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ESTIMATION OF GROSS AND NET TECHNICAL EFFICIENCIES OF WHEAT PRODUCTION IN BANGLADESH UNDER TWO ALTERNATIVE FUNCTIONAL FORMS

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ABSTRACT

This study aims at estimating gross and net technical efficiencies using four alternative Cobb-Douglas stochastic production frontiers. This study reveals that production of wheat in Bangladesh is profitable and small farmers earned significantly higher yield and net returns per hectare than other fart groups. Technical efficiency scores estimated from different models vary from 46 percent to 99 percent and the maximum efficiency attained at the level 90-100 percent. Average gross technical efficiency varies from 86 to 89 percent whereas average net technical efficiency varies from 90 to 92 percent. This study also reveals that wheat output can be increased in the range 8-11 percent by using the existing resources and technology. It is obvious that environmental factors have positive impact on both production and technical efficiency. The development of advanced technology is the only option to increase wheat production in the long-run.

I. INTRODUCTION

Wheat is the second most important cereal crop in Bangladesh. Average per capita per day calorie intake is 2240 Kilocalories (estimated), of which a significant percent comes from wheat. About 5 percent of total cultivable land are utilised for wheat production. Crop sector contributes about 14 percent to the country's Gross Domestic Product (GDP) of which a remarkable portion is contributed by the wheat (BBS 2000). In 1998-99 crop year Bangladesh produced 1903 thousand tons of wheat whereas in the same year Bangladesh imported 2424 thousand tons of wheat, which is 56 percent of total demand for wheat (BBS 2000). To meet domestic requirement of wheat, Bangladesh has to import increased amount of wheat every year, which strikes scarce foreign currency as well as balance of trade. In the present economic condition, it is our striking need to increase total production of wheat to keep pace• with the demand for wheat. Due to the continuous pressure on the demand for wheat, the government of Bangladesh used to import wheat from the neighbouring countries. Sometimes we used to hear that the imported wheat is not of good quality and some portions of it is not congenial for human consumption. The low quality of wheat jeopardises human health. At the present context, we will have to increase wheat production several times more than the present volume of production. We will have to explore and use all avenues and growth

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promoting factors for sustainable growth of wheat. Production of wheat, in general, can be increased in different ways. First, wheat production an be increased by increasing cultivable area. But an increase in wheat production by increasing area is not possible since total cultivable area is decreasing day by day due to the increased use of land for non-agricultural purposes. Second, production may be increased from increased use of inputs. But farmers of Bangladesh face resource limitation. Third, wheat production can be increased by improving the production technology without increased use of inputs. This technological improvement consists of improved package of inputs, such as improved water management, High Yielding Variety (HYV) seed, chemical fertiliser, agricultural credit, integrated pest control and appropriate land tenure systems. But production technology of developing countries can not be changed rapidly due to several institutional, economic, physical and natural factors. Production of wheat can not be increased by adopting advanced technology for certain economic condition of Bangladesh. Fourth, output can also be increased by increasing the productivity of inputs by reallocating and combining them optimally without changing total quantity of inputs and technology. This technology is generally termed as efficient production technology, which is the main concern of this study. That is, increasing the technical efficiency of wheat using existing technology can increase production.

The measurement of the productive efficiency in agricultural production is an important issue from the standpoint of agricultural development exercises in developing countries since it gives pertinent information useful for making sound management decisions in resource allocations and for formulating agricultural policies and institutional improvements. Technical efficiency refers to the ability of a firm to obtain maximal output from a given set of inputs under certain production technology (Rahman 2002). In Bangladesh, where resources are scarce and opportunities for new technologies are lacking, efficiency (or inefficiency) studies will be able to show that it is possible to raise productivity by improving efficiency without new investment or developing new technology. It is generally assumed that farmers in Bangladesh are inefficient at producing wheat and there are significant efficiency differences among regions, among farm groups and also among crops. After the measurement of efficiency differences, proper measures can be undertaken to reduce them. It is equally important to identify environmental factors, which influence inefficiency effects or efficiency.

The possibilities of economic growth solely through the more efficient use of existing resources will obviously be exhausted when an efficient production technology is reached. In other words, the process of increasing wheat output only by improving efficiency can not continue indefinitely, since under perfect technically efficient conditions the frontier output level will be reached. Thus, other growth promoting strategies need to be considered when it is not possible to increase wheat output only through efficient utilisation of existing resources. The use of modern technology in agriculture to raise wheat output per unit of input is one such strategy. A sound and realistic agricultural policy is one of the most important instruments through which agricultural production can be increased.

Objectives

This study aims at identifying and explaining the possibilities for improving productivity and profitability of wheat crop by increasing the technical efficiency of wheat farmers of Bangladesh.

The specific objectives of this study are as follows :

(i) to estimate gross and net technical efficiencies of wheat farmers in Bangladesh;

(ii) to estimate returns to scale of wheat production;

(iii) to measure the productivity and profitability of wheat production;

(iv) to identify factors influencing technical efficiency of wheat production;

(v) to suggest some policies to increase productivity and technical efficiency wheat.

This paper has been organised in four sections. Section 2 describes research methodology and section 3 contains results and discussion. Some conclusions and policy implications are made in the final section.

II. RESEARCH METHODOLOGY

Sampling Technique and Data Collection

Sadar police station of Dinajpur district and sadar police station of Natore district were selected purposively for this study. Ten villages of Dinajpur district and ten villages of Natore district were selected at random using simple random sampling technique. The selected villages of Dinajpur districts were Maheshpur, Chalkparbatipur, Parbatipur, Paramesharpur, Mohanpur, Chalkgopal, Boraipur, Margram, Radanagar and Shalkiduapara. The selected villages of Natore district were Shonarigram, Mohanpur, Korota, Hajranatak Shidrigram, Sultanpur, Dastanoaj, Kumerpur, Maitapara and Chanpur. One hundred farmers of different size-groups were selected from Dinajpur district using stratified random sampling technique and another one hundred farmers of same size groups were selected from Natore district using the same technique. Among the farm-groups, 40 percent were small farmers, 30 percent were medium farmers and 30 percent were large farmers for both Dinajpur and Natore districts (Table 1).

Table 1: Distribution of collected farm household in the study areas

Farm size group	Dinajpur (No.)	Natore (No.)
Small	40(40%)	40(40%)
Medium	30(30%)	30(30%)
Large	30(30%)	30(30%)
Total	100(100%)	100(100%)

Values in the parentheses indicate percentages.

The primary data were collected from wheat farmers with direct interview method using pretested questionnaires in 2003.

The Production Frontier and the Environment

One of the main assumptions underlying frontier analysis and technical efficiency measurement is that all the firms in an industry share the same production technology and face similar environmental conditions. We know, however, that this is not generally the case and, for the case of wheat production, factors such as age experience and education of farm operators, farm size, market structure, etc. may influence performance measures obtained.

Two conflicting views exist in the efficiency measurement literature regarding the way that the issue of environment should be addressed. The first approach assumes that the environmental factors influence the shape of the technology and hence that these factors should be included directly in the production function as regressors (Good *et al.* 1993). The second approach assumes the environmental factors influence the degree of technical inefficiency (and not the shape of technology) and hence that these factors should be modeled so that they directly influence the inefficiency term (Battese and Coelli 1995). Both approaches appear reasonable depending upon ones philosophical perspective. We, therefore, present and compare the results obtained under the two alternative approaches.

One of the first points that must be made regarding the above two approaches is that the first approach (hereafter termed Case 1) produces technical efficiency scores which are net of environmental influences, while the second approach (Case 2) produces technical efficiency scores which incorporate the environmental effects and hence may be termed gross technical efficiency scores. To make these scores comparable we propose a method that may be used to convert the Case 1 net technical efficiency scores into gross measures and an additional method that may be used to convert the Case 2 gross technical efficiency scores into net scores. The latter approach is based upon the efficiency decomposition procedure proposed by Gathon and Pestieau (1995) for instances when a two-stage estimation method is to estimate the Case 2 model.

There are wide spread applications of stochastic production frontiers on crops around the world. Although numerous studies have been done on crops with the stochastic frontiers, the application of stochastic frontier on wheat production is relatively little. Battese and Broca (1997) used different functional forms of stochastic frontier production functions while studying wheat farmers in Pakistan. They considered translog and Cobb-Douglas stochastic frontiers in which the technical inefficiency effects were defined by three different models. The models involved were the time-varying inefficiency model, proposed by Battese and Coelli (1992), the inefficiency effects model for panel data, proposed by Battese and Coelli (1995), and the non-neutral frontier model, proposed by Huang and Liu (1994). Technical change was also accounted for in the frontier models. Predicted technical efficiencies of the wheat farmers and estimates of the elasticities of wheat production with respect to different inputs and the returns-to-scale parameter were compared under different model specifications.

Tian and Wan (2000) studied technical efficiency and its determinants in China's grain production. Using survey data from China, they estimated frontier production functions individually for rice, wheat and corn and suggested that one could not be optimistic about the future of China's grain sector as the scope for output growth through input injection and efficiency gain was found to be quite limited.

The models discussed above are a bit different from the models specified for this study in the context of using them. Stochastic frontier models similar with this proposed study were used by Coelli et al. (1999) while studying technical efficiencies of international airlines. They accounted for environmental influences in stochastic frontier models and estimated gross and net technical efficiencies.

For this study, a Cobb-Douglas stochastic production frontier with four alternative forms was used. Following Aigner, Lovell and Schmidt (1977), a Cobb-Douglas stochastic production frontier specified with a composed error term is,

$$\ln y_i = \beta_0 + \sum_{k=1} \beta_k \ln x_{ki} + v_i - u_i \qquad (1)$$

Where y_i and x_{ki} indicate the output and the inputs, respectively (i =1, 2, ... , N farms and k =1, 2, ... , n number of inputs); β_0 and the β_k are parameters to be estimated; v is a random error term and u is a non-negative random variable assumed to represent technical inefficiency in production.

To estimate the parameters of this model using maximum likelihood one must select distributional forms for the two error terms (v and u). The most commonly made assumptions are that the random error term, v, is independently and identically distributed as N $(0,\sigma^2_v)$, and the non-negative inefficiency random variable, u, is distributed independently of the v, and has a half-normal distribution. That is, it has a distribution equal to the upper half of the N $(0, \sigma^2_u)$ distribution.

The intuition behind the error component specification is that any deviation from the frontier caught by the technical efficiency term, u, is the result of factors under the firm's control, such as the will and effort of the producer and his employees, and factors such as defective and damaged product (Aigner, Lovell and Schmidt 1977). However, the frontier itself can vary randomly across firms due to the random error v. On this interpretation, the frontier is stochastic, with random disturbance v, being the result of favourable or unfavourable external events such as luck or climate. Moreover, errors of observation and on measurement of production constitute another basis for the presence of v in the frontier model.

Given the definition of the stochastic frontier production function in equation (1), we note that the realisations of the u_i are not observable. That is, following the estimation of the unknown parameters of the model defined in equation (1), the residuals of the model will be realisations of $\varepsilon_i = v_i - u_i$, not of u_i. Battese and Coelli (1988) observe that a best predictor for u_i

is the conditional expectation of u_i, given the value of $\varepsilon_i = v_i - u_i$. That is, one may define the firm-specific technical efficiency predictor using

$$TE_i = [\exp\{-E(u_i/ \varepsilon_i)\}] \quad (2)$$

The above defined frontier model does not attempt to account for the possibility that different firms may experience different environmental conditions, which may subsequently have an influence upon their technical efficiency levels.

In order to take into account this situation we consider two alternative approaches:

Case 1: assume that environmental conditions or factors influence the shape of the production technology,

or

Case 2: assume that environmental conditions or factors influence the firm's technical efficiency.

We shall now deal with each of these cases in turn.

Case 1 : In Case 1 we consider that the environment has a direct influence on the production structure and model the technology by introducing some representative variables aside the production factors. It is assumed that in this case each firm faces a different production frontier. In terms of equation (1) and assuming that M (firm-specific) factors representing the environment, z_j, enter in a simple log-linear way in the production frontier, we will have a modified production frontier:

$$\ln y_i = \beta_0 + \sum_{k=1}^{n} \beta_k \ln x_{ki} + \sum_{j=1}^{M} \theta_j \ln z_{ji} + v_i - u_i , \quad (3)$$

Where the θ_j are parameters to be estimated.

When equation (2) is used to define predictors of technical efficiency relative to the frontier model defined in equation (3) the technical efficiency measures obtained will be net of environmental influences. That is, this technical efficiency may be termed as net technical efficiency. One may also obtain measures of gross efficiency (i.e., inclusive of environmental influences) by re-evaluating the technical efficiency predictors with $\sum_{j=1}^{M} \theta_j \ln z_{ji}$ replaced with $\max [\sum_{j=1}^{M} \theta_j \ln z_{ji}]$. Thus all firms will be compared with the frontier associated with the most favourable environment.

Case 2 : In other studies (Kumbhakar, Ghosh and McGuckin 1991 and Battese and Coelli 1995) environmental factors are assumed to directly affect technical efficiency. Then the underlying hypothesis is that all firms share the same technology represented by the production frontier (1) and the environmental factors have an influence only on the distance that separate each firm from the best practice function. When equation (2) is used to define predictors of technical efficiency relative to the frontier model defined in equation (1), the predicted technical efficiency is usually termed as Gross technical efficiency.

Some early empirical studies (Pitt and Lee 1981 and Kalirajan 1989) also took the viewpoint that the environmental factors have an influence on efficiency. These studies adopted a two-stage estimation approach, in which the first stage involved the specification and estimation of a stochastic frontier production function (such as equation (1)) and the prediction of the technical efficiency scores of the firms. In second stage of analysis, the technical efficiencies were regressed upon certain explanatory factors (such as environmental or management factors).

There is an inconsistency, however, in the above two-stage method. As noted by Battese and Coelli (1995), the stochastic frontier production function is estimated in the first stage under the assumption that the inefficiency effects (error term) are identically distributed, while in the second stage the predicted technical efficiencies are regressed upon a number of factors, hence suggesting the inefficiency effects are not identically distributed. A more appropriate approach involves the specification of a model in which both relations are estimated in a single stage.

As opposed to the situation in case 1, in case 2 the technical efficiencies were measured. To obtain measures of net technical efficiency (net of environmental factors) we replace the $\sum_{j=1}^{M} \delta_j z_{ji}$ with min $[\sum_{j=1}^{M} \delta_j z_{ji}]$ and then recalculate the technical efficiency predictions. These adjusted predictions may then be interpreted as net efficiency scores because they involve predictions of efficiency levels when all firms are assumed to face identical environmental conditions (Coelli *et al.* 1999).

For this study, stochastic frontier production function and technical inefficiency effect model have been estimated simultaneously in a single stage for both the cases. For the production of wheat, land, seed, human labour, bullock power, fertiliser and irrigation were considered as factors of production while age, education, experience and farm-size were taken as environmental or management or farm-specific factors.

The possible null hypotheses to be tested are that (i) the inefficiency effects are not present; (ii) the inefficiency effects are not stochastic; and (iii) the coefficients of the variables in the model for the inefficiency effects are zero. These and other null hypotheses of interest have been tested using the generalised likelihood-ratio test and t-test.

The generalised likelihood ratio test statistic is calculated as

$$LR = -2\{\ln[L(H_0) / L(H_1)]\} = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \quad (4)$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses, H_0 and H_1, respectively. The generalised likelihood-ratio statistic LR, has asymptotic distribution which is a mixture of chi-square distributions (Coelli 1995a).

To measure the productivity and profitability of wheat production, some partial measures such as yield, net return, gross margin and benefit-cost ratio etc. are also calculated.

Specification of Alternative Production Frontier Models.

Table 2. Specification of alternative production frontier models

Parameters		Cobb-Douglas Production frontier without environment (1)	Environment in Production Case 1 (2)	Environment in inefficiency Case 2 (3)	Nested model (Environment in both production and Inefficiency) (4)
β_0	Constant	β_0	β_0	β_0	β_0
β_1	$\ln x_1$ (land)	β_1	β_1	β_1	β_1
β_2	$\ln x_2$ (labour)	β_2	β_2	β_2	β_2
β_3	$\ln x_3$ (seed)	β_3	β_3	β_3	β_3
β_4	$\ln x_4$ (fertiliser)	β_4	β_4	β_4	β_4
β_5	$\ln x_5$ (manure)	β_5	β_5	β_5	β_5
β_6	$\ln x_6$ (bullock power)	β_6	β_6	β_6	β_6
β_7	$\ln x_7$ (irrigation cost)	β_7	β_7	β_7	β_7
θ_1	Z_1 (education of farmer)	-	θ_1	-	θ_1
θ_2	$\ln Z_2$ (age of farmer)	-	θ_2	-	θ_2
θ_3	$\ln Z_3$ (experience of farmer)	-	θ_3	-	θ_3
θ_4	$\ln Z_4$ (farm size)	-	θ_4	-	θ_4
∂_0	Constant	-	-	∂_0	∂_0
∂_1	Z_1 (education)	-	-	∂_1	∂_1
∂_2	Z_2 (age of farmer)	-	-	∂_2	∂_2
∂_3	Z_3 (experience)	-	-	∂_3	∂_3
∂_4	Z_4 (farm size)	-	-	∂_4	∂_4

For this study four different Cobb-Douglas stochastic production frontiers were specified (Table 2). The above alternative Cobb-Douglas stochastic production frontiers were estimated with Frontier 4.1c package. The first model consisted of material inputs only and environmental factors were nowhere in the model. That is, environmental factors were absent from the stochastic frontier as well as from the technical inefficiency effect model. Farm specific technical efficiencies estimated from the model 1 are called the gross technical efficiencies. For model 2, environmental factors were included in the stochastic frontier but not in the technical inefficiency effect model. Farm specific technical efficiencies estimated from model 2 are called net technical efficiencies since they are the net effect of material inputs and environmental factors. For the model 3, environmental factors were included in the technical inefficiency effect model but not in the stochastic frontier. These environmental factors such as education, age and experience of farm operators and farm size were assumed to have no impact on the general structure of production but they may have impact on technical efficiency. Farm-specific technical efficiencies estimated from model 3 are also called gross technical efficiencies. Model 4 encompasses environmental factors both in the stochastic frontier and also in the technical inefficiency effect model. This type of model is generally called nested model and the estimated farm-specific technical efficiencies from this model are also called net technical efficiencies (Coelli *et al.* 1999).

III. RESULTS AND DISCUSSION

Socioeconomic Characteristics of Farm Households

The average age of farm operators was 47.58 years and the average education was 7.48 years of schooling. Large farmers were more educated than other farmers groups. Farming experiences of farmers were about same among the groups and the average farming experience was 25.99 years. Average own cultivable land and total farm size were respectively 2.41 hectares and 2.51 hectares. Area of wheat production of medium farmer was significantly higher than those of other farm groups and average area was 0.64 hectare (Table 3).

Table 3. Socioeconomic characteristics of farm households in the study area

Farm category	Age (Years)	Education (Year of schooling)	Experience (Years)	Own cultivable land (hectare)	Total farm size (hectare)	Area of wheat (hectare)
Small farm	45.65 (14.28)	6.13 (4.50)	27.45 (14.18)	0.57 (0.29)	0.83 (0.28)	0.26 (0.10)
N	0	80	80	80	80	80
Medium farm	45.33 (11.86)	8.47 (3.67)	23.33 (13.75)	1.19 (0.54)	1.89 (0.53)	0.91 (2.13)
N	60	60	60	60	60	60
Large farm	52.40 (13.54)	8.30 (3.93)	26.70 (16.02)	5.31 (2.10)	5.36 (1.87)	0.81 (0.27)
N	60	60	60	60	60	60
Total	47.58 (13.61)	7.48 (4.21)	25.99 (14.59)	2.41 (2.32)	2.51 (2.20)	0.64 (1.21)
N	200	200	200	200	200	200
F-value	2.79	3.65^{*}	0.72	137.44^{**}	158.69^{**}	3.66^{*}

Values in the parentheses indicate standard deviations and N indicates sample size.
** and * indicate significance at 0.01 and 0.05 probability level, respectively.
Source : Farm Survey 2003.

Average number of literate male was 2.57 persons per family whereas average number of literate female was 1.66 persons. There were significant variations of literate male among the farm groups. Average family size of farm households was 5.28 persons (Table 4).

Table 4. Education and family size of farm households in the study area

Farm category	No. of literate male	No. of illiterate male	No. of literate female	No. of illiterate female	Total family member
Small farm	2.20 (.88)	.56 (.59)	1.55 (.88)	.85 (.70)	5.18 (1.08)
Medium farm	2.67 (.76)	.33 (.55)	1.63 (.72)	.57 (.50)	5.20 (.81)
Large farm	2.97 (.56)	.13 (.35)	1.83 (.75)	.57 (.50)	5.50 (.51)
Total	2.57 (.82)	.37 (.54)	1.66 (.79)	.68 (.60)	5.28 (.87)
F-value	9.06**	637**	1.12	2.76	1.40

Values in the parentheses indicate standard deviations
** indicates significance at 0.01 probability level
Source : Farm Survey 2003.

Table 5 reveals the income distribution of farm households from different sectors. Significant variation of sectoral income distribution was found among different farm groups. The average income of farm households was Taka 66,217.23 where the share of income from crop sector was 88 percent. The share of income from crop sectors for small, medium and large farms were 61 percent, 91 percent and 98 percent, respectively. It is evident that large farmers are mostly dependent on crop sector for their income followed by medium farmers and small farmers, respectively.

Table 5. Income distribution of farm households from different sectors

Farm category	Income from crops (Tk.)	Income from fisheries (Tk.)	Income from livestock and poultry (Tk.)	Income from service (Tk.)	Income from other sources (Tk.)	Total Income	Percentage share of income from crop sector
Small farm	22885.58 (8069.71)	805.00 (1256.97)	2940.00 (1454.93)	1550.00 (4379.15)	9312.50 (3650.94)	37493.08 (7714.54)	61
Medium farm	49797.00 (14117.71)	1040.00 (1197.58)	1433.33 (1755.45)	.00 (.00)	2633.33 (3210.79)	54903.67 (14023.99)	91
Large farm	113363.00 (33367.12)	.00 (.00)	1200.00 (1972.22)	.00 (.00)	1266.67 (2863.97)	115829.67 (32931.14)	98
Total	58102.23 (43099.33)	634.00 (1107.30)	1966.00 (1876.99)	620.00 (2852.54)	4895.00 (4908.92)	66217.23 (38945.53)	88
F-value	171.14**	8.54**	10.91**	3.74*	60.99**	135.99**	

Values in the parentheses indicate standard deviations
**and * indicate significance at 0.01 and 0.05 probability level, respectively
Source: Farm Survey 2003.

Small farmers produced significantly more output (2852.76 kg/ha) followed by medium farmers (2730.11 kg) and large farmers (2363.28 kg), respectively (Table 6). Average per hectare full cost was Tk. 21064.66 and average per hectare cash cost was Tk. 6277.23 but cash cost is significantly higher for large farmers (Tk. 7956.80/ha) followed by medium farmers (Tk. 6608.51/ha) and small farmers (Tk. 4769.10/ha), respectively. This indicated that large farmers used significantly more purchased input than other farm groups. Average net returns for full cost and cash cost basis were Tk. 14088.41 and Tk. 28875.84, respectively. Small farmers earned significantly higher net returns for both full and cash cost basis than other farm groups. Net returns and benefit cost ratios showed that production of wheat in Bangladesh was profitable.

Table 6. Per hectare cost and return of wheat production

Farm category	Output (kg/ha)	Full cost (Tk./ha)	Cash cost (Tk./ha)	Net return (full cost basis) (Tk./ha)	Net return (cash cost basis) (Tk./ha)	BCR (full cost basis)	BCR (cash cost basis)
Small farm	2852.76	20559.29	4769.10	17809.62	33599.81	1.93	8.88
	(361.81)	(4161.07)	(1648.88)	(5792.58)	(5438.90)	(0.41)	(2.89)
Medium farm	2730.11	20548.90	6608.51	14871.11	28811.50	1.74	5.63
	(696.68)	(4182.50)	(1981.69)	(7711.25)	(9284.82)	(0.33)	(1.68)
Large farm	2363.28	22254.24	7956.80	8344.12	22641.55	1.38	3.91
	(217.81)	(2021.362)	(1072.94)	(3357.86)	(3249.05)	(0.17)	(.63)
Total	2669.12	21064.66	6277.23	14088.41	28875.84	1.71	6.41
	(500.74)	(3708.73)	(2089.42)	(7051.19)	(7797.04)	(0.40)	(2.96)
F-value	10.07**	2.26	34.25**	22.55**	25.22**	23.87**	52.34**

Values in the parentheses indicate standard deviations
** indicates significance at 0.01 probability level
Source: Farm Survey 2003.

Per hectare output was relatively higher than the national average. But the average yield is consistent with the national average. Table 7 shows the regions, area under wheat production, output per hectare and total production in the years 2001-2002 and 2202-2003 in Bangladesh. The total area under the wheat crop has been estimated 7,06,475 hectares in 2002-2003 whereas it was 7,41,830 hectares in 2001-2002 indicating 4.77 percent decrease. Average per hectare output was 2.133 tons in 2002-2003 as compared to 2.165 tons in 2001-2002. The per hectare output has slightly declined to 1.49 percent. Total production was 15,06,710 tons in 2002-2003 while it was 16,05,760 tons in the previous year. Total wheat production has decreased about 6.17 percent this year as compared to the previous year.

Table 7. Area, yield and total production of wheat in Bangladesh

Regions	2001-2002			2002-2003		
	Area (hectare)	Yield per hectare (ton)	Total production (ton)	Area (hectare)	Yield per hectare (ton)	Total production (ton)
1. Bandarban	-	-	-	-	-	-
2. Chittagong	60	0.833	50	60	0.833	50
3. Comilla	44565	1.770	78880	47790	1.813	86620
4. Khagrachari	10	1.000	10	0	0	0
5. Noakhali	865	1.110	960	1030	1.553	1600
6. Rangamati	-	-	-	-	-	-
7. Sylhet	3615	2.108	7620	3500	1.994	6980
8. Dhaka	39550	1.904	75290	33235	1.868	62080
9. Faridpur	52960	1.762	93300	42165	1.748	73700
10. Jamalpur	32360	1.953	63190	31070	2.064	64130
11. Kishoregonj	8990	1.868	16790	10310	1.887	19460
12. Mymensingh	7915	1.799	14240	7950	1.850	14710
13. Tangail	25085	1.732	43450	26165	1.668	43640
14. Barisal	6940	1.663	11540	6280	1.831	11500
15. Jessore	49710	2.293	113990	46610	2.349	1095000
16. Khulna	2210	2.154	4760	2310	2.117	4890
17. Kushtia	45495	2.295	104400	42990	1.970	84670
18. Patuakhali	-	-	-	-	-	-
19. Bogra	20430	2.240	45760	18555	2.243	41620
20. Dinajpur	143080	2.357	337190	139055	2.283	317450
21. Pabna	84270	2.222	187330	81820	2.214	181130
22. Rajshahi	88550	2.320	205510	86000	2.315	199100
23. Rangpur	85170	2.366	201500	79580	2.311	183880
BANGLADESH	741830	2.165	1605760	706475	2.133	1506710

Source : BBS 2003.

Estimation of Frontier Models

Land, labour and seed had positive impact on wheat output provided by all models. Fertiliser was found to have positive impact on wheat output provided by model 3. As far as environmental factors were concerned, age of farm operator has positive impact on wheat output provided by models 2 and 4, and education has also positive impact on output provided by model 4 but farm size has negative impact on output. It is obvious that environmental factors influence the shape of production technology.

The coefficients of education and age and experience of farmer were negative in technical inefficiency effect model which are expected but they are not significant. But the coefficient of farm size is significantly positive in the technical inefficiency effect model which indicates that technical inefficiency increases with the increase in farm size. That is, large farms tend to have greater inefficiency effects (or smaller efficiency) than smaller farms. This is consistent with the claim that smaller farms tend to be more efficient than larger farms. The quasi-function coefficients estimated from models 1, 2, 3 and 4 are respectively 0.9560, 1.0700, 0.9060 and 1.2341 which show that model 1 entails constant return to scale, model 3 entails decreasing return to scale and models 2 and 4 entail increasing return to scale.

The variance ratio parameter is significant in all models which means that there is significant technical inefficiency in the production of wheat (Table 8).

Table 8. Maximum likelihood estimates of four alternative Cobb-Douglas stochastic production frontiers

Parameters		Cobb-Douglas Production frontier without environment (Model 1)	Environment in Production Case 1 (Model 2)	Environment in inefficiency Case 2 (Model 3)	Nested model (Environment in both production and Inefficiency) (Model 4)
β_0	Constant	3.5845^{**} (0.5347)	3.1821^{**} (0.5073)	3.5706^{**} (0.6697)	2.2729^{**} (0.5407)
β_1	$\ln x_1$ (land)	0.2247^{**} (0.0724)	0.2243^{**} (0.0705)	0.1873^{*} (0.0875)	0.1956^{**} (0.0762)
β_2	$\ln x_2$ (labour)	0.1819^{**} (0.0690)	0.2293^{**} (0.0701)	0.1831^{*} (0.0801)	0.2462^{**} (0.0738)
β_3	$\ln x_3$ (seed)	0.3042^{*} (0.1263)	0.3019^{*} (0.1239)	0.2612^{*} (0.114)	0.3633^{**} (0.1249)
β_4	$\ln x_4$ (fertiliser)	0.0621 (0.0599)	0.0657 (0.0581)	0.0968^{*} (0.0435)	0.0637 (0.0587)
β_5	$\ln x_5$ (manure)	0.0048 (0.0611)	-0.0182 (0.0607)	0.0128 (0.0819)	-0.0411 (0.0607)
β_6	$\ln x_6$ (bullock power)	0.1326 (0.0972)	0.1686 (0.0964)	0.1578 (0.1314)	0.1305 (0.0963)
β_7	$\ln x_7$ (irrigation cost)	-0.0106 (0.0703)	0.0016 (0.0784)	0.0070 (0.2599)	-0.0015 (0.0787)
θ_1	Z_1 (education of farmer)	-	0.0055 (0.0054)	-	0.0171^{*} (0.0071)
θ_2	$\ln Z_2$ (age of farmer)	-	0.2791^{*} (0.1225)	-	0.5494^{**} (0.1722)
θ_3	$\ln Z_3$ (experience of farmer)	-	-0.0873 (0.0579)	-	-0.1411 (0.0768)
θ_4	$\ln Z_4$ (farm size)	-	-0.1005^{*} (0.0440)	-	-0.1480^{**} (0.0538)
∂_0	Constant	-	-	0.2485 (0.2031)	-2.4895 (1.7149)
∂_1	Z_1 (education)	-	-	-0.0121 (0.0429)	0.0913 (0.0615)
∂_2	Z_2 (age of farmer)	-	-	-0.0029 (0.0179)	0.0413 (0.0275)
∂_3	Z_3 (experience)	-	-	-0.0015 (0.0128)	-0.0119 (0.0136)
∂_4	Z_4 (farm size)	-	-	0.009^{**} (0.0007)	-0.0008 (0.0007)
	Function coefficient	0.9560	1.0700	0.9060	1.2341
σ^2		0.0379^{**} (0.0054)	0.0343^{**} (0.0050)	0.0369^{**} (0.0086)	0.0859^{*} (0.0401)
γ		0.0701^{**} (0.0096)	0.1152^{**} (0.0102)	0.0351^{**} (0.0079)	0.7304^{**} (0.1746)
	Log likelihood function	21.67	26.69	23.20	13.72

Values in the parentheses indicate asymptotic standard error.

** and * indicate significance at 0.01 and 0.5 probability level, respectively.

Source : Own estimation.

Table 9 suggests that there is significant technical inefficiency effect in the production of wheat in the study areas.

Table 9. Test of Hypothesis for the coefficients of the Explanatory Variables for the Technical Inefficiency Effects in Cobb-Douglas Production Frontiers

Null hypothesis	Log-likelihood value	Test statistic LR	Critical value	Decision
$H_0 : \gamma = 0$				
Model 1	27.66	12.23	2.71	Rejected
Model 2	26.69	14.71	2.71	Rejected
$H_0 : \gamma = \delta_0 = \delta_1 = ... \delta_4 = 0$				
Model 3	23.20	15.08	10.65	Rejected
Model 4	31.54	13.70	10.65	Rejected

Table 10 shows farm-specific technical efficiency scores (gross and net) and technical efficiency ratio estimated from 4 alternative Cob-Douglas stochastic production frontiers.

Table 10. Farm-Specific technical efficiency (Gross and Net) and technical efficiency ratio obtained from four alternative Cobb-Douglas stochastic production frontiers

Efficiency Level (%)	Gross Technical Efficiency (%) (Model 1)		Net Technical Efficiency (%) (Model 2)		Ratio of net to gross Technical Efficiency	Gross Technical Efficiency (%) (Model 3)		Net Technical Efficiency (%) (Model 4)		Ratio of net to gross Technical Efficiency
	No. of farmers	Mean Efficie-ncy	No. of farmers	Mean Efficiency		No. of farmers	Mean Efficiency	No. of farmers	Mean Efficiency	
40-50	0 (0.00)	-	0 (0.00)	-	-	2 (1.00)	46	2 (1.00)	47	1.02
50-60	2 (1.00)	52	2 (1.00)	54	1.04	2 (1.00)	52	2 (1.00)	53	1.02
60-70	8 (4.00)	66	6 (3.00)	67	1.02	10 (5.00)	63	4 (2.00)	65	1.03
70-80	6 (3.00)	72	8 (4.00)	75	1.04	18 (9.00)	76	12 (6.00)	78	1.03
80-90	22 (11.00)	84	20 (10.00)	85	1.01	74 (37.00)	82	38 (19.00)	83	1.01
90-100	162 (81.00)	92	164 (82.00)	94	1.02	94 (47.00)	94	142 (71.00)	95	1.01
Total no. of farmers	200 (100.00)	-	200 (100.00)	-	-	200 (100.00)	-	200 (100.00)	-	-
Mean Efficiency	-	89	-	92	1.03	-	86	-	90	1.05
Minimum	-	52	-	54	1.04	-	46	-	47	1.02
Maximum	-	99	-	99	1.00	-	99	-	99	1.00

Figures in the parentheses indicate percentage.
Source: Own estimation

Technical efficiency scores varied from 46 percent to 99 percent and the maximum efficiency attained at the level 90-100 percent. Average gross technical efficiencies estimated from model 1 and 3 are respectively 89 percent 86 percent whereas average net technical efficiencies estimated from model 2 and 4 are respectively 92 percent and 90 percent. Average ratios of net to gross technical efficiency are 1.03 and 1.05. It is obvious that environmental factors have positive impact on technical efficiency. Table 10 also reveals that wheat output can be increased in the range 8-11 percent by using the existing resources and technology. But the process of increasing output only by improving efficiency will be exhausted very soon. The development of modern technology in terms of High Yielding Varieties (HYV), improved water management, Integrated Pest Management (IPM) strategy etc. is the only option to increase production in the long-run.

IV. CONCLUSION AND POLICY IMPLICATION

This study attempted to elucidate wheat production technology using four alternative Cobb-Douglas stochastic production frontiers under two alternative functional forms. The study observed that average age and experience of farm operators are respectively 47.58 and 25.99 years and average education of farm operators is 7.48 years of formal schooling. Own cultivable land, total farm size and area of wheat are respectively 2.41, 2.51 and 0.64 hectare per farm. The study reveals that farmers earn 88 percent of income from crop sector including wheat and large farmers are mostly dependent on crop sector for their income followed by medium farmers and small farmers, respectively. Per hectare yield, net return in full cost and cash cost basis are respectively 2669.12 kg, Tk. 14,088.41 and Tk. 28,875.84. Small farmers earned significantly higher yield and net returns per hectare than other farm groups. Net returns and benefit cost ratios show that production of wheat in Bangladesh is profitable.

The study shows that land, labour, seed and fertiliser have positive impact on wheat output and some environmental factors such as age and education have also positive impact on wheat output but farm size has negative impact on it. The quasi-function coefficients estimated from the models suggest that model 1 entails constant returns to scale, model 3 entails decreasing returns to scale and models 2 and 4 entail increasing returns to scale. There is significant technical inefficiency in the production of wheat. Technical efficiency scores estimated from different models vary from 46 percent to 99 percent and the maximum efficiency attained at the level 90-100 percent. Average gross technical efficiency varies from 86 to 89 percent whereas average net technical efficiency varies from 90 to 92 percent. The study reveals that wheat output can be increased in the range 8-11 percent by using the existing resources and technology. It is obvious that environmental factors have positive impact on both production and technical efficiency.

It is difficult to draw policy to increase wheat output from this study. To draw an appropriate policy a rigorous analysis on production and marketing aspects covering all the old districts of Bangladesh should be made. But it is obvious from this study that the development of advanced technology is the only option to increase wheat production in the long-run.

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