

AN ECONOMETRIC ANALYSIS OF TECHNICAL INEFFICIENCY OF FARM HOUSEHOLDS IN BANGLADESH

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ABSTRACT

This paper conducts an analysis of farm-specific technical inefficiency using farm-level cross-sectional survey data of rice farmers in Bangladesh. A stochastic frontier production function model is estimated in a single-stage estimation technique applying the maximum likelihood estimation method. The nonnegative technical inefficiency effects are regressed on farm-specific socioeconomic factors, irrigation infrastructure and environmental factors. The results indicate that factors measuring land fragmentation, irrigation infrastructure and environmental degradation have significant influences on the technical inefficiency effects. Therefore policies that reduce land fragmentation, promote irrigation infrastructure and reduce environmental degradation would reduce inefficiency and hence improve efficiency and farm revenue of farm households in Bangladesh.

Keywords : Stochastic frontier, technical inefficiency effects.
JEL Classification Number: P5, P15, Q16, D43.

1. Introduction

Agriculture in Bangladesh accounts for about 59.56 per cent of the total land area, employs about 66 per cent of the labour force and provides the main sources of income for 80 per cent of the population. The average growth rate of agricultural sector from 1990 to 1996 is 1.34 per cent and that of crop sector is only about 0.18 per cent (Bangladesh Economic Review, 1997). The share of agriculture in GDP has fallen from 57 per cent in the 1970s to 35 per cent in the 1990s. The rice crop accounts for 74 per cent of the cultivated area, 83 per cent of irrigated area, 88 per cent of fertilizer consumption and 68 per cent of caloric intake. The amount of rice produced is set against a population of 114.4 million with a growth rate of 2.17 per cent in 1991. In the 1960s Bangladesh agriculture started to adopt the prescriptions of the Green Revolution. There has been a widespread adoption of new varieties and modern inputs. The government of Bangladesh also liberalized the markets for agricultural inputs and outputs

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through agricultural reform policy. This policy greatly increased the use of purchased inputs by reducing their prices. The average overall food deficit over recent years is about 1.5 million metric tonnes of rice per annum (Bangladesh Economic Review, 1997). The policy makers might consider two issues to enhance agricultural productivity gains: technological improvement and efficiency improvement. Output gains stemming from productivity improvement through improvements in efficiency are important considering that the scope to enhance farm production by bringing land into cultivation has reduced to an insignificant level.

Farm households in Bangladesh are generally large with a low level of literacy. Production is hampered by land fragmentation, environmental degradation, in particular land degradation, weak irrigation infrastructure, ineffective and bureaucratic extension services, restricted access to credit, poor transport systems, and storage facilities. These factors are likely to affect the efficiency performance of the farm households.

Technical efficiency, as it is measured here, is concerned with how farmers utilize existing technology to achieve maximum output, given input prices. Thus the question arises as to which farm households types are relatively efficient and whether barriers to efficiency are due to environmental degradation, weak irrigation infrastructure or the socioeconomic characteristics of the farm households. The policy issue concerns whether or not it is better to pursue policies which introduce new technologies or those which increase technical efficiency of the farm households. This is of great importance to land-scarce Bangladesh because environmental degradation and irrigation infrastructure have the potentials to decrease agricultural output. Identifying sources of inefficiency plays an important role in designing policies to improve the performance of farm households. Measuring efficiency is important in that the determinants of inefficiency can be hypothesized by estimating efficiency and isolating their effects from the effects of the environment in which production occurs.

The remainder of this paper is structured as follows: Section 2 describes the stochastic frontier analysis; Section 3 provides data and empirical model; Section 4 explains empirical results; and Section 5 concludes.

2. Stochastic Frontier Model and Efficiency Measurement

Standard econometric production function models assume that all farms become successful in maximizing output so that a systematic stochastic error term, with zero mean, attributes the discrepancies between the observed and the

expected output values. A frontier production relaxes the assumption of equal efficiency and hence the assumption of systematic error terms with zero mean. The general stochastic frontier production, independently proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977), decomposes the composed error term into two components: a stochastic random error component and a technical inefficiency component. Reviews of the various stochastic frontier models are provided by Førsund et al. (1980), Schmidt (1986), Bauer (1990), Battese (1992), Brevo-Ureta and Pinherio (1993), Fried et al. (1993), Greene (1993) and Coelli (1995). Kumbhakar et al. (1991), Huang and Liu (1994) and Battese and Coelli (1995) proposed various stochastic frontier models in which the technical inefficiency effects are modelled as a function of other observable explanatory variables. The general stochastic frontier production model is defined as:

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

Where y_i denotes the output of the i th farm, x_i is a $(1 \times K)$ vector of inputs and β is a vector of parameters. The error term u_i is decomposed into a random error, ξ_i and the asymmetric non-negative random error ζ_i . The random variables, ξ_i 's, accounts for random variations in output because of factors not under the control of the farm households and are assumed to be independently and identically distributed as $N(0, \sigma_\xi^2)$. The asymmetric non-negative random error, ζ_i , measures the technical inefficiency relative to the stochastic frontier and is assumed to be independently and identically distributed non-negative truncations (at zero from below) of the $N(\mu, \sigma_\zeta^2)$ distribution. Thus $\zeta_i = 0$ implies the farm lies on the stochastic production frontier and hence the farm is efficient and $\zeta_i > 0$ indicates the farm is inefficient. Furthermore ξ_i and ζ_i are assumed to be independent of each other and also independent of the input vector x . The variance parameters of the models are expressed as:

$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2 \text{ and } \gamma = \sigma_\zeta^2 / \sigma_u^2 \quad (2)$$

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

defined as the ratio of the observed output (y_i) to the corresponding frontier output (y_i^*), given the levels of the inputs utilized by that farm. The farm specific technical efficiency, τ_i , can be measured as:

$$\tau_i = \frac{y_i}{y_i^*} = \frac{f(x_i, \beta)e^{(\xi_i - \zeta_i)}}{f(x_i, \beta)e^{\xi_i}} = e^{-\zeta_i} \quad (\text{so that } 0 \leq \tau \leq 1) \quad (3)$$

Estimate of the farm-specific efficiency, $e^{-\zeta_i}$, depends upon the decomposition of u_i , and can be derived from the conditional expectation of $e^{-\zeta_i}$ given u_i . The measure of technical efficiency is obtained by applying standard integral, given the probability density functions of both ξ_i and ζ_i as:

$$\tau_i = E(e^{-\zeta_i} | u_i) = \left[\frac{1 - \Phi\left\{\frac{\sigma_{i\zeta}^* - (\mu_i^* / \sigma_{i\zeta}^*)}{\sigma_{i\zeta}^*}\right\}}{1 - \Phi\left(-\mu_i^* / \sigma_{i\zeta}^*\right)} \right] e^{\left(-\mu_i^* + \frac{1}{2}\sigma_{i\zeta}^{*2}\right)} \quad (4)$$

Where $\mu_i^* \equiv \frac{\mu\sigma_{\xi}^2 - u_i\sigma_{\zeta}^2}{\sigma_{\xi}^2 + \sigma_{\zeta}^2}$, $\sigma_{\zeta}^{*2} \equiv \frac{\sigma_{\xi}^2\sigma_{\zeta}^2}{\sigma_{\xi}^2 + \sigma_{\zeta}^2}$ and $\Phi(\cdot)$ is the cumulative distribution function (Battese and Coelli, 1988). Technical inefficiency is estimated by $1 - E\left\{e^{-\zeta_i} | u_i = \xi_i - \zeta_i\right\}$. The efficiency index, $e^{-\zeta_i^*}$, of each farm can be constructed using the results from the above equation. The mean technical efficiency of the farms, $\bar{\tau} = E\left[e^{-\zeta_i}\right]$, is obtained as:

$$\bar{\tau} = \left[\frac{1 - \Phi\left\{\frac{\sigma_{\zeta} - (\mu / \sigma_{\zeta})}{\sigma_{\zeta}}\right\}}{1 - \Phi\left(-\mu / \sigma_{\zeta}\right)} \right] e^{\left(-\mu + \frac{1}{2}\sigma_{\zeta}^2\right)} \quad (5)$$

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

$$\tau_i = E\left[e^{-\zeta_i | u_i}\right] = 1 - \Phi(\sigma_i^*) e^{\frac{1}{2}\sigma_i^{*2}} \quad \text{and} \quad \bar{\tau} = 1 - \Phi(\sigma^*) e^{\frac{1}{2}\sigma^{*2}} \quad (6)$$

3. Data and Empirical Models

3.1. Data Description

The data used in this study are collected from two villages in the High Barind of Bangladesh by a cross-sectional survey of households conducted in

1997 (for details of the survey, see Wadud, 1999). Output (y) is defined as the market value of the observed rice production. It is measured in Bangladesh taka. Land (x_1) represents the total rental value of lands used for rice production of the farm household. Labour (x_2) includes both family and hired labour engaged in rice production. It represents the total costs of labour measured by market price. Irrigation (x_3) represents the total irrigation cost for rice production. This cost is estimated from total rice land irrigated and market price of irrigation for each acre of land. Fertilizer (x_4) includes all sorts of organic and inorganic fertilizer used by the farm households for rice production. It represents the total cost of fertilizer measured by market prices. Pesticides (x_5) represents the market costs of pesticides used for rice production.

3.2. Empirical Model

The stochastic frontier production model is represented by specifying the Cobb-Douglas model (Seyoum et al., 1998; Son et al., 1993; Tadesse and Krishnamoorthy, 1997).¹ We specify the following Cobb-Douglas stochastic frontier production model:

$$\ln y_i = \beta_0 + \sum_{i=1}^5 \beta_i \ln x_i + \xi_i - \zeta_i \quad (7)$$

Where y_i represents the value of rice output, x_1 is the rental value of land input utilized, x_2 represents the total labour costs, x_3 , x_4 and x_5 represent the irrigation, fertilizer and pesticides costs respectively, \ln indicates the natural logs. The systematic error components, ξ_i , are assumed to be independently and identically distributed random errors having normal distribution with mean zero and variance σ_ξ^2 , i.e., $\xi_i \sim N(0, \sigma_\xi^2)$ and the technical inefficiency effects, ζ_i , are assumed to be independently distributed of ξ_i such that ζ_i is satisfied by the truncation (at zero from below) of the $N(\mu_i, \sigma_\zeta^2)$ where μ_i can be specified and defined as:

$$\mu_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4 + \delta_5 z_5 \quad (8)$$

Where z_1 denotes the age of the farmer, z_2 is the farmer's year of schooling, z_3 represents land fragmentation, z_4 is the irrigation infrastructure dummy which assumes the value 1 if the farmer buys irrigation water from diesel powered schemes and zero otherwise; and z_5 denotes the environmental degradation dummy variable which takes the value 1 if the land is undegraded and zero otherwise.

The age of the farmers might have a positive or a negative effect upon the inefficiency effects. The older farmers are likely to be more experienced and hence be more efficient. However, they are likely to be less willing to adopt new practices and conservative, thereby perhaps having greater inefficiency in production. *A priori*, the greater levels of education are expected to be associated with the smaller levels for the inefficiency effects. The greater the plot size (less fragmentation) of a farm the greater the opportunity to apply new technologies such as tractors and irrigation and hence the farmers with less land fragmentation could be expected to be more efficient. Thus, land fragmentation is likely to have negative effects upon efficiency. Irrigation infrastructure and environmental degradation, i.e., land degradation could have positive effects upon the size of the inefficiency effects (for details of the variables, see Wadud, 1999).

This study applies the single stage estimation technique to solve the problem in the two stage estimation technique. The two stage technique first calculates the technical efficiency for each farm under the assumption that the inefficiency effects are identically distributed ignoring the fact that the technical inefficiency is a function of farm-specific variables; and technical inefficiency estimates are further regressed in the second stage on a set of farm-specific factors that may explain differences in technical inefficiency among farms using OLS. The OLS results in the second step contradict the assumption of identically distributed inefficiency effects in the stochastic frontier model since the technical inefficiency - the dependent variable - is one sided (Kumbhakar et al., 1991). The single stage technique specifies the technical inefficiency effects (Kumbhakar et al., 1991) and estimates the stochastic frontier and the inefficiency effects simultaneously, given appropriate distributional assumptions (Battese and Coelli, 1995). The simultaneous estimation of the stochastic production frontiers and models of technical inefficiency using maximum likelihood techniques has been proposed by Kumbhakar et al. (1991), Reifschneider and Stevenson (1991), Huang and Lui (1994), Battese and Coelli (1995). This one-stage approach is statistically consistent and leads to more efficient inference with respect to the parameters (Coelli and Battese, 1996).

4. Empirical Results and Discussion

We calculate the maximum likelihood estimates of the coefficients of parameters of the Cobb-Douglas stochastic frontier model, given the technical inefficiency effects model for both the half-normal and truncated normal distributions. The null hypothesis of the half-normality of the technical inefficiency effects model is tested using the generalized likelihood ratio (*LR*) statistic:

$$LR = -2 \ln[L(H_0)/L(H_A)] \quad (9)$$

Where $L(H_0)$ and $L(H_A)$ are the values of the likelihood function under the null and alternative hypotheses respectively.² The estimated LR value, 51.4166, is substantially greater than the critical value of 3.841 at 5 per cent level of significance. Therefore the half-normal distribution is an inadequate representation for the distribution of the inefficiency effects. Accordingly we explain the results obtained using the truncated normal distribution and the results are given in Table 1. The signs of the β -coefficients are all positive as expected and five out of the six coefficients are significant.

Table 1: Maximum Likelihood Estimates of the Cobb-Douglas Frontier Model

Name of Variables	Parameters	Coefficients	t-ratios
Stochastic frontier			
Constant	β_0	2.7152*	7.5704
Land	β_1	0.2922*	7.1224
Labour	β_2	0.2060*	6.9401
Irrigation	β_3	0.2784*	7.1607
Fertilizer	β_4	0.0078	0.4164
Pesticides	β_5	0.0810*	3.5982
Inefficiency model			
Constant	δ_0	0.0245	0.1468
Age of farmers	δ_1	0.0040	1.7481
Land fragmentation	δ_2	-0.5043	-1.5919
Year of schooling	δ_3	0.0031	0.5347
Irrigation infrastructure dummy	δ_4	0.2996*	3.3441
Environmental degradation dummy	δ_5	-0.2364*	-2.3314
Variance parameters			
Sigma-squared	$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2$	0.0377*	4.3312
Gamma	$\gamma = (\sigma_\zeta^2 / \sigma_u^2)$	0.8146*	10.6860
Sigma-squared of	σ_ξ^2	0.0069	
Sigma-squared of	σ_ζ^2	0.0307	
Log-likelihood		72.8365	

Note: * indicates that the variables are significant.

The relative significance of the production inputs is predicted by the elasticity estimates from the stochastic frontier production function. All the elasticities of output have the expected positive signs and the partial elasticities of output are highly significant. The highest elasticity of output for land shows this input to be the most dominant factor of production. This is consistent that land is scarce to the farm households in Bangladesh. The policy implication of this observation is that the concerned authority could provide incentives to the farm households to hold their existing cultivated lands and bring to use cultivable waste for production. With growing population, reduction in farm size/land size could have not only a direct effect on agricultural output as land input has the major influence on output but also an indirect effect on agricultural production through decreasing the marginal productivity of other inputs. Irrigation appears to be the second important factor of production followed by labour input. Two land-augmenting factors of production are irrigation and fertilizer in a sense that these factors increase the fertility/quality of existing lands and hence enhance yields per acre. In this particular region in Bangladesh land degradation and low soil quality fall among major technical constraints on production and the effects of these constraints can be decreased through efficient utilization of fertilizer and irrigation facilities, and appropriate combination of the two inputs. The scale elasticity of 0.8655 indicates slightly decreasing returns which imply that the farmers produce on a non-optimal scale of operation.

4.1. Inefficiency Effects

We now turn to the parameters associated with σ_u^2 and γ which are of particular interest. The estimated value of σ_u^2 is significant at the 5 per cent level of significance which is consistent with the results of Hjalmarsson et al. (1996). The estimated value for the variance parameter, γ , is highly significantly different from zero, which indicates that inefficiency effects have a significant contribution in determining the level and variability of output of the farm households. This result conforms with the results of Sharma et al. (1997), Hjalmarsson et al. (1996), Coelli and Battese (1996), Kalirajan (1981), Ajibefun et al. (1996), Ali and Flinn (1989). The null hypothesis of no technical inefficiency is tested using the LR test given in (9).³ The estimated LR statistic of 79.3537, is substantially greater than the χ_6^2 critical value of 16.812. Thus the null hypothesis of no technical inefficiency is rejected at 1 percent level of significance. This conforms that the large estimated value of γ -parameter in the inefficiency effects model is highly significant in the analysis of the value of output of the farmers. This suggests that the technical inefficiency effects in the model are random for the farm households in the High Barind Bangladesh

leaving the traditional response function, with no technical inefficiency, an inadequate representation of the agricultural production. Furthermore, the estimated variance of the technical inefficiency effects term exceeds the estimated variance of the random error term which is in conformity with the empirical results of Kalirajan (1981) but in contrast to results of Aigner et al. (1972). The significant estimated values of γ and σ_u^2 indicate that the distributional assumptions of ξ_i and ζ_i are acceptable for this data set which conforms with the result of Kalirajan (1981).

The signs of the estimated coefficients for δ_i associated with the explanatory variables in the stochastic frontier model for the technical inefficiency effects need to be analyzed carefully because variation in technical efficiency of farm households arises due to these variables as they affect the capability of the farm households to adequately utilize the existing facilities and technologies. We test the null hypothesis that the farm-specific variables have no significant effects on the level of inefficiency using the LR test in (9).⁴ The estimated LR statistic, of 49.68, is greater than the χ^2_5 critical value of 11.070, and the null hypothesis is rejected, i.e., the farm-specific variables together have significant effects on inefficiency.

The coefficient of the age of the farmers is estimated to be positive which implies that the older agricultural farm households tend to have more technical inefficiencies than younger farm households. This conforms with results obtained by Ajibefun et al. (1996), Seyoum (1998) and Coelli and Battese (1996). This could be explained that older farmers are likely to be conservative and less receptive to new practices. The estimate for the coefficient of year of schooling is positive, as unexpected but highly insignificant with t-ratio 0.14. This result is in conformity with the result obtained for the Kanzara village in India by Coelli and Battese (1996). The estimated coefficient for land fragmentation is positive, as expected. This implies that farm households with larger land plot size are more technically efficient. This is consistent with Coelli and Battese's (1996) results for the Indian farmers. This can be attributed to the applicability of technologies like irrigation and others on lands. The policy implication is that farm households could be encouraged to keep their land with greater plots so that modern facilities for cultivation and harvesting, irrigation facilities could be applied.

The coefficient of irrigation infrastructure dummy is estimated to be positive and significant. This indicates that the irrigation schemes operated with diesel have increased technical inefficiency in agricultural production. This could be attributed in terms of the lower water extraction capacity of such irrigation schemes. Water extraction capacity of diesel pumps is lower than

electricity-operated pumps and diesel costs are higher than electricity costs. The expansion of the electrification program of the government of Bangladesh in this region could decrease farming costs and inefficiency of the farm households significantly and hence increase farm revenue and household welfare.

The estimate of the coefficient on the environmental degradation dummy, i.e., land degradation dummy is calculated to be negative and significant, as is expected. This implies that the farmers with undegraded lands have had smaller technical inefficiency in agricultural farm operation. In this region topsoil degrades through runoff of heavy rainfall water during rainy season and hence fertility of soils decreases. The higher the productivity of a land the greater the fertility. This also indicates that reduction of environmental degradation, that is, in particular, improvement of land quality will reduce the costs of farming operations and hence will increase farm revenue.

4.2. Technical Efficiency Estimates of Farm Households

The frequency distribution of the estimated technical efficiencies and the summary statistics are presented in Table 2. The estimated technical efficiencies obtained from the specification of the stochastic frontier and technical inefficiency effects model exhibit substantial variability among the farmers ranging between 40 and 98 per cent with the mean technical efficiency of 80 per cent and standard deviation of 13 per cent. Therefore there is room for productivity gains through efficiency improvement.

Table 2: Frequency Distribution of Farm-Specific Technical Efficiency

Efficiency Index (%)	Number of farms	Percentage of farms
0-50	1	0.67
50-55	3	2.00
55-60	3	2.00
60-65	19	12.67
65-70	19	12.67
70-75	13	8.67
75-80	21	14.00
80-85	16	10.67
85-90	40	26.67
90-95	4	2.67
95-100	11	7.33
Mean	80	
Minimum	40	
Maximum	98	
Standard Deviation	13	

5. Conclusions

This paper analyzes estimates the specification of the Cobb-Douglas stochastic frontier model and the technical inefficiency effects model. The Cobb-Douglas stochastic frontier and the inefficiency effects model are estimated using the single stage maximum likelihood estimation technique. The inefficiency effects model includes the farm-specific factors, like age and education of the farmers, land fragmentation, irrigation infrastructure and land degradation. The estimated coefficients of the parameters of the stochastic frontier model have all the expected sign. The farm households appear to be characterized by slightly decreasing returns to scale in agricultural production. The technical efficiency among the farm households varies from 40 to 98 per cent with the mean value of the technical efficiency of 80 per cent.

Given the specification of the technical inefficiency effects model, the inefficiency effects are influenced significantly by the explanatory variables included in the model. The results of the analysis of technical inefficiency by socio-economic factors show that the younger farmers with more receptive tendency to new technology and more education are most likely to operate farming activities efficiently. Moreover the larger the land plot sizes the greater the technical efficiency. Policies which promote land tenure and land management in contracting land fragmentation are beneficial to improving technical efficiency.

A significant contribution of our paper of the inefficiency effects model is that it includes irrigation infrastructure and environmental degradation factors to examine their effects on technical inefficiency. Technical inefficiency effects in agricultural production are positively influenced by the irrigation infrastructure, i.e., diesel-operated irrigation schemes as indicated by the results. The results also indicate that land degradation as an environmental factor also increases technical inefficiency. The rural electrification programmes which will convert diesel-operated irrigation schemes into electricity-operated schemes, and policies that lead to reduce land degradation remain beneficial in decreasing the technical inefficiency effects in agricultural production, thereby increasing productivity and household welfare for the rice farmers in Bangladesh.

Notes:

- 1 The Cobb-Douglas specification is restrictive. However this provides an adequate representation as interest lies on efficiency measurement and not an analysis of production structure. The functional specification has been widely used in efficiency analyzes for both developing and underdeveloping countries (Taylor et al., 1992; Wadud, 1999). A subsequent paper will use the translog specification.
- 2 The alternative hypothesis is that the technical inefficiency effects follow the truncated normal distribution.
- 3 The alternative hypothesis is that there are technical inefficiency effects.
- 4 The alternative hypothesis is that the farm-specific variables have significant effects on the level of inefficiency.

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