0.366 (0.29)	1.1567 (2.14)	0.432 (0.48)
Labor (person)	22 (17.68)	18 (12.69)	40 (78.38)	19 (16.84)
Seed (Kg)	18.99 (12.38)	16.105 (11.70)	63.645 (88.13)	20.152 (19.94)
Fertilizer (Kg)	79.315 (69.56)	176.630 (345.42)	338.655 (747.40)	173.605 (202.62)
Pesticide (Taka)	324.225 (246.24)	324.225 (246.24)	662.920 (1389.30)	357.145 (284.52)
Family Member (number)	5 (2)	6 (2)	5 (3)	5 (2)
Education (Years)	3.97 (4)	5 (4)	5 (5)	5 (4)
Experience (Years)	14 (7)	14 (6)	22 (11)	20 (14)
Variables	**Barisal Region**	**Sylhet Region**	**Rangpur Region**	
Production (Kg)	1733.385 (1987.54)	1358.000 (5676.8)	1084.300 (824.23)	
Area (Ha)	0.472 (1.0499)	0.862 (0.96)	0.334 (0.20)	
Labor (person)	21 (14.94)	14 (7)	37 (38.47)	
Seed (Kg)	37.255 (36.07)	20.266 (15.29)	13.525 (8.62)	
Fertilizer (Kg)	89.034 (107.58)	33.351 (31.02)	221.615 (248.28)	
Pesticide (Taka)	506.750 (702.26)	150.226 (66.95)	554.275 (446.07)	
Family Member (number)	5 (2)	5 (2)	5 (2)	
Education (Years)	4 (4)	3 (4)	5 (5)	
Experience (Years)	18 (15)	14 (7)	11 (5)	

Note: Values in parentheses are the standard deviations

Methods

In efficiency analysis, the most established parametric approach is SFA was initiated by (Aigner, Lovell, & Schmidt, 1977; Meeusen & van den Broeck, 1977). The choice of the inefficiency effects model of Battese & Coelli (1995) is made to examine the impact of socio economic factors and others farm specific variables in productivity of rice farming. Parametric approach SFA, are used when the distribution of the random input variables and the technical inefficiencies are known. But, SFA may not hold in conditions of the distribution of the random variables are unknown. To address these types of concerns, DEA was developed by Charnes, Cooper & Rhodes (1978) had chosen to measure efficiency. The distributed efficiency scores have been estimated and compared by using the method of SFA and DEA techniques in several studies along with rice farms (Hjalmarsson, Kumbhakar, & Heshmati, 1996; Lawanson & Novignon, 2017; Neff, Garcia, & Nelson, 1993; Sharma, Leung, & Zaleski, 1997; S. Sherlund, Barrett, & Adesina, 2011; S. M. Sherlund, Barrett, & Adesina, 2002; Silva, Tabak, Cajueiro, & Dias, 2017; Theodoridis & Anwar, 2011; A. Wadud & B. White, 2000). There are few works in the literature on DEA where potential explanatory variables have been considered in Bangladesh rice farm (Balcombe, Fraser, Latruffe, Rahman, & Smith, 2008; Boubacar, Hui-qiu, Rana, & Ghazanfar, 2016; S. Sherlund et al., 2011; A. Wadud & B. White, 2000). There is also some work based on literature of SFA (Ferdushi, Kamil, Ahmed, & Kawsar, 2020; Karagiannis & Kellermann, 2019; Sharif & Dar, 1996; Wadud, 2003).

Data Envelopment Analysis

The assessment of the efficiency of T. AMAN rice farms were considered followed by CRS-DEA under constant returns to scale. First, it has been assumed that the possible sets of combination are positive for single output and multiple inputs based on the condition of no measurement error. Second, it has been assumed that a linear combinations of possible sets exist i.e., a convexity frontier model.

$$\begin{gathered}\underset{\varphi_i,\lambda_{j=1,\dots n_k},}{\text{Max}} \quad \varphi_i \\ s.t.\varphi_i y_{\text{pi}} \leq \sum_{j}^{n_k} y_{\text{pj}}\lambda_{\text{pj}}\,, p = 1,\dots, M, \\ x_{\text{qi}} \geq \sum_{j}^{n_k} x_{\text{qj}}\lambda_{\text{qj}}\,, q = 1,\dots, Q, \\ \lambda_j \geq 0; j = 1,2,\dots, n_k, n_{k=1,\dots,7},\end{gathered} \tag{2}$$

where

$j = 1,2,\dots, n_k$, represents farm units for selected seven regions $n_{k=1,\dots,7,}$;

φ_i is the proportional increase in outputs could be obtained by the $\left(j^{\text{th}} = i^{\text{th}}\right)$ farm unit;

y_{pj} denotes output vector (production) obtained by j^{th}farm units;

x_{qj} denotes the amount of $q = s + r$ inputs and farm-specific variables were used by j^{th} DMU's (area, labor and seed etc.);

$\lambda$is the weighting of j^{th} unit of farm.

The i^{th} unit of farm will be efficient and lie on the frontier, if$\varphi_i = 1$. The output oriented technical efficiency of each farm will be estimated by using the following formula:

$$\text{TE}_{\text{it}}^{\text{DEA}} = \frac{y_{\text{pi}}}{y_{\text{pi}}} = \frac{y_{\text{pi}}}{\sum_j^{n_k} \lambda_{\text{pj}} y_{\text{pi}}} = \frac{y_{\text{pi}}}{\varphi_i y_{\text{pi}}} = \frac{1}{\varphi_i}; 0 \leq \text{TE}_{\text{it}}^{\text{DEA}} \leq 1. \tag{3}$$

Equation 2 and 3 were estimated using the software DEAP 2.1 by Coelli (1996).

Stochastic Frontier Analysis

The general form of the stochastic frontier model is as follows:

$$y_{\text{it}} = f(x_{\text{it}}; \beta)\exp(\varepsilon_{\text{it}}) \tag{4}$$

where

y_{it} represents output;

x_{it} represents input matrix;

$\beta$is the vector of parameters to be estimated;

ε_{it}can be decomposed with two types of error, $\varepsilon_{\text{it}} = v_{\text{it}} - u_{\text{it}}$. The v_{it} is two-sided error are independently and identically normally distributed$v_{\text{it}} \sim N(0, \sigma^2)$. The one-sided distribution of u_{it} make sure inefficiency would be positive only.

Inefficiency effects model had been chosen on the basis of the farm specific variables. Battese & Coelli (1995) proposed a simple model that can be used to estimate the farm-specific inefficiencies where u_{it}^kwere non-negatives and independently distributed and obtained through the truncation of the distribution$N(\mu_{\text{it}}, \sigma_u^2)$. The farm specific inefficiency model can be written as

$$u_{\text{it}}^k = z_{\text{it}}^k \xi^k + W_{\text{it}}^k \tag{5}$$

where

u_{it}^k each farm production must lie on or below its frontier,

z_{it}^k farm-specifics variables which may vary over time,

ξ^k unknown coefficient of the farm-specific inefficiency variable.

The random variable $W_{\text{it}}^k$is explicit by truncation at zero of normal distribution with mean zero and varianceσ_w^2. $-z_{\text{it}}^k \xi^k$ is the truncation point and possible to write the following way$W_{\text{it}}^k > -z_{it}^k \xi^k$.These assumptions are consistence if u_{it}being non-negative truncation of the $N(\mu_{\mathrm{it}}, \sigma^2)$distribution.

The technical efficiency of the i^{th} farm with respect to the $\mathrm{group}\ ^k$frontier can be obtained using the result:

$$\mathrm{TE}_{\mathrm{it}}^{\mathrm{SFA}} = \frac{y_{\mathrm{it}}}{y_{\mathrm{it}}} = \frac{f(x_{\mathrm{it}};\beta)\exp(\varepsilon_{\mathrm{it}})}{f(x_{\mathrm{it}};\beta)\exp(v_{\mathrm{it}})} = e^{-u_{\mathrm{it}}^k}; 0 \le \mathrm{TE}_{\mathrm{it}}^{\mathrm{SFA}} \le 1. \tag{6}$$

Equation 4 and 5 were estimated by the software Frontier 4.1 Coelli (1996b).

Kernel Density Estimation

Kernel density estimation (KDE) process had been completed through the SHAZAM software version 10 Whistler, White, & Bates (2007). The parameter h, is called the smoothing parameter or bandwidth which determines their width. BANDWIDTH PARAMETER (0.36710) was set by the automatic bandwidth selection procedure. In most KDE techniques, the kernels have the same shape and bandwidth. The most common method of appropriate kernel size is the Sheather-Jones Plug-In is applied method. Mathematical expression for the KDE procedure can be written as:

$$\hat{f}(x) = \frac{1}{\sum_{i=1}^{n} W_i} \sum_{i=1}^{n} W_i\, \phi_h(x - X_i) \tag{7}$$

and Standard Normal Density Function with bandwidth adjustment

$$\phi_h(x) = \frac{1}{\sqrt{2\pi h}} \exp\left(\frac{-x^2}{2h^2}\right) \tag{8}$$

Results

Results of Hypothesis Tests

The results of formal tests of different null hypotheses were obtained using the LR statistic and are presented in Table 4.

The first hypothesis was to choose trans-log (TL) production model versus Cobb-Douglas production model. The hypothesis$H_0\colon \beta_{\mathrm{ij}} = 0, i \le j = 1,2.3,4,5$ was rejected in favor of TL stochastic frontier production model in all regions except Dhaka. This result indicates the data adequately fit well with TL production model as shown by Giannakas, Tran, & Tzouvelekas (2003).

The second hypothesis was indicating that socioeconomic and farm-specific factors were not associated with inefficiency in all regional rice farms. The hypothesis: $H_0\colon \xi_0 = \xi_1 = ... = \xi_{12} = 0$ was rejected, means that socioeconomic and farm-specific factors were creating inefficiency.

The third hypothesis explored that socioeconomic factors were not associated with inefficiency in all regional rice farms. The hypothesis$H_0\colon \xi_1 = ... = \xi_6 = 0$ was rejected. The fourth hypothesis was also $H_0\colon \xi_6 = ... = \xi_{12} = 0$ rejected, mentioned that the farm-specific factors were associated with inefficiency. The fifth hypothesis was that there were not technical inefficiency effects in the model. The hypothesis $H_0\colon \gamma = 0$ was rejected, which confirmed inefficiency effects exist in the model and supported with the results of Dhehibi, Alimari, Haddad & Aw-Hassan (2014).

Table 4. Generalized likelihood-ratio test of hypothesis for stochastic frontier analysis

Null Hypothesis	$L(H_0)$	**Test Statistics (T.S.)**	**C.V.**	**Decision**
Dhaka Region				
$H_0\colon \beta_{\mathrm{ij}} = 0, i \le j = 1,2.3,4,5$	67.74	-.03	10.371	Accept
Inefficiency Effects Model				
$H_0\colon \xi_0 = \xi_1 = ... = \xi_{12} = 0$	46.52	42.41	25.549	Reject
$H_0\colon \xi_1 = ... = \xi_6 = 0$	57.50	20.45	16.074	Reject
$H_0\colon \xi_6 = ... = \xi_{12} = 0$	56.16	23.13	16.074	Reject
$H_0\colon \gamma = 0$	34.40	66.65	36.935	Reject
Chittagong Region				
$H_0\colon \beta_{\mathrm{ij}} = 0, i \le j = 1,2.3,4,5$	27.53	159.318	10.371	Reject

Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$	46.98	120.418	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	84.09	46.198	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	76.97	60.438	16.074	Reject
$H_0: \gamma = 0$	46.98	120.418	36.935	Reject
Rajshahi Region				
$H_0: \beta_{\text{ij}} = 0, i \leq j = 1,2.3,4,5$	162.08	227.85	10.371	Reject
Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$	-63.74	31.17	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	-50.59	4.87	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	-61.82	27.33	16.074	Reject
$H_0: \gamma = 0$	-79.99	63.67	36.935	Reject
Khulna Region				
$H_0: \beta_{\text{ij}} = 0, i \leq j = 1,2.3,4,5$	-62.015	72.818	10.371	Reject
Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$	-77.36	103.508	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	-.52.40	53.588	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	-49.47	47.728	16.074	Reject
$H_0: \gamma = 0$	-102.24	153.268	36.935	Reject
Barisal Region				
$H_0: \beta_{\text{ij}} = 0, i \leq j = 1,2.3,4,5$	-138.85	54.498	10.371	Reject
Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$		38.058	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	-119.55	15.898	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	-121.17	19.138	16.074	Reject
$H_0: \gamma = 0$	-178.78	134.558	36.935	Reject
Sylhet Region				
$H_0: \beta_{\text{ij}} = 0, i \leq j = 1,2.3,4,5$	-189.43	241.128	10.371	Reject
Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$	-141.13	144.528	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	-75.00	12.268	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	-135.04	132.348	16.074	Reject
$H_0: \gamma = 0$	-147.47	157.208	36.935	Reject
Rangpur Region				
$H_0: \beta_{\text{ij}} = 0, i \leq j = 1,2.3,4,5$	55.84	81.206	10.371	Reject
Inefficiency Effects Model				
$H_0: \xi_0 = \xi_1 = ... = \xi_{12} = 0$	62.38	68.126	25.549	Reject
$H_0: \xi_1 = ... = \xi_6 = 0$	76.84	39.206	16.074	Reject
$H_0: \xi_6 = ... = \xi_{12} = 0$	88.34	16.206	16.074	Reject
$H_0: \gamma = 0$	49.61	93.666	36.935	Reject

Note: All critical values are at 5% level of significance and obtained from Table of Kodde & Palm (1986)

Correlation test

The Jarque-Bera test of normality has been done for the collected data set. There was no evidence to reject the null hypothesis that residuals were normally distributed. There was no strong correlation in between output, input and socioeconomic variables which has been given in Table 5. The correlation between y and x_1 was 0.62, which represent the existence of a moderate positive relationship. The correlation among *y* andx_2, x_3 and x_4 were found moderate. A weak relationship between *y* and$x_5$had been observed. Multi-collinearity test showed that there was no high multi-collinearity among the input variables. To test whether the differences exists among the production of different regional rice farms are statistically significant or not, Levene's robust test of Brown & Forsythe (1974) for equality of variance was done. The null hypothesis mentioned about no variability in production within the regions was rejected 14.153 (*P = 0.000*) at 1% level of significance. Consequently, estimating a common production function for all seven regions would be incorrect.

Table 5. Correlation Test

	y	x_1	x_2	x_3	x_4	x_5	z_1	z_2	z_3	z_4	z_5	z_6	z_7	z_8	z_9	z_{10}	z_{11}	z_{12}
y	1																	
x_1	0.62***	1																
x_2	0.59***	0.49***	1															
x_3	0.61***	0.66***	0.49***	1														
x_4	0.54***	0.49***	0.49***	0.34***	1													
x_5	0.39***	0.26***	0.33***	0.20**	0.43***	1												
z_1	0.20**	0.04	0.24**	0.07	0.23**	0.18**	1											
z_2	-0.02	0.14*	0.04	0.08	0.12	-0.00	-0.06	1										
z_3	0.21**	0.14*	0.15*	0.15*	0.09	0.01	0.30	-0.6	1									
z_4	0.11*	0.09	0.09	0.21**	0.17**	0.15*	0.07	0.09	-0.05	1								
z_5	0.15*	0.06	0.16	0.05	0.22***	0.18**	0.20**	0.03	0.12	0.09	1							
z_6	0.08	0.05	0.06	0.10	0.06	0.09	0.11*	-0.01	0.10	0.08	0.45	1						
z_7	-0.05	0.12*	0.07	0.10	0.15	0.01	0.08	0.07	0.04	0.01	0.00	0.02	1					
z_8	0.14**	-0.03	-0.03	-0.08	0.03	0.11*	0.15*	-0.00	0.02	-0.01	0.09	0.09	0.05	1				
z_9	-0.06	-0.11	0.05	-0.03	-0.03	0.10	0.04	0.02	-0.09	0.10	0.22***	0.18**	-0.18	0.06	1			
z_{10}	-0.01	0.09	0.02	-0.21	0.15	0.16**	0.01	-0.00	-0.08	-0.01	-0.05	-0.07	-0.00	0.15	0.15	1		
z_{11}	0.09	0.29**	0.18**	0.12*	0.16**	0.14*	-0.04	0.08	-0.05	-0.03	-0.20**	-0.25***	0.12	0.00	0.06	0.14	1	
z_{12}	-0.02	-0.01	-0.2	-0.01	-0.3	-0.01	-0.04	0.00	-0.01	-0.02	-0.02	0.2	-0.07	-0.0	0.01	-0.08	-0.04	1

Note: ***, **, * are significance level at 1%, 5%, 10% respectively.

Estimated Parameter by Maximum Likelihood Estimation Method

A trans-log stochastic production function was estimated with a two-step process to get technical efficiency in terms of farm-specific variables through the maximum likelihood estimation (MLE) method. MLE method estimates stochastic frontier model with farm-specific inefficiency effects model separately based on different regions namely DHR, CHR, RAJR, KHR, BAR, SYR and RANGR. The estimated results have been presented in Table 6.

Table 6. Stochastic frontier model estimates

Variables	Trans-log Stochastic Production Model							
	Maximum Likelihood							
		DHR	CHR	RAJR	KHR	BAR	SYR	RANGR
	PMTR	COEF	COEF	COEF	COEF	COEF	COEF	COEF
(a) Production Factors								
Constant	(β_0)	5.754*	10.909*	2.845*	-1.744**	3.842*	2.397	7.954*
Area	(β_1)	0.333	3.558*	0.590	-1.992*	-0.241	0.632	0.577
Labor	(β_2)	-0.009	-0.064	1.478	1.669*	0.585	-0.263	-0.824*
Seed	(β_3)	0.989	-1.588**	-0.184	-2.562*	0.288	0.031	0.759
Fertilizer	(β_4)	0.068	0.067	-0.489	3.293**	0.041	0.923**	0.418***
Pesticide	(β_5)	-0.202	0.094	1.384*	0.098	0.221	1.175**	-0.754*
(b) Interaction Factors								
Area* Area	(β_{11})	-0.122	0.587*	-0.005	-0.126*	-0.020	0.359*	0.028
Labor* Labor	(β_{22})	0.224*	-0.015	0.196*	-0.134*	0.185*	0.084	0.035
Seed *Seed	(β_{33})	0.139	0.128	0.044	0.154	0.070	-0.148	-0.103*
Fertilizer* Fertilizer	(β_{44})	-0.053**	-0.033	0.182*	-0.147**	0.022	-0.046	-0.024
Pesticide* Pesticide	(β_{55})	-0.027	0.040	-0.078*	0.032	-0.128	-0.003	0.097*
Area* Labor	(β_{12})	0.038	-0.075	0.140*	0.098	0.121***	-0.239	0.007
Area* Seed	(β_{13})	0.275***	-0.620*	-0.092	-0.379**	-0.094	-0.133	0.054
Area* Fertilizer	(β_{14})	0.036	-0.146**	-0.090	0.496*	-0.075	-0.133	-0.095
Area* Pesticide	(β_{15})	-0.188*	0.135	-0.018*	0.069	0.087	0.346*	-0.013
Labor* Seed	(β_{23})	-0.531*	0.016	-0.117	0.038	-0.039	0.175	0.146*
Labor* Fertilizer	(β_{24})	0.018	0.119	-0.300*	-0.064	-0.019	0.040	0.085*
Labor* Pesticide	(β_{25})	0.088	-0.055	-0.086	-0.069	-0.156	-0.163	0.009
Seed* Fertilizer	(β_{34})	0.073	0.067	0.024	-0.020	-0.164*	0.039	-0.078
Seed* Pesticide	(β_{35})	-0.013	-0.012	-0.032	0.280*	0.064	0.059	-0.029

Fertilizer * Pesticide	(β_{45})	0.027	-0.046	0.015	-0.183**	0.068	-0.152	-0.050
(c) Inefficiency Effects Model								
Constant	(ξ_0)	0.833	0.443	2.052	-0.860	0.143	2.798	0.168
STS	(ξ_1)	-0.165	-0.103	0.102	-0.754*	0.035	-2.437	-0.701*
MEM	(ξ_2)	-0.030	-0.006	-0.018	0.054	0.014	-0.020	0.082*
EDU	(ξ_3)	0.009	0.003	-0.022	-0.057*	-0.026**	0.014	-0.007
EXP	(ξ_4)	-0.034**	-0.001	-0.001	0.020*	-0.001	0.002	-0.022*
CEO	(ξ_5)	-0.430	0.043	-0.699	-0.385*	0.071	-0.122	-0.163
TR	(ξ_6)	0.0516	0.297*	-0.137	-0.363*	-0.180	0.299	-0.363***
PS	(ξ_7)	0.179	-0.228*	0.867**	-0.691	-0.017	-0.287	-0.329
ST	(ξ_8)	0.075	-0.010	-0.107	0.172	-0.156	-0.165	-0.167*
IS	(ξ_9)	-0.085**	0.034**	-0.012	0.032*	0.028	-0.029	-0.241*
CL	(ξ_{10})	-1.027**	0.084**	-0.227	1.101*	0.133**	-1.13*	0.097*
NCL	(ξ_{11})	0.002	-0.179*	-1.367**	-0.311*	0.133*	0.167	0.505
DSE	(ξ_{12})	0.833	0.443	2.052	-0.860	0.143	2.798	0.168
σ^2		0.170*	0.022*	0.434**	0.710*	0.180*	0.170*	0.087*
γ		0.936*	0.999*	0.936*	0.999*	0.013	0.922*	0.886*
Log-likelihood		62.725	107.189	-48.155	-25.606	-111.601	-68.866	96.443

Note: *, **, *** are significance level at 1%, 5%, 10% consecutively

Determinants of Inefficiency

The results show that input variable labor was negative in the DHR. The most important variable labor found insignificant and negative in the farm of DHR, CHR and SYR. In KHR labor was highly statistically positively significant at 1% level of significance. This result had been confirmed from the study Coelli, Rahman & Thirtle (2002) and showed that labor had low output elasticity. Positive means if owners of the farm increase labor then production will also increase. And negative sign implies there is already shortage of this variable and negatively significant to the output of rice farms. Seed was negatively significant in the farms of CHR and KHR. This variable was negative impact on production in the farms of RAJR. Fertilizer was showing highly positively statistically significant in those farms of KHR, SYL and RANG. Pesticide was positively related with the output in almost five regional farms namely CHR, RAJR, KHR, BAR and SYL. This variable was positively significant at 10% level of significance in the farms of SYR and was negatively highly significant at 1% level of significance in those of farms of RANG. The coefficient of the square product of labor and fertilizer had driven out to be statistically significant at 1% and 5% level of significance based on the asymptotic t-values whereas the square product of seed and pesticide were found to be insignificant. The square product of pesticide was found negative also. The interaction between area and seed, area and pesticide, labor and seed were found significant for the DHR.

It is noted that in CHR, β_0 was positive and statistically significant, i.e., technological progress improved over time. The coefficient of labor input variable showed negative sign, indicating that farm with small labor size produced more output. Sometimes, due to high cost to hire labor, it becomes impossible for farmers to hire labor. A farm with larger household size was more technically efficient Ajayi & Olutumise (2018). All the second order parameters except variable area appeared as statistically significant. Training was positively significant at 1 percent level of significance indicated that more training can enrich farmer practices. An irrigation system plays a vital role to increase productivity in rural area. IS were positively related with inefficiency in DHR, RAJR, SYR, and RANGR but negatively related in CHR, KHR and BAR. IS and CL were statistically significant at 1% level of significance. The land condition was good, good condition of land may help to grow up rice plant. In this case, higher efficiency was expected.

In KHR, economic status of farmers, the years of schooling, experience, contact with extension officer, training all socioeconomic variables were significantly different from zero at the 1% level at least indicating that the inclusion of these variables were correctly justified in explaining the farmers' action to attain the level of efficiency. The age of farmers was positive which implies that the older agricultural farm households are more technically inefficient than younger farm households. This also means that older agricultural household obviously will be more experienced and efficient. In this study, experience was showing positive in KHR that means more experienced agricultural farm household were more technically efficient Coelli, Rahman & Thirtle (2005) and contradict with the previous results. In some cases, the older or more experienced farmers are reluctant to accept the new technology.

The results of RANGR showed that labor and pesticide were statistically different from zero at 1% level of significance. The status of RANGR farmers was negatively significant. Basically poor farmers always choose to crop T. AMAN rice farm due to less cultivation cost. The status of the farmers is poorest in RANGR among other regions. Experience was negatively related with the production which is significant at 1% level of significance.

Family size that means variable MEM was sowing negative relation with the inefficiency in four regions namely DHR, CHR, RAJR and SYR. But this same variable MEM was showing positive relation in the context of inefficiency in KHR, BAR and RANGR regional farm. Family size was positively related with inefficiency. A similar result was found by Bozoğlu & Ceyhan (2007). Djokoto & Gidiglo (2016) showed training in farm management are required to make up for the mean difference. They also showed that age and family size showed a positive relationship with inefficiency. Farm-specific variables, NCL and DSE were insignificant in RANGR. In the sampling year 2018, T. AMAN rice farm had not been faced with any natural calamity. The mean technical efficiency of AMAN rice farms for seven selected regions is presented in Table 7. The mean technical efficiency was found 86.5%, 56.6%, 73.5%, 66.4%, 92.2%, 45.7%, and 86.5% by using efficiency analysis of stochastic frontier model in different regions in DHR, CHR, RAJR, KHR, BAR, SYR and RANGR. On the other hand, the mean technical efficiency was found 67.8%, 79.5%, 73.2%, 64.1%, 72.4%, 64.0%, 66.5% by using non parametric efficiency analysis of the data envelopment in DHR, CHR, RAJR, KHR, BAR, SYR, and RANGR respectively. The average technical efficiency is from 0.45 to 0.92 percent out of 1 which was calculated by using the method of SFA. And, the technical efficiency is from 64.0% to 79.5% by the efficiency estimation method of DEA. This results are supported by (Ajayi & Olutumise, 2018; Balcombe et al., 2008; T. Coelli et al., 2002; Wadud, 2003).

Table 7. Region wise mean efficiencies of T. AMAN rice farms in Bangladesh

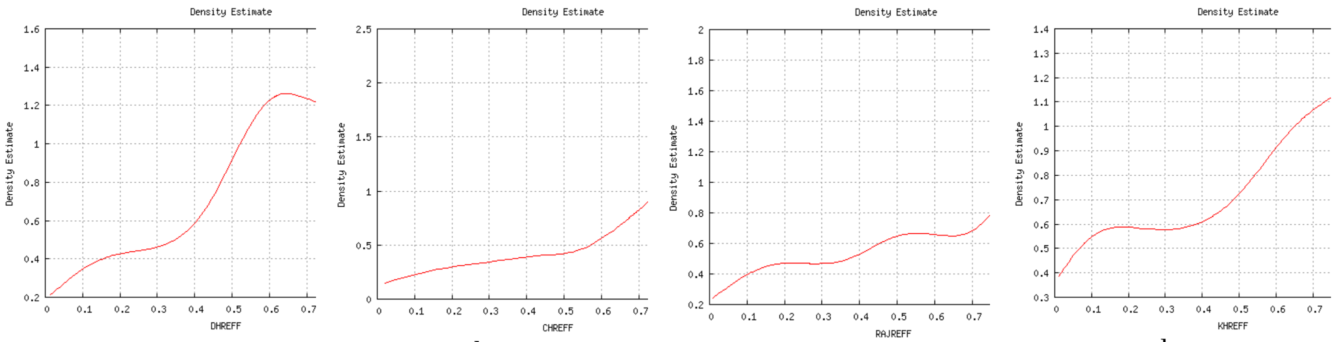
Region	Mean Efficiency for DEA	Mean Efficiency for SFA
DHR	0.678	0.865
CHR	0.795	0.566
RAJR	0.732	0.735
KHR	0.641	0.664
BAR	0.724	0.922
SYR	0.640	0.457
RANGR	0.665	0.865

The TE of DEA and SFA were same in RAJR and KHR. Jalilov et al. (2019) showed that 83% of rice farms of northwest Bangladesh were efficient whereas only 2% farms were inefficient. Fuwa, Edmonds, & Banik (2007) distinguished efficiency in medium land, upland and lowland and showed that small holder rain fed rice farms were efficient cultivators. Feng (2008) showed that the mean technical efficiency of rice production in the northeast Jiangxi Province ranged from 0.36 to 0.97. Djokoto & Gidiglo (2016) nontraditional agricultural production showed higher mean technical efficiency than traditional agriculture. Correlation between technical efficiency of SFA and DEA for different regions has been shown in Table 8. A very weak positive relationship exists in between DEA and SFA technical efficiency in Dhaka region (DE_DHR, SF_DHR). Strong downhill linear relationship found between Chittagong region and Barisal Region (DE_BAR; SF_CHR), Chittagong region and Sylhet region (DE_SYR; SF_CHR), Chittagong region and Rangpur Region (DE_RANGR; SY_CHR). From the correlation, it can be said that there was a significant difference in DEA and SFA technical efficiency score. Fig. 1 and 2 present the density estimates of the original efficiency estimates of SFA and DEA respectively

Table 8. Correlation between SFA and DEA technical efficiency

TE	DE_DHR	DE_CHR	DE_RAJR	DE_KHR	DE_BAR	DE_SYR	DE_RANGR
SF_DHR	0.018	0.105	0.232^{**}	0.227	0.280^{**}	0.240^{**}	0.273^{**}
SE_CHR	-0.564^{**}	-0.559^{**}	-0.640^{**}	-0.694	-0.778^{**}	-0.753^{**}	-0.767^{**}
SF_RAJR	-0.195^{**}	-0.231^{**}	-0.343^{**}	-0.340	-0.400^{**}	-0.405^{**}	-0.393^{**}
SF_KHR	0.288^{**}	0.248^{**}	0.408^{**}	0.418	0.508^{**}	0.484^{**}	0.521^{**}
SF_BAR	0.098	0.121	0.085	0.210	0.230^{**}	0.220^{**}	0.230^{**}
SF_SYR	-0.425^{**}	-0.384^{**}	-0.591^{**}	-0.581	-0.673^{**}	-0.675^{**}	-0.699^{**}
SF_RANGR	-0.358^{**}	-0.269	-0.310^{**}	-0.392	0.328^{**}	0.392^{**}	-0.338^{**}

Note::*, **, ***denotes significance level at 1%, 5%, 10% consecutively.



a b c d

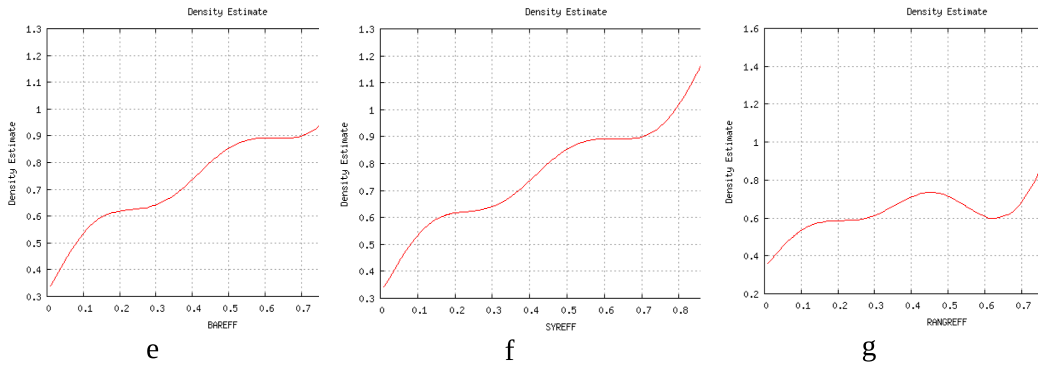


Fig. 1. Kernel density estimates of technical efficiencies for selected regions by SFA.

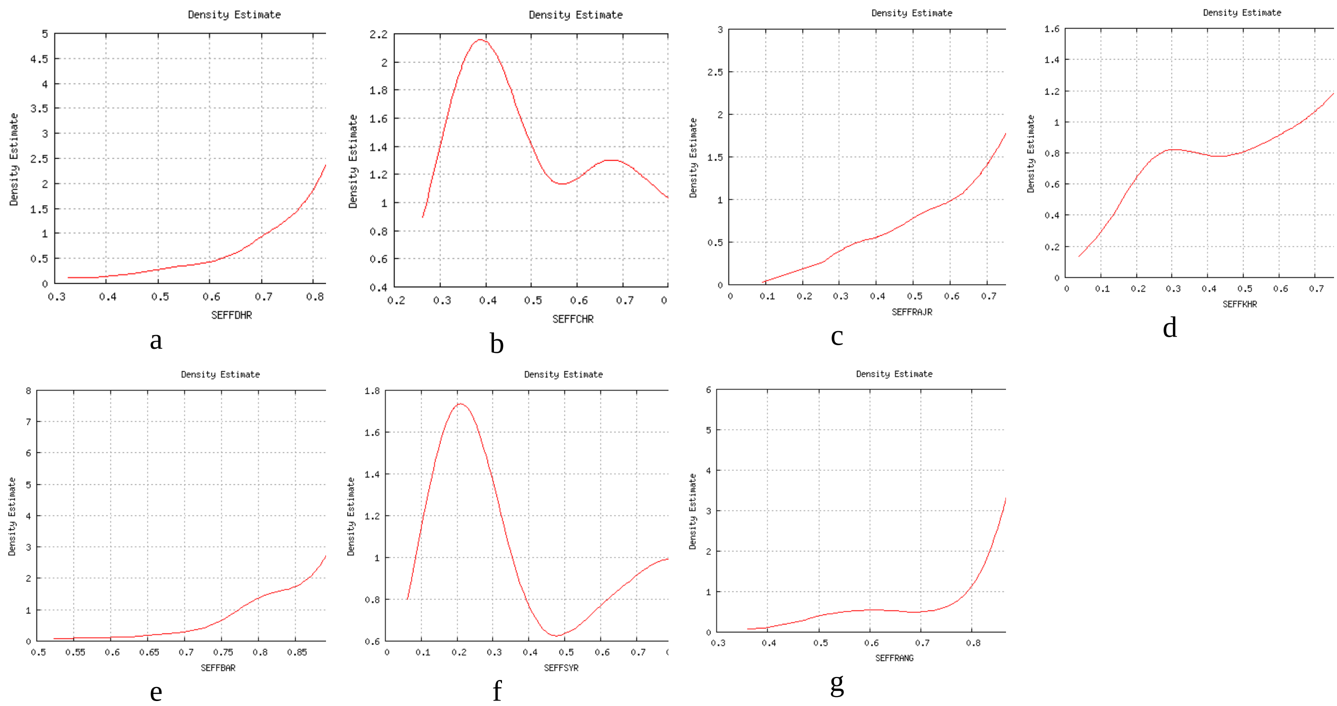


Fig. 2. Kernel density estimates of technical efficiencies for selected regions by DEA.

The calculation of the density estimates was done using the “normal reference rule of-thumb” approach bandwidth selection (Silverman, 2018) and a second order Gaussian kernel. It seemed that the original CRS DEA efficiency is asymmetric. The efficiency of DHR, RAJR, KHR, BAR, SYR and RANGR regions were negatively skewed. The graphical representation of the density estimates indicated that inefficiencies were present among the farms in the different regions. The original distributed efficiency score of SFA was also asymmetric.

Discussion

The study deals with association of farmers’ socioeconomic and farm-specific factor effects on production, specifically its impact on the efficiency through using the method of both parametric SFA and non-parametric DEA approaches since the sustainability of agricultural production depends largely on the action of the farmers. Rahman (2003) in his analysis on farmers’ perceptions and determination in Bangladesh concluded that the socioeconomic factors, education and extension contacts play an important role in raising awareness. In this backdrop, it may be possible to increase efficiency through the awareness and farming practices. There was high inefficiency in farmers’ management systems. Socioeconomic and farm-specific results showed that the farmers’ level of performance remained confined due to the lacking of awareness of government of Bangladesh. The age of farmers was positive which implies that younger farm households are more technically efficient than the older agricultural farm households. This result was supported by (Ajibefun, Daramola, & Falusi, 2006; Battese & Coelli, 1995; M. A. Wadud & B. White, 2000). The farm-specific attributes such as plough systems (PS), seed types (ST) and irrigation systems (IS) were directly influenced by farmers’ performance. Zaibet & Dharmapala (1999) showed small farm size exposed to be negative with productivity and this happened in case of Sylhet regional farms. One major important reason behind of the efficiency is that most of the people in Sylhet are likely to stay abroad. Major parts of the people are reluctant about the agricultural activities in Sylhet region. Many cultivable lands are inactive in Sylhet region. From this point, it was imperative to study the regional efficiency to identify the limitations of agricultural farms. Koirala, Mishra, & Mohanty (2016) land ownership has a significant impact on efficiency. Government must take an attractive package to inspire farmers of Sylhet region in agriculture. Although inefficiency exists in T. AMAN rice farms, the average efficiency ranged from 60% to 90% in SFA whereas the technical efficiency estimated from DEA ranged 64% to 79%. Still there exists substantial opportunity to enhance the efficiency.

Conclusion

In this study, we have used two, parametric SFA and nonparametric DEA CRS models to compare the distributed technical efficiency scores of rice farms in Bangladesh. The tested hypothesis confirmed that the differences of efficiency were explained significantly by farm specific, socioeconomic conditions of managers or owners of farm household. The results proved that inefficiency has taken place in agricultural production for existing variation in production technology among the sampled farms.

Main production factor labour is negative in most of the region means that there is scarcity of labour in those farms. Another most important factor is area. This variable is positively and significantly related in production in most regions. Bangladesh is an agro-economy based country. Land of this country is very fertile to grow rice crop. Seed is negatively statistically significant. Sometimes it becomes hard for farm owners to manage improved seed. In that case, they use their home made seedlings for their production. Fertilizer is positively statistically significant with the production. Pesticide is also positively statistically significant with the production. The sample farmers could enrich their rice production by 54.3% to 7.8% got from SFA method. The farm in Sylhet regions have to enrich their production level up to 54.3%. The results indicate that there is potentiality for increasing production of the farms to proper utilization on input which can help to meet up country's own need and as well as export for other countries. If T. AMAN farm can enhance their efficiency, not only poor owners will be promoted, but also the country will be gainer. This study recommends to make policy to provide improved seed, low cost fertilizer, and pesticide for marginal or poor farmers. It will be better if training programs can be introduced for marginal farmers from govt. co-operative organization and provide access to credit to enhance technical efficiency. Rayp & Van De Sijpe (2007) showed governments in developing countries play an important role in the growth process by their budgetary policies. Ferdushi et al. (2019) showed that vulnerable farmers can adapt better by the provided credit or loan from NGO or others.

References

ADB. (2009). *The Economics of Climate Change in Southeast Asia: A Regional Review*. Asian Development Bank.

Aigner, D., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1), 21-37. doi:https://doi.org/10.1016/0304-4076(77)90052-5

Ajayi, C., & Olutumise, A. (2018). Determinants of food security and technical efficiency of cassava farmers in Ondo State, Nigeria*. International Food and Agribusiness Management Review*, 21, 1-14. doi:10.22434/IFAMR2016.0151

Ajibefun, I. A., Daramola, A. G., & Falusi, A. O. (2006). Technical efficiency of small scale farmers: An application of the stochastic frontier production function to rural and urban farmers in Ondo State, Nigeria. *International Economic Journal*, 20(1), 87-107. doi:10.1080/10168730500515498

Balcombe, K., Fraser, I., Latruffe, L., Rahman, M., & Smith, L. (2008). An application of the DEA double bootstrap to examine sources of efficiency in Bangladesh rice farming. *Applied Economics*, 40(15), 1919-1925. doi:10.1080/00036840600905282

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325-332. doi:10.1007/BF01205442

BBS. (2012b). *Estimates of Aman rice 2011-2012: Government of the People's Republic of Bangladesh*, Bangladesh Bureau of Statistics, Agriculture Wing, Parishankhyan Bhaban, E-27/A, Agargaon, Dhaka-1207.

BBS. (2017). *Estimates of Aman rice 2016-2017: Government of the People's Republic of Bangladesh*, Bangladesh Bureau of Statistics, Agriculture Wing, Parishankhyan Bhaban, E-27/A, Agargaon, Dhaka-1207.

Bishwajit, G., Sarker, S., Kpoghomou, M. A., Gao, H., Jun, L., Yin, D., & Ghosh, S. (2013). Self-sufficiency in rice and food security: a South Asian perspective. *Agriculture & Food Security*, 2. doi:10.1186/2048-7010-2-10

Boubacar, O., Hui-qiu, Z., Rana, M. A., & Ghazanfar, S. (2016). Analysis on Technical Efficiency of Rice Farms and Its Influencing Factors in South-western of Niger. *Journal of Northeast Agricultural University* (English Edition), 23(4), 67-77. doi:https://doi.org/10.1016/S1006-8104(17)30009-0

Bozoğlu, M., & Ceyhan, V. (2007). Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey. *Agricultural Systems*, 94(3), 649-656. doi:https://doi.org/10.1016/j.agsy.2007.01.007

Brown, M. B., & Forsythe., A. B. (1974). Robust test for the equality of variances. *Journal of the American Statistical Association*, 69(346), 364-367.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429-444. doi:https://doi.org/10.1016/0377-2217(78)90138-8

Coelli, T., Rahman, S., & Thirtle, C. (2002). Technical, Allocative, Cost and Scale Efficiencies in Bangladesh Rice Cultivation: A Non-parametric Approach. *Journal of Agricultural Economics*, 53(3), 607-626. doi:10.1111/j.1477-9552.2002.tb00040.x

Coelli, T., Rahman, S., & Thirtle, C. (2005). Technical, Allocative, Cost and Scale Efficiencies in Bangladesh Rice Cultivation: A Non-parametric Approach. *Journal of Agricultural Economics*, 53, 607-626. doi:10.1111/j.1477-9552.2002.tb00040.x

Coelli, T. J. (1996). *A Guide to DEAP version 2.1: A Data Envelopment Analysis (Computer) Program*: CEPA Working Papers 96/98.

Coelli, T. J. (1996b). *A guide to FRONTIER version 4.1: A computer program for stochastic frontier production and cost function estimation*: CEPA Working papers.

Dhehibi, B., Alimari, A., Haddad, N., & & Aw-Hassan, A. (2014). Technical Efficiency and Its Determinants in Food Crop Production: A Case Study of Farms in West Bank, Palestine. *Journal of Agricultural Science and Technology*, 717-730.

Djokoto, J. G., & Gidiglo, K. F. (2016). Technical Efficiency in Agribusiness: A Meta-Analysis on Ghana. *Agribusiness*, 32(3), 397-415. doi:10.1002/agr.21457

FAO. (2013). The State of Food and Agriculture, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. (2014). Rice Market Monitor. XVII (3), Food and Agriculture Organization of the United Nations, Rome, Italy

FAO. (2017). FAOSTAT, Statistics Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. (2018). Rice Market Monitor. XXI (1), Food and Agriculture Organization of the United Nations, Rome, Italy.

Feng, S. (2008). Land rental, off-farm employment and technical efficiency of farm households in Jiangxi Province, China. NJAS - Wageningen *Journal of Life Sciences*, 55(4), 363-378. doi:https://doi.org/10.1016/S1573-5214(08)80026-7

Ferdushi, K. F., Ismail, M. T., & Kamil, A. A. (2019). Perceptions, Knowledge and Adaptation About Climate Change: A Study on Farmers of Haor Areas After a Flash Flood in Bangladesh*. Climate*, 7(7), 85.

Ferdushi, K. F., Kamil, A. A., Ahmed, S., & Kawsar, L. A. (2020). The Measures of Efficiency of Power Generation Plants in Sylhet of Bangladesh. *International Journal of Mathematics and Mathematical Sciences*, 2020, 9308174. doi:10.1155/2020/9308174

Fuwa, N., Edmonds, C., & Banik, P. (2007). Are small-scale rice farmers in eastern India really inefficient? Examining the effects of microtopography on technical efficiency estimates. *Agricultural Economics*, 36(3), 335-346. doi:10.1111/j.1574-0862.2007.00211.x

Giannakas, K., Tran, K. C., & Tzouvelekas, V. (2003). On the choice of functional form in stochastic frontier modeling. *Empirical Economics*, 28(1), 75-100. doi:10.1007/s001810100120

Hijioka, Y., Lin, E., Pereira, J. J., Corlett, R. T., Cui, X., Insarov, G. E., . . . Surjan, A. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. *Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge,UK; New York, NY, USA (Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.;), 1327–1370.

Hjalmarsson, L., Kumbhakar, S. C., & Heshmati, A. (1996). DEA, DFA and SFA: A comparison. *Journal of Productivity Analysis*, 7(2), 303-327. doi:10.1007/BF00157046

Hossain, M., Jaim, W. M. H., Parish, T. R., & Hardy, B. (2012). *Adoption and diffusion of modern rice varieties in Bangladesh and eastern India*. Los Banos (Philippines): International Rice Research Institute (IRRI).

Islam, M. N. (2005). *Introduction to sampling methods: theory and applications*. Dhaka: Book World.

Jalilov, S., Mainuddin, M., Alam, & Kabir, M. (2019). Efficiency in the Rice Farming: Evidence from Northwest Bangladesh. *Agriculture*, 9. doi:10.3390/agriculture9110245

Karagiannis, G., & Kellermann, M. (2019). Stochastic frontier models with correlated effects. *Journal of Productivity Analysis*, 51(2), 175-187. doi:10.1007/s11123-019-00551-y

Karunarathna, M., & Wilson, C. (2017). Agricultural biodiversity and farm level technical efficiency: An empirical investigation. *Journal of Forest Economics*, 29, 38-46. doi:https://doi.org/10.1016/j.jfe.2017.08.002

Khan, M., Huda, F., & Alam, M. (2010). Farm Household Technical Efficiency: A Study on Rice Producers in Selected Areas of Jamalpur District in Bangladesh. *European Journal of Social Sciences*, 14, 262-271.

Kodde, D. A., & Palm, F. C. (1986). Wald Criteria for Jointly Testing Equality and Inequality Restrictions*. Econometrica*, 54(5), 1243-1248. doi:10.2307/1912331

Koirala, K. H., Mishra, A., & Mohanty, S. (2016). Impact of land ownership on productivity and efficiency of rice farmers: The case of the Philippines. *Land Use Policy*, 50, 371-378. doi:https://doi.org/10.1016/j.landusepol.2015.10.001

Lawanson, A. O., & Novignon, J. (2017). Comparative Analysis of SFA and DEA Models: An Application to Health System Efficiency in SSA. *Asian Journal of Humanities and Social Studies*, 2321-2799. 5(1).

Mainuddin, M., & Kirby, M. (2015). National food security of Bangladesh to 2050. *Food Secur*, 7, 633–646.

Mainuddin, M., Kirby, M., Chowdhury, R. A. R., Sanjida, L., Sarker, M. H., & Shah-Newaz, S. M. (2014). *Bangladesh Integrated Water Resources Assessment Supplementary Report: Land Use, Crop Production, and Irrigation Demand*. CSIRO: Water for a Healthy Country Flagship, Australia.

Meeusen, W., & van den Broeck, J. (1977). Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review*, 18(2), 435-444.

Neff, D. L., Garcia, P., & Nelson, C. H. (1993). TECHNICAL EFFICIENCY: A COMPARISON OF PRODUCTION FRONTIER METHODS. *Journal of Agricultural Economics*, 44(3), 479-489. doi:10.1111/j.1477-9552.1993.tb00289.x

Rahman, S. (2003). Environmental impacts of modern agricultural technology diffusion in Bangladesh: an analysis of farmers' perceptions and their determinants. *Journal of Environmental Management*, 68(2), 183-191. doi:https://doi.org/10.1016/S0301-4797(03)00066-5

Rayp, G., & Van De Sijpe, N. (2007). Measuring and explaining government efficiency in developing countries. *The Journal of Development Studies*, 43(2), 360-381. doi:10.1080/00220380601125230

Sharif, N. R., & Dar, A. A. (1996). Stochastic Frontiers and Technical Efficiency Distributions: An Analysis Based on Rice Farming Data for Bangladesh. *The Canadian Journal of Economics / Revue canadienne d'Economique*, 29, S582-S586. doi:10.2307/136112

Sharma, K. R., Leung, P., & Zaleski, H. M. (1997). Productive Efficiency of the Swine Industry in Hawaii: Stochastic Frontier vs. Data Envelopment Analysis. *Journal of Productivity Analysis*, 8(4), 447-459. doi:10.1023/A:1007744327504

Sherlund, S., Barrett, C., & Adesina, A. (2011). Smallholder technical efficiency controlling for environmental production conditions. *Journal of Development Economics*, 69, 85-101. doi:10.1016/S0304-3878(02)00054-8

Sherlund, S. M., Barrett, C. B., & Adesina, A. A. (2002). Smallholder technical efficiency controlling for environmental production conditions. *Journal of Development Economics*, 69(1), 85-101. doi:https://doi.org/10.1016/S0304-3878(02)00054-8

Silva, T. C., Tabak, B. M., Cajueiro, D. O., & Dias, M. V. B. (2017). A comparison of DEA and SFA using micro- and macro-level perspectives: Efficiency of Chinese local banks. *Physica A: Statistical Mechanics and its Applications*, 469, 216-223. doi:https://doi.org/10.1016/j.physa.2016.11.041

Silverman, B. W. (1986). *Density estimation: For statistics and data analysis*. Monographs on Statistics and Applied Probability, London: Chapman and Hall.

Theodoridis, A. M., & Anwar, M. M. (2011). A Comparison of DEA and Sfa Methods: A Case Study of Farm Households in Bangladesh. *The Journal of Developing Areas*, 45, 95-110.

Uddin, M. T., & Dhar, A. R. (2018). Government input support on Aus rice production in Bangladesh: impact on farmers' food security and poverty situation. *Agriculture & Food Security*, 7(1), 14. doi:10.1186/s40066-018-0167-3

Wadud, A., & White, B. (2000). Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. *Applied Economics*, 32(13), 1665-1673. doi:10.1080/000368400421011

Wadud, M. A. (2003). Technical, Allocative, and Economic Efficiency of Farms in Bangladesh: A Stochastic Frontier and DEA Approach. *The Journal of Developing Areas*, 37, 109-126.

Wadud, M. A., & White, B. (2000). Farm Household Efficiency in Bangladesh: A Comparison of Stochastic Frontier and DEA Methods. *Applied Economics*, 32, 1665-1673. doi:10.1080/000368400421011

Whistler, D., White, K. J., & Bates, D. (2007). *SHAZAM Econometrics Software: User's Reference Manual Version 10*: Vancouver: Northwest Econometrics.

Zaibet, L., & Dharmapala, P. S. (1999). Efficiency of government-supported horticulture: the case of Oman. *Agricultural Systems*, 62(3), 159-168. doi:https://doi.org/10.1016/S0308-521X(99)00061-X