Farm-Specific and Farm-Size-Specific Efficiency Measurements and Related Policies for Bangladesh Rice Crops

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Abstract

Farm-specific and farm-size-specific efficiencies are estimated through single estimation of Cobb-Douglas stochastic production and cost frontiers. The factors which influence inefficiency effects are identified through simultaneous estimation of the stochastic frontiers (production and cost) and inefficiency effect models. Government extension service has positive impact on the production of *Boro* and *Aman* whereas education has negative effect on them. Human labour, seed, fertiliser, age and experience are important factors for the production of *Boro*. Age and extension contact have negative impact on the technical inefficiency. Similarly, age and farm size have positive impact on the economic inefficiency whereas extension contact has negative effect on it. Medium farmers achieve maximum technical and economic efficiencies for all rice crops. From a policy point of view, the main responsibility of the government in this area is to ensure that the land market is flexible enough to allocate land to the most efficient farmers. Furthermore, the government can assist the land market by offering extension programmes to encourage farmers not to fragment land.

1. INTRODUCTION

The measurement of the productive efficiency of a farm relative to other farms or to the "best practice" in an industry has long been of interest to agricultural

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economists. Efficiency measurement has received considerable attention from both theoretical and applied economists. From a theoretical point of view, there has been a spirited exchange about the relative importance of various components of firm efficiency (Leibenstein 1966,1977; Comanor and Leibenstein 1969; Stigler 1976). From an applied perspective, measuring efficiency is important because this is the first step in a process that might lead to substantial resource savings. These resource savings have important implications for both policy formulation and firm management (Bravo-Ureta and Rieger 1991)

In the policy arena, there is a continuing controversy regarding the connection between farm size, efficiency and the structure of agricultural production. For individual farms, gains in efficiency are particularly important in periods of financial stress. Efficient farms are more likely to generate higher incomes and thus stand a better chance of surviving and prospering.

Economic development in Bangladesh mainly depends on the progresses to be made in the agricultural sector, but agricultural development is dependent on appropriate policies relating to augmenting productivity and efficiency of agricultural crops. Increase of productivity and efficiency are based on some socio-economic and demographic variables. Proper policies can be formulated only after the empirical measurement of the core variables.

When one talks about the efficiency of a firm one usually means its success in producing as large as possible an output from a given set of inputs. Economic efficiency is generally defined as the ability of a production organisation or any other entity, for instance, a farm to produce a well-specified output at the minimum cost. Farrell (1957) proposed that economic or overall efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs under certain production technology, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. In fact, economic efficiency is the product of technical and allocative efficiencies. If a firm has achieved both technically efficient and allocatively efficient levels of production, then the firm is economically efficient. A firm is technically inefficient if it fails to produce the mximum output from a given bundle of inputs. On the other hand the firm is said to be allocatively inefficient when the marginal rate of technical substitution is not equal to the inverse of their price ratio. Putting it differently a firm is considered to be allocatively inefficient in the sense that marginal value product may not be equal to marginal cost, given input prices. Both types of inefficiencies are costly to the society and thus should be eliminated.

Economic relationships based on optimisation behaviour define efficient frontiers of minimum (e.g. cost) or maximum (e.g. production) attainment. Traditional econometric methods for estimating stochastic economic relationships have implicitly assumed that all economic agents are successful in reaching the efficient frontier. If, however, the economic agents are not equally efficient, then the average relationships estimated by ordinary least squares methods might not reflect the frontier relationships (Stevenson, 1980).

Numerous studies have been devoted to the respecification of empirical production and cost models to make them more compatible with the underlying theory, and to the derivation of appropriate estimators. In some cases, this has amounted to minor modifications of least squares results. The remaining estimators are based on two distinct specifications. The very recent work on composite disturbances has relaxed somewhat the orthodox interpretation of the underlying function as a strict frontier with all observations lying on one side of it, and has produced well behaved maximum likelihood estimators with all of the usual desirable properties (Greene, 1980).

The objectives of this paper, therefore, are: (i) to develop a specification and estimation for a stochastic production and cost frontier models; (ii) to estimate farm-size-specific and farm-specific technical, allocative and economic efficiencies for individual sample farmers; (iii) to identify the factors causing variations in inefficiency (both technical and economic) effects (or efficiencies) among the sample farmers; and (iv) to suggest some policies to increase efficiency of farm production.

This paper has been organised in four sections. In section 2 data and specification of stochastic production frontier and technical inefficiency effect model are described. Section 3 contains empirical results and discussions. Some conclusions and policy implications are made in the final section.

2. DATA AND SPECIFICATION OF STOCHASTIC PRODUCTION AND COST FRONTIERS AND INEFFICIENCY EFFECT MODEL

Data

The three regions, that is, Brahmanbaria, Mymensingh and Dinajpur were selected purposively considering the relative importance of these regions in producing rice. These three great regions (old district) produce about 16 percent of total rice in Bangladesh (BBS 1998). Considering their contribution to the total output, the selection of these regions was appropriate for a study on the efficiency of rice production. Moreover, the soil texture of these regions represents a good cross section of the soil texture of the country. Farmers of these regions are familiar with new inputs of production such as HYV* seeds, artificial irrigation, chemical fertiliser etc. for several years and in these regions there are the requisite number of households with different farm sizes. The regions are also relatively easily accessible and well communicated. Since Dinajpur is the north-west district of the country, Mymensingh is the middle district and Brahmanbaria is the south-east district, the selection of these areas was uniform on the spatial context.

To collect primary data from the farmers of Bangladesh, probability sampling technique was adopted. At first a sampling frame of farmers was constructed with the help of village leaders and some other relevant persons. The villages were selected with simple random sampling technique but the farmers were selected with stratified random sampling with arbitrary allocation. The data were collected for the crop year July 1998 to June 1999. The sample was composed of small (below 1.00 hectare), medium (1.00 - 3.00 hectares) and large (above 3.00 hectares) farms. Within the sample, 50 percent were small, 30 percent were medium and 20 percent were large farmers. Five hundred farmers in total were interviewed in this study. Of the five hundred sampled farmers, 300 farmers had direct contact with extension workers and were selected 100 from each region to ascertain the importance of extension service in Bangladesh. Another 200 farmers who had no relationship with the extension workers were selected, 100 from each region except Mymensingh region. For the region Mymensingh, only a sample of 100 farmers with access to the extension service was collected but no sample of non-extension farmers was collected because there is one agricultural university known as Bangladesh Agricultural University and from this university every year several extension programmes are carried out in this region side by side with government extension programmes. Thus most of the farmers in this region are connected to extension programmes. To compare the productivities and efficiencies between farmers with extension services and farmers without extension services, these two types of data are very useful.

Model Specification

In order to estimate the level of technical efficiency (TE) in a way consistent with the theory of production function we have specified a Cobb-Douglas type stochastic frontier production function. We will estimate economic efficiencies (EE) from the Cobb-Douglas normalised derived stochastic cost frontiers. The allocative efficiencies (AE) are estimated by using the expression, AE = EE/TE, which is obtained from the relationship, EE = TE X AE. The Cobb-Douglas form of production function has some well-known properties that justify its wide application in economic literature (Henderson and Quandt 1971). It is a homogeneous function that provides a scale factor enabling one to measure the returns to scale and to interpret the elasticity coefficients with relative ease. It is also easy to estimate and mathematically manipulate. On the other hand, the Cobb-Douglas production function makes several restrictive assumptions. It is assumed that the elasticity coefficients are constant, implying constant shares for the inputs. The elasticity of substitution among factors is unity in the Cobb-Douglas form. Moreover, this being linear in logarithm, output is zero if any of the inputs is zero, and the output expansion path is assumed to pass through the origin. However, it is also argued that if interest rests on efficiency measurements and not on an analysis of the general structure of the underlying production technology, the Cobb-Douglas specification provides an adequate representation of the production technology. In addition, its simplicity and widespread use in agricultural economics outweigh its drawbacks.

The explicit Cobb-Douglas stochastic frontier production function is given below:

$$\ln Y_i = \ln \beta_0 + \sum_{i=1}^{9} \beta_i \ln X_i + \beta_{10}\,\mathrm{EDU} + \beta_{11}\,\mathrm{EXT} + V_i - U_i \qquad (1)$$

where Y = Output (kg)

X_1= Area under rice crops (hectare)
X_2= Human labour (man-days)
X_3= Seed (kg)
X_4= Fertiliser (kg)
X_5= Manure (kg)
X_6= Bullock power (pair-days)
X_7= Irrigation cost (real value, Taka)
X_8= Age of farm operator
X_9= Experience of farm operator
EDU = Education of farm operator (year of schooling)
EXT = Extension service (Dummy variable which receives 1 if the farm had contact with extension agents and receives 0 otherwise)

V_i are assumed to be independently and identically distributed random errors, having $N(0, \sigma_v^2)$-distribution; and the U_i are non-negative one-sided random variables, called technical inefficiency effects, associated with the technical inefficiency of production of the farmers involved. It is assumed that the inefficiency effects are independently distributed with a half normal distribution $(U \sim N(0, \sigma_u^2))$.

The Cobb- Douglas normalised stochastic frontier cost function for *Boro* rice is given below:

$$\ln(C_i/P_{fi}) = \beta_0 + \beta_1\,EDU + \beta_2\,EXT + \beta_3\ln(AGE) + \beta_4\ln(EXPERIENCE) + \beta_5\ln(Q_i) + \beta_6 \ln(W_i/P_{fi}) + \beta_7\ln(P_{si}/P_{fi}) + \beta_8\ln(P_{bi}/P_{fi}) + \beta_9\ln(C_{ii}/P_{fi}) + \beta_{10}\ln(R_{li}/P_{fi}) + (V_i + U_i) \quad (2)$$

where C_i is the observed cost of production for the ith farm;
EDU, EXT, AGE and EXPERIENCE are defined as earlier;
Q_i is the output quantity (kg) for the ith farm;
P_{fi} is the price of fertiliser per kg for the ith farm;
W_i is the labour price (wage rate) for the ith farm;
P_{si} and P_{bi} are price of seed and bullock power for the ith farm, respectively; and
C_{ii} and R_{li} are cost for irrigation per hectare and rent of land per hectare for the ith farm, respectively.
U is a non-negative cost inefficiency effect, which is assumed to have a half-normal distribution;
V is a random variable, which is assumed to be independently and normally distributed with 0 mean and constant variance $^{2}{}_{v}$.

We may note that the inefficiency effect, U, is added in the cost frontier, instead of being subtracted, as in the case of the production frontier. This is because the cost function represents minimum cost, whereas the production function represents maximum output. Stochastic frontiers of equation (1) and (2) will be applied to estimate farm-size-specific and farm-specific efficiency measures.

The model for the inefficiency effects in the stochastic frontier of equation (1) and (2) is defined by

$$U_i = d_0 + d_1\,AGE_i + d_2\,EDU_i + d_3\,EXPERIENCE_i + d_4\,CONTACT_i + d_5\,FARMSZ_i + W_i \quad (3)$$

Where AGE represents age of farm operator;
EDU is defined as earlier;
EXPERIENCE is the experience of the farm operator;
CONTACT represents extension contact by the extension agents to the farmers;
FARMSZ represents farm size; and the W_i are unobservable random variables, which are assumed to be independently distributed with a positive half normal distribution.

The β and δ coefficients are unknown parameters to be estimated, together with the variance parameters which are expressed in terms of

$s^2 = s_u^2 + s_v^2$ (4)

and

$l = s_u^2/s^2$ (5)

where the -parameter has a value between zero and one. The parameters of the stochastic production and cost frontier models are estimated by the maximum likelihood method, using the computer program, FRONTIER Version 4.1.

It is important to note that the model for the inefficiency effects (3) can only be estimated if the inefficiency effects are stochastic and have a particular distributional specification. Hence there is interest to test the null hypotheses that the inefficiency effects are not present, H_0: $g = {}_0 = d_1 = d_2 = d_3 = d_4 = d_5 = 0$; the inefficiency effects are not stochastic, H_0 : = 0; and the coefficients of the variables in the model for the inefficiency effects are zero, $H_0 : d_1 = d_2 = ... = d_5 = 0$. These and other null hypotheses of interest are tested using the generalised likelihood ratio test and t-test. The generalised likelihood ratio test is a one-sided test since can not take negative values. The generalised likelihood-ratio test requires the estimation of the model under both the null and alternative hypotheses. Under the null hypothesis, $H_0 : g = 0$, the model is equivalent to the traditional average response function, without the technical inefficiency effect, U_i. The test statistic is calculated as

$$LR = -2\{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0) - \ln[L(H_1)]\} \quad (6)$$

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 technical efficiency of a farmer at a given period of time is defined as the ratio of the observed output to the frontier output which could be produced by a fully-efficient firm, in which the inefficiency effect is zero. Similarly, economic efficiency or cost efficiency of a farmer is defined as the ratio of frontier minimum cost to the observed cost. Given the specifications of the stochastic frontier model (1) – (3), the efficiency (both technical and economic) of the ith farmer can be shown to be equal to

$$\begin{aligned} TE_i &= \exp(-U_i) \\ &= \exp\{E(U_i/\Sigma\iota)\} \\ &= 1 - E(U_i/{}_i) \end{aligned} \quad (7)$$

Thus the technical efficiency as well as economic efficiency of a farmer is between zero and one and is inversely related to the inefficiency effect. The farm-specific efficiencies are predicted using the predictor that is based on the conditional expectation of U_i given composed error $_i = (V_i - U_i)$ for production function and $_i = (V_i + U_i)$ for cost function.

Firm-specific or observation-specific estimates of technical inefficiency, U (subscripts can safely be omitted here), can be obtained by using the expectation of the inefficiency term conditional on the estimate of the entire composed error term, as suggested by Jondrow et al. (1982) and Kalirajan and Flinn (1983). One can use either the expected value or the mode of this conditional distribution as an estimate of U:

where f and *F* are, respectively, the standard normal density and distribution functions, evaluated at el/s, $s^2 = s_u^2 \, s_v^2 / s^2$, $l = s_u / s_v$ and $s^2 = s_u^2 + s_v^2$.

The mean technical efficiency or the mathematical expectation of the farm-specific technical efficiencies can be calculated for given distributional assumptions for the technical inefficiency effects. The mean technical or economic efficiency can be defined by

$$\text{Mean T.E.} = E\,[\exp\text{-}\{E(U_i/\Sigma_1)\}] = E\Sigma_1 - E(U_i/\Sigma_1) \qquad (9)$$

Because the individual efficiencies of sample farms can be predicted, an alternative estimator for the mean efficiency is the arithmetic average of the predictors for the individual technical efficiencies of the sample farms. This is what is calculated by FRONTIER (Version 4.1c) Package. With the help of the FRONTIER programme the parameters of the stochastic frontiers (1) and (2) are estimated, together with farm-specific efficiencies and mean efficiency for the farms involved.

The above models have been estimated for three different rice crops, *Boro*, *Aus* and *Aman*, for all farms and for different farm-size groups separately in all regions. The data used in this model are cross-sectional data and sample sizes for *Boro*, *Aus* and *Aman* rice are 490, 82 and 460, respectively.

3. RESULTS AND DISCUSSION

Table 1 shows the simultaneous estimation of the maximum likelihood estimates for parameters of Cobb-Douglas stochastic production frontiers and technical inefficiency effect model for *Boro*, *Aus* and *Aman* rice. If we estimate the technical efficiency effects frontier by FRONTIER 4.1 package, we can simultaneously estimate the stochastic frontier and technical or economic inefficiency effect model. The stochastic frontier estimated simultaneously is a little bit different in respect of some significant coefficients from the single estimation procedure. Although the simultaneous estimation procedure has simultaneous-equation bias, it is also important to identify the factors, which influence the technical inefficiency of farmers. Kumbhakar, Ghosh and McGuckin (1991), Reifschneider and Stevension (1991), Huang and Lui (1994) and Battese and Coelli (1995) specify stochastic frontiers and models for the technical inefficiency effects and simultaneously estimate all the parameters involved. This one-stage approach is less objectionable from a statistical point of view and is expected to lead to more efficient inference with respect to the parameters involved. Table 1 reveals that for *Boro* rice extension, human labour, seed, fertiliser, age and experience variables have positive and significant coefficients and the coefficient of education is also significant but it is negative. Indeed, there have been many empirical tests of the effect of education on farm productivity. These generally have employed Cobb-Douglas production functions. Lockheed et al. (1980) have surveyed many of these studies. Although they conclude that the effect of education on productivity is positive, a significant number of studies (40%) found either a negative effect or no impact on productivity. For *Aus* rice, area and bullock power have significant coefficients but education has significantly negative impact on production. For *Aman* rice, extension, area and bullock power are found to have positive and significant coefficients but education and age have significantly negative coefficients.

The estimated -coefficients in Table 1 associated with the explanatory variables in the model for the inefficiency effects are worthy of deeper discussion. We observe that age of the farmers has a significantly negative effect upon the inefficiency effects for all rice crops. That is, the older farmers tend to have smaller inefficiencies than younger farmers. In other words, we can also say that the older farmers are technically more efficient than the younger farmers. Coelli and Battese (1996) found the same results while studying technical efficiency of Indian farmers.

Education is found to have no effect upon the technical inefficiency effects for all rice crops since its coefficient is insignificant for these crops. Kalirajan and Flinn (1983) and other researchers did not find any impact of formal education on the technical inefficiency effects.

Experience of farm operators has negative and significant effect upon the inefficiency effects for *Boro* and *Aman* rice. This means that the inefficiency effects decrease with the increase of the experiences of farm operators for *Boro* and *Aman* rice. That is, technical efficiency increases with the increase of experiences of the farmers for *Boro* and *Aman* rice. Experienced farmers can manage and allocate inputs more efficiently than less experienced farmers. For *Aus* rice, the effect of experience upon the inefficiency effect is also negative but not significant. These findings are in conformity with findings of Herdt and Mantac (1981) and Kalirajan (1984). They found that technical efficiency increases with the increase in experiences of farmers.

Extension contact has significantly negative effect upon the inefficiency effects for *Boro*, *Aus* and *Aman* rice. That is, farmers with more extension contacts with the extension agents are more technically efficient than farmers with less extension contacts or with no contact at all. Kalirajan (1984) and Herdt and Mantac (1981) found the same result. Kalirajan (1984) studied technical efficiency of rice farmers in Philippines. He found that technical efficiency increases with the increase in the number of extension contacts. He also showed that there existed a wide variation in the level of technical efficiencies among the sample farmers and an extension service had been identified as an important factor causing such variations.

Herdt and Mantac (1981) concluded in their study that the lack of effective extension service was responsible for lower output in the Philippines.

The coefficient of the farm size variable in the model for the inefficiency effect is estimated to be significantly negative for *Boro* rice. This indicates that farmers with larger farms tend to have smaller inefficiency effects than farmers with smaller operations. The same phenomenon was observed by Coelli and Battese (1996) while studying technical efficiency of Indian farmers. This contradicts the claim, which is frequently made for developing country agriculture, that smaller farmers tend to be more efficient in production than larger farms. The coefficient of farm size for *Aus* rice is also negative in the inefficiency effect model but it is not found to be significant while the corresponding coefficient for *Aman* rice is positive and insignificant.

The -parameter associated with the variances in the stochastic frontier is significant for all rice crops. It indicates that there are inefficiency effects in the production of rice crops and the random component of the inefficiency effects does make a significant contribution in the analysis of agricultural production.

Table 2 reveals that there are significant technical inefficiency effects in small and large farm groups but in medium farm group there is no inefficiency effect in the production of *Boro* rice. That is, small and large farmers are technically inefficient but medium farmers are technically efficient for producing *Boro* rice. In case of

Table 1: Maximum Likelihood (ML) Estimates for Parameters of Cobb-Douglas Stochastic Production Frontier Functions and Technical Inefficiency Effect Model for Boro, Aus and Aman Rice

Variables	Parameters	Rice crops		
		Boro	*Aus*	*Aman*
Stochastic Frontier:				
Intercept	β_0	3.66487** (0.13028)	5.646703** (1.23827)	5.33988** (0.36731)
Education (EDU)	β_1	-0.00001182** (0.00000052)	-0.00000995** (0.00000129)	-0.00000831** (0.00000065)
Extension (Dummy)	β_2	0.00825* (0.00383)	0.00967458 (0.0114258)	0.011887* (0.00534)
Area	β_3	-0.06293 (0.04129)	0.00000379** (0.00000123)	0.0000025* (0.0000012)
Human labour	β_4	0.68233** (0.05294)	0.007801826 (0.11337730)	-0.044411 (0.044729)
Seed	β_5	0.000006709** (0.00000075)	-0.00000265 (0.00000175)	-0.00000049 (0.00000074)
Fertilizer	β_6	0.07499* (0.03583)	-	-
Manure	β_7	0.00000107 (0.00000069)	-	-
Bullock power	β_8	0.03569 (0.03592)	0.7612193** (0.1725159)	0.64954** (0.036802)
Irrigation cost	β_9	0.000000025 (0.00000058)	-	-
Age	β_{10}	0.15364** (0.03492)	0.34402435 (0.1151759)	-0.140091** (0.051822)
Experience	β_{11}	0.000001602* (0.00000066)	-0.19449378 (0.25152956)	0.1612939 (0.100812)
Inefficiency Model: Intercept	δ_0	-0.000000000041 (0.000000000033)	2.003633* (0.814667)	1.59587** (0.1721)
Age	δ_1	-0.000000000031** (0.000000000011)	-0.0000091** (0.0000022)	-0.0000092** (0.0000016)
Education	δ_2	0.00000173 (0.0000012)	0.0843766 (0.1158312)	-0.05613 (0.05060)
Experience	δ_3	-0.000000000036* (0.000000000016)	-0.00000186 (0.00000194)	-0.00000215* (0.00000099)
Extension contact	δ_4	-0.0000000239** (0.0000000035)	-0.15929535* (0.07758695)	-0.25741** (0.05785)
Farm size	δ_5	-0.000000000158* (0.000000000071)	-0.00000198 (0.00000151)	0.00000029 (0.00000084)
Variance	α^2	0.134* (0.0651)	0.1017** (0.0162)	0.129** (0.0096)
Parameters:	λ	0.680** (0.2159)	0.999** (0.1701)	0.787** (0.095)
Log-likelihood function		-152.34	-22.60	-164.11

** and * indicate significance at 0.01 and 0.05 probability level, respectively.

Source: Own estimation.

Aus rice, there are no technical inefficiency effects in small and medium farms but large farm is characterised by technical inefficiency effect. There are significant technical inefficiency effects in all farm groups in the production of *Aman* rice. There are significant technical inefficiency effects for all rice crops.

Table 2: Test of Hypothesis for Coefficients of the Explanatory Variables for the Technical Inefficiency Effects in Farm-Size-Specific Cobb-Douglas Stochastic Frontier Production Functions

Null Hypothesis	Log-likelihood value	Test statistic LR	Critical value	Decision
$H_0: \gamma = \delta_0 = \delta_1 = ... = \delta_5 = 0$				
All farms:				
Boro rice	-152.34	15.36	12.02	Rejected
Aus rice	-22.60	35.72	12.02	Rejected
Aman rice	-164.11	235.36	12.02	Rejected
Boro Rice:				
Small farm	8.45	12.81	12.02	Rejected
Medium farm	-84.41	1.77	12.02	Accepted
Large farm	-13.42	33.28	12.02	Rejected
Aus rice:				
Small farm	-9.27	0.98	12.02	Accepted
Medium farm	4.12	1.19	12.02	Accepted
Large farm	4.54	17.03	12.02	Rejected
Aman rice:				
Small farm	-65.37	120.62	12.02	Rejected
Medium farm	-46.43	82.74	12.02	Rejected
Large farm	-12.37	50.14	12.02	Rejected

Source: Own estimation

To have an idea of the farm-specific variables that influence economic inefficiency effect, we have estimated simultaneously Cobb-Douglas stochastic normalised cost frontiers and economic inefficiency effect models for *Boro*, *Aus* and *Aman* rice. Table 3 shows ML estimates of normalised cost frontiers and economic inefficiency effect models. For *Boro* rice, cost function was normalised with fertiliser price and for *Aus* and *Aman* rice cost functions were normalised with seed price. The coefficients of education and age are significantly negative for all rice crops in the cost frontiers.

For *Boro* rice, the coefficients of experience, output, labour price (wage), per hectare irrigation cost and per hectare rent of land are positive and significant in the stochastic cost frontier. In the economic inefficiency effect model, the coefficients of age and farm size are significantly positive which indicates that the economic inefficiency effect increases with the increase in age and farm size. That is, there is inverse relation between age and economic efficiency and between farm size and economic efficiency. The coefficients of experience and extension contact are found to be negative and significant which means that the economic inefficiency effects decreases with the increase in experience of farmers and with the increase in extension contact of extension agents with farmers.

For *Aus* rice, the coefficient of per hectare rent of land is positive and significant in the cost frontier. In the economic inefficiency effect model, the coefficients of age and farm size are positive and significant whereas the coefficient of extension contact is significantly negative.

The coefficient of per hectare rent of land is positive and significant in the cost frontier for *Aman* rice. The coefficients of age, education and farm size are found to be positive and significant whereas the coefficient of extension contact is significantly negative in the economic inefficiency effect model for *Aman* rice.

The significant value of indicates that there are significant economic inefficiency effects in the production of *Boro, Aus Aman* rice crops.

Table 4 shows generalised likelihood ratio test statistic to detect the presence of economic inefficiency effects in the farm-size-specific Cobb-Douglas stochastic cost frontiers for all rice crops. Table 4 reveals that in the production of *Boro* and *Aman* rice crops there are significant economic inefficiency effects in all farm size groups. For *Aus* rice, there is no significant economic inefficiency effect in small farm but inefficiency effect is significant in medium and large farms.

Individual farm-specific technical efficiency measures are more useful for policy makers than the average technical efficiency estimates. Individual farm-specific efficiency measures facilitate identification of the determinants of efficiency ratings among farms. Appropriate policies then may be formulated to decrease efficiency differentials, which is important to accelerate the overall growth of farms.

Table 5 shows frequency distribution of farm-specific technical, allocative and economic efficiency estimates for *Boro*, *Aus* and *Aman* rice from Cobb-Douglas stochastic frontiers. These farm-specific efficiencies are estimated by single estimation of Cobb-Douglas stochastic production and cost frontiers. A careful examination of the results reveals that only about 5% of sample farmers were

Table 3: Maximum Likelihood (ML) Estimates for Parameters of Cobb-Douglas Stochastic Normalised Cost Frontier and Economic Inefficiency Effect Model Boro, Aus and Aman Rice

		Rice crops		
Variables	Parameters	Boro	Aus	Aman
Intercept	ß$_0$	-0.139335 (0.365222)	0.48056 (0.88409)	0.749115 (0.411309)
Education (EDU)	ß$_1$	-0.00000921** (0.0000046)	-0.0000112** (0.00000148)	-0.0000097** (0.00000078)
Extension (Dummy)	ß$_2$	-0.0037849 (0.0043796)	0.01286 (0.01218)	-0.002488708 (0.00564227)
Age	ß$_3$	-0.3293718** (0.0406014)	-0.29884** (0.08853)	-0.315697** (0.05196)
Experience	ß$_4$	0.8142846** (0.022885)	0.21215 (0.27679)	0.08645 (0.11019)
Output	ß$_5$	0.00000966** (0.00000036)	0.00000178 (0.00000362)	0.000000578 (0.00000138)
Labour price (wage)	ß$_6$	0.2434224** (0.0943733)	-0.007351 (0.10569)	0.049843 (0.054028)
Seed price	ß$_7$	0.00000164 (0.0000081)	-	-
Bullock power price	ß$_8$	0.0936754 (0.0437707)	0.0000000269 (0.00000168)	0.00000073 (0.00000085)
Per hectare irrigation cost	ß$_9$	0.00000159** (0.00000065)	-	-
Per hectare rent of land	ß$_{10}$	0.3276076** (0.0592764)	0.608917** (0.076258)	0.7198295** (0.0279797)
Inefficiency effect model:				
Intercept	0	-0.000000000053 (0.00000000065)	0.007668 (0.565308)	-1.52219 (0.07321)
Age	1	0.0000070284** (0.000000447)	0.00000483** (0.000001718)	0.0000075** (0.00000093)
Education (EDU)	2	0.00000000011 (0.0000000021)	0.219793 (0.22201)	0.964716** (0.04778)
Experience	3	-0.000005293** (0.000000239)	0.00000142 (0.00000223)	0.00000868 (0.00000091)
Extension contact	4	-0.000661** (0.0000562)	-0.00045** (0.000036)	-0.0000667** (0.0000075)
Farm size	5	0.0000000000229* (0.000000000011)	0.217822* (0.100999)	0.1348833** (0.0415128)
Variance parameters:	2	0.17544** (0.01456)	0.09513** (0.018379)	0.1446007** (0.011042)
Log likelihood function		0.440** (0.0627)	0.99999** (0.25866)	0.7190691** (0.015962)
		-169.34	-18.03	-198.01

** and * indicate significance at 0.01 and 0.05 probability level, respectively.

Source: Own estimation.

obtaining outputs which were very close to the maximum output estimated through frontier (efficiency is 90% to100%) and there are about 92% of sample farmers whose technical efficiency levels range from 80% to 90% for *Boro* rice.

There are 70% sample farmers who can optimally allocate their inputs for *Boro* rice production and whose allocative efficiency levels vary from 90% to 100%. There are only about 3% *Boro* rice farmers whose observed costs of production are very much close to the frontier minimum cost (economic efficiency is 90% to 100%) and observed costs of most of the farmers lie above the frontier minimum cost. The average technical, allocative and economic efficiency indexes computed for *Boro* rice are 86%, 92%, and 79%, respectively.

Table 4: Test of Hypotheses for Coefficients of the Explanatory Variables for the Economic Inefficiency Effects in the Cobb-Douglas Normalised Stochastic Cost Frontiers

Null Hypothesis	Log-likelihood value	Test statistic LR	Critical value	Decision
$H_0: = {}_0 = {}_1 = ... = {}_5 = 0.$				
Boro rice:				
Small farm	-35.88	18.98	12.02	Rejected
Medium farm	-61.41	21.02	12.02	Rejected
Large farm	-28.19	13.24	12.02	Rejected
Aus rice:				
Small farm	-7.79	0.44	12.02	Accepted
Medium farm	3.92	12.76	12.02	Rejected
Large farm	12.01	28.18	12.02	Rejected
Aman rice:				
Small farm	-100.54	111.77	12.02	Rejected
Medium farm	-34.07	85.96	12.02	Rejected
Large farm	-6.16	95.02		Rejected

Source: Own estimation.

Table 5 reveals that for *Aus* rice all of the farmers were found to be produced outputs which were very close to the maximum frontier outputs (efficiency levels vary from 90% to 100%) but *Aus* rice farmers were not allocatively and economically efficient since only about 13% of sample farmers were found to be allocated their inputs near about optimally (allocative efficiency ranges from 90% to 100%) and there are only about 2% sample farmers whose observed costs are very close to the frontier minimum cost and observed costs of rest of the farmers

Table 5: Frequency Distribution of Farm-Specific Technical, Allocative and Economic Efficiency Estimates from Cobb-Douglas Stochastic Frontiers

Efficiency level (%)	Crops								
	Boro			*Aus*			*Aman*		
	Technical Efficiency	Allocative Efficiency	Economic Efficiency	Technical Efficiency	Allocative Efficiency	Economic Efficiency	Technical Efficiency	Allocative Efficiency	Economic Efficiency
35-40	0	0	1 (0.20)	0	0	1 (1.22)	1 (0.22)	1 (0.22)	2 (0.44)
40-45	0	1 (0.20)	2 (0.41)	0	1 (1.22)	0	1 (0.22)	1 (0.22)	2 (0.44)
45-50	0	2 (0.41)	1 (0.41)	0	0 (1.22)	2	0 (0.22)	2 (0.22)	2 (0.44)
50-55	1 (0.20)	1 (0.20)	1 (0.20)	0	2 (2.44)	3 (3.66)	0	2 (0.44)	8 (1.74)
55-60	1 (0.20)	1 (0.20)	1 (0.20)	0	3 (3.66)	6 (7.32)	1 (7.32)	2 (0.44)	16 (3.48)
60-65	2 (0.41)	1 (0.20)	3 (0.61)	0	6 (7.32)	4 (4.88)	2 0.44)	3 (0.65)	49 (10.65)
65-70	1 (0.20)	2 (0.41)	13 (2.66)	0	5 (6.09)	8 (9.76)	15 (3.26)	9 (1.96)	72 (15.65)
70-75	2 (0.41)	4 (0.82)	42 (8.58)	0	7 (8.54)	10 (12.20)	55 (11.96)	25 (5.43)	107 (23.25)
75-80	8 (1.64)	11 (2.25)	153 (31.22)	0	8 (9.76)	19 (23.16)	120 (26.08)	38 (8.26)	117 (25.43)
80-85	103 (21.02)	39 (7.96)	189 (38.57)	0	16 (19.51)	20 (24.38)	203 (44.13)	55 (11.96)	66 (14.35)
85-90	347 (70.82)	85 (17.35)	71 (14.49)	0	23 (28.05)	7 (8.54)	7 (11.52)	73 (15.87)	18 (3.91)
90-95	24 (4.90)	145 (29.59)	13 (2.66)	75 (91.46)	6 (7.32)	2 (2.44)	9 (1.95)	79 (17.17)	1 (0.22)
95-100	1 (0.20)	198 (40.41)	0	7 (8.54)	5 (6.09)	0	0	170 (36.95)	0
Total number of farms	490 (100.00)	490 (100.00)	490 (100.00)	82 (100.00)	82 (100.00)	82 (100.00)	460 (100.00)	460 (100.00)	460 (100.00)
Mean Efficlency	86	92	79	93	77	72	80	89	71
Minlmum Efficilency	54	43	38	92	42	39	39	38	35
Maximum Efficlency	96	99	93	95	99	92	93	99	90

Figures in the parentheses indicate percentage.

Source: Own estimation.

lie above the frontier minimum cost. The average technical, allocative and economic efficiency indexes computed for *Aus* rice are 93%, 77%, and 72%, respectively.

An examination of farm-specific technical efficiency for *Aman* rice reveals that only about 2% of sample farmers were obtaining outputs which were very close to the frontier maximum outputs (efficiency 90% or more), and the rest were far below the frontier. But about 54% farmers can allocate inputs for producing *Aman* rice near about optimally (efficiency levels 90% or more) while no farmer was found to achieve economic efficiency in this level. The average technical, allocative and economic efficiency indices computed for *Aman* rice are 80%, 89%, and 71%, respectively.

Table 6 presents crop-specific and farm-size-specific technical, allocative and economic efficiency estimates from single estimation of Cobb-Douglas stochastic frontiers. It reveals that the technical efficiency for all rice crops is the highest for medium farm, which is 88% followed by large farm (84%) and small farm (82%), respectively. The allocative efficiency for all rice crops is the highest for small farm (92%) followed by medium farm (91%) and large farm (85%), respectively. The economic efficiency is the highest for medium farm (80%) followed by small farm (75%) and large farm (71%), respectively. It is obvious that medium farmers are the most efficient farmers, which achieve maximum technical and economic efficiencies for all rice crops.

4. CONCLUSIONS AND POLICY IMPLICATIONS

Farm-size-specific and farm-specific efficiencies (technical, allocative and economic) are estimated through single estimation of Cobb-Douglas stochastic production and cost frontiers. To identify factors which influence inefficiency effects (technical and economic) simultaneous estimation of stochastic frontiers and inefficiency effects models were done. The factors which help increase production of *Boro* rice are extension service, human labour, seed, fertiliser, age and experience. Area and bullock power have positive effect on the *Aus* output. Similarly, extension service, area and bullock power have positive effect on the *Aman* output. But age has negative impact on the production of *Aman* rice. Education has negative effect on the production of all rice crops.

The factors, which have negative impact on the technical inefficiency effects, are age, extension contact for all rice crops. Experience has negative impact on the technical inefficiency effects for *Boro* and *Aman* rice while farm size has negative impact on it.

There are technical inefficiency effects for all rice crops. But medium farmers are technically efficient for *Boro* rice, and small and medium farmers are technically efficient for *Aus* rice. But for *Aman* rice all farm groups are technically inefficient.

Table 6: Crop-Specific and Farm-Size-Specific Technical, Allocative and Economic Efficiency Estimates from Cobb-Douglas Stochastic Frontiers

Farm	Crops											
size	*Boro*			*Aus*			*Aman*			All crops		
l	T.E. (%)	A. E. (%)	E. E. (%)	T. E. (%)	A. E. (%)	E. E. (%)	T. E. (%)	A. E. (%)	E. E. (%)	T. E. (%)	A. E. (%)	E.E (%)
Small	86	93	80	99	86	85	76	92	70	82	92	75
	(243)	(243)	(243)	(34)	(34)	(34)	(229)	(229)	(229)	(506)	(505)	(506)
Medlum	93	92	86	96	70	67	80	94	75	88	91	80
	(148)	(148)	(148)	(27)	(27)	(27)	(139)	(139)	(139)	(314)	(314)	(314)
Large	76	92	70	76	92	70	94	76	71	84	85	71
	(99)	(99)	(99)	(21)	(21)	(21)	(92)	(92)	(92)	(212)	(212)	(212)
All	86	92	79	93	77	72	80	89	71	84	89	75
	(490)	(490)	(490)	(82)	(82)	(82)	(460)	(460)	(460)	(1032)	(1032)	(1032)

Figures in the parentheses indicate sample sizes. T.E.= Technical Efficiency, A.E.= Allocative Efficiency, E. E. = Economic Efficiency.
Source: Own estimation.

The factors which increase the cost of *Boro* rice are experience, output, labour price (wage), per hectare irrigation cost and per hectare rent of land. But for *Aus* and *Aman* rice, only per hectare rent of land has positive effect on the cost of production. Education and age have negative effect on the cost of production of all rice crops.

Age and farm size have positive impact on the economic inefficiency effects whereas extension contact has negative effect on it for all rice crops. Experience has negative impact on the economic inefficiency effects for *Boro* rice whereas education has positive impact on it. There are economic inefficiency effects in all farm groups for all rice crops except for small farm for *Aus* rice. Small farmers for *Aus* rice are economically efficient.

Medium farmers are the most efficient farmers, which achieve maximum technical and economic efficiencies for all rice crops. From a policy point of view, the main responsibility of the government in this area is to ensure that the land market is flexible enough to allocate land to the most efficient farmers. Furthermore, the government can assist the land market by offering extension programmes to encourage farmers not to fragment land, which is an effect of the inheritance law. As the study shows, agricultural extension services can be extended to all farmers in order to enhance sustainable agricultural growth.

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