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Full Length Research Paper

Modeling technical inefficiencies effects in a stochastic frontier production function for panel data

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A stochastic frontier production function is defined for panel data on tea industries, in which the non-negative technical inefficiency effects are assumed to be a function of industry-specific variables and time. The inefficiency effects are assumed to be independently distributed as truncations of normal distributions with constant variances but with means it is a linear function of observable variables. Panel data were used in this study to estimate the production frontier and the technical inefficiency effects of tea production using a Stochastic Frontier Analysis (SFA) methodology. An empirical application of the model is obtained using up to fifteen years of data on tea industries from seven tea regions of Bangladesh. The study observed that Stochastic Frontier Translog Production Function was more preferable compared to Stochastic Frontier Cobb-Douglas Production Function. The findings suggested that 49% technical inefficiency existed in tea yield. The null hypotheses, that the inefficiency effects are not stochastic or do not depend on the labor-specific variables and time of observations, are rejected for these data. This study also revealed that their existence was a negative relationship between size and yield.

Key words: Efficiency, stochastic frontier translog production function, Bangladesh tea Industry.

INTRODUCTION

Farm efficiency and the question of how to measure it, is an important subject in developing countries, agriculture (Shah, 1995; Hazarika and Subramanian, 1999). There are four major approaches to measure efficiency (Coelli et al., 1998). These are the non-parametric programming approach (Charnes et al., 1978) the parametric programming approach (Aigner and Chu, 1968; Ali and Chaudry, 1990) the deterministic statistical approach (Afriat, 1972; Schippers, 2000; Fleming et al., 2004). Among these, the stochastic frontier and non-parametric programming, known as Data Envelopment Analysis (DEA), are the most popular approaches. The stochastic frontier approach is preferred for assessing efficiency in agriculture because of the inherent stochasticity involved (Ezeh, 2004; Coelli, 1995). Since the stochastic frontier production function was independently proposed in Aigner, et al. (1977) and Meeusen and van den Broeck (1977), there has been considerable research to extend and apply the model. Reviews of much of this research are provided in Forsund et al (1980), Schmidt (1986), Bauer (1990), Battese (1992), (Krikley et al., 1995) and Greene (1993).

Hazarika and Subramanian (1999) have estimated the technical efficiency of tea industry in Assam using the stochastic frontier production model. Their study concentrates on the productivity and production factors only. Mahesh et al. (2002) analyzed the technical efficiency of Indian tea production and concluded that there existence was a good scope for improving tea productivity with the proper allocation of existing resources. Ariyawardana (2003) examined the sources of competitive advantage and studied how it was related to the performance of the tea growers in Sri-Lanka. His study provided a deep understanding of this issue from the management point of view but failed to focus on the efficiency of tea industries. Mahmud (2004) observed that the demand of tea in the market of Bangladesh was increasing 3.5 % each year and the supply of tea was increasing only by 1% each

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year. Saha (2005) studied only on economic analysis of tea industry in Bangladesh. Haque (2006) explained the possibility of alliance among the closely located tea gardens situated in the South-eastern part of Bangladesh. These studies do not adopt with a stochastic frontier analysis for the productivity and efficiency measurement of tea industries of Bangladesh, which is generally thought as an essential analytical analysis for tea industry.

The stochastic frontier production function postulates the existence of technical inefficiencies of production of firms involved in producing a particular output. Most theoretical stochastic frontier production functions have not explicitly formulated a model for these technical inefficiency effects in terms of explanatory variables. So far little rigorous work has been undertaken to study quantitatively the efficiency levels of existing tea production in Bangladesh with a purpose of identifying ways of improving efficiency. In this study efforts have been made to analyze the measurement of productivity of tea and its technical efficiency using the stochastic frontier production function model specified by (Battese and Coelli, 1995) for the panel data. This study will also identify the factors causing technical inefficiency of tea industry as well as show the robustness of technical efficiency estimates with respect to functional form specification.

METHODOLOGY

Inefficiency stochastic frontier model

We have considered the stochastic frontier model introduced by Battese and Coelli (1995) for panel data:

$$Y_{it} = \exp\left(\beta X_{it} + \zeta_{it} - \xi_{it}\right) \quad i = 1,2,......,N; \quad t = 1,2,.....,T \tag{1}$$

Where; Y_{it} is the output of the ***i***th tea industry in *t*th period; X_{it} is a vector of input quantities and other explanatory variables associated with *i*th tea industry in *t*th period; β is a vector of unknown parameters to be estimated; ζ_{it} ***'s*** are random variables which are assumed to be i.i.d. $N\left(0, \sigma_\zeta^{\,2}\right)$ and independent of ξ_{it}; the ξ_{it} ***'s*** are non-negative random variables, associated with technical inefficiency of production, which are assumed to independently distributed as truncations at zero of the $N\left(\mu, \sigma_\xi^{\,2}\right)$ distribution; where $\mu = z_{it}\delta$ *and* variance, $\sigma_\xi^{\,2}$; z_{it} is a $1 \times p$ vector of explanatory variables associated with technical inefficiency of tea production industry over time; and δ is a $p \times 1$ vector of unknown parameters.

Equation (1) specifies the stochastic frontier production function interms of original production values. However, the technical inefficiency effects, ξ_{it} 's are assumed to be a function of explanatory variables, the z_{it} $'s$, and an unknown vector of coefficients, δ. The technical inefficiency effect ξ_{it} in the stochastic frontier model (1) is specified in equation (2),

$$\xi_{it} = z_{it}\delta + \tau_{it} \tag{2}$$

Where; the random variable τ_{it} follows truncated normal distribution with mean zero and variance σ^2, such that the point of truncation is $-z_{it}\delta$ that is, $\tau_{it} \geq -z_{it}\delta.$ These assumptions are consistent with ξ_{it} 's being a non-negative truncation of the $N\left(z_{it}\delta, \sigma_\xi^{\,2}\right)$-distribution (Battese and Coelli, 1995). The mean, $z_{it}\delta,$ of the normal distribution, which is truncated at zero to obtain the distribution of ξ_{it}, is not required to be positive for each observation (Reifschneider and Stevenson, 1991).

The likelihood function and its partial derivatives with respect to the parameters of the model are presented in Battese and Coelli (1993). The method of maximum likelihood is proposed for simultaneous estimation of the parameters of the stochastic frontier (1) and the model (2) for the technical inefficiency effects. The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_\zeta^{\,2} + \sigma_\xi^{\,2}.$

After obtaining the estimates of ξ_{it}, the technical efficiency of the *i*th tea industry at *t*th observation is defined by equation (3),

$$TE_{it} = \exp\left(-\xi_{it}\right) = \exp\left(-z_{it}\delta - \tau_{it}\right) \tag{3}$$

Specification of stochastic frontier and technical inefficiency effects model

The data were collected from the various issues of Annual Report of Bangladeshyio Cha Sansad (BCS) and International Tea Committee (ITC*)*. Our study covers total tea Industry available under registered tea gardens of Bangladesh over the reference period 1990 to 2004 and the collected data of 15 years from 1990 to 2004 used 1 for year 1990, 2 for 1991 and so on. Information on variables, such as the Time, Temperature, Rainfall and Herfindahl index for seven tea regions from Bangladesh are used to explain the differences in the inefficiency effects among the tea industries.

The functional form of the stochastic frontier production function to be estimated is

$$\ln\left(Y_{it}\right) = \beta_0 + \beta_1 T + \beta_2 \ln A_{it} + \beta_3 \ln L_{it} + \tfrac{1}{2}\left(\beta_{11}T^2 + \beta_{22}\ln A_{it}^{\;2} + \beta_{33}\ln L_{it}^{\;2}\right)$$
$$+\beta_{12}\ln A_{it} * T + \beta_{13}\ln L_{it} * T + \beta_{23}\ln A_{it} * \ln L_{it} + \zeta_{it} - \xi_{it} \tag{4}$$

Where; Y_{it} = output Variables (Yield) of the ith tea industry in the t-th period in values (taka).

T = Time as input variable.

A_{it} = Area of i-th tea industry in the t-th period.

L_{it} = Labour of i-th tea industry in the t-th period.

ζ_{it} = a disturbance term with normal properties as explained above.

ξ_{it} = industry, specific error term as defined in equation (1).

Where; the technical inefficiency effects are assumed to be estimated by

$$\xi_{it} = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4 + \tau_{it} \qquad (5)$$

Where; $\delta_j \left(j = 1,2,3,4 \right)$ is the parameter for the j-th explanatory variables;

z_1 is the time as explanatory variable.

z_2 is the temperature of i-th tea industry in the t-th period.

z_3 is the rainfall of i-th tea industry in the t-th period.

z_4 is the Herfindahl index of i-th tea industry in the t-th period.

ζ_{it} and τ_{it} are defined in the previous section.

The Time variable in the stochastic frontier (4) accounts for Hicksian neutral technological change. However, the Time variable in the efficiency model (5) specifies that the inefficiency effects may change linearly with respect to time period. The parameters, β_0 and δ_0, are the intercepts of the stochastic frontier and the inefficiency model respectively.

Given the specification of the stochastic frontier production function, defined by (4), the null hypothesis that technical inefficiency is not present in these model, is defined by $H_0 : \gamma = 0$ where γ is the variance ratio, explaining the total variation in output from the frontier level of output attributed to technical efficiency and defined by, $\gamma = \sigma_{\xi}^2 \Big/ \left(\sigma_{\xi}^2 + \sigma_{\zeta}^2 \right)$. This is done with the calculation of the maximum likelihood estimates for the parameters of the stochastic frontier models by using the computer program frontier version 4.1 developed by Coelli (1994). If the null hypothesis is accepted, this would indicate that σ_{ξ}^{2} is zero and hence that the ξ_{it} term should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least square (OLS). Further the null hypothesis that the technical inefficiency effects are time invariant defined by $H_0 : \eta = 0$. If the null hypothesis is true, the generalized likelihood ratio statistic (λ) is asymptotically distributed as a chi-square (or mixed chi-square) random variable.

RESULTS AND DISCUSSION

Selection of the Translog stochastic frontier production function

In order to select the best specification for the production function (Cobb-Douglas or Translog) for the given data set, we conducted hypothesis tests for the parameters of the stochastic production frontier model using the generalized likelihood-ratio (LR) statistic defined by;

$$\lambda = -2\left\{ \ln\left[L\left(H_0\right) / L\left(H_1\right) \right] \right\} = -2\left\{ \ln\left[L\left(H_0\right) \right] - \ln\left[L\left(H_1\right) \right] \right\} \qquad (6)$$

Where; $\ln\left[L\left(H_0\right)\right]$ is the value of the log likelihood functions for the stochastic frontier estimated by pooling the data for all the seven regions and $\ln\left[L\left(H_1\right)\right]$ is the sum of the values of the log-likelihood functions for the seven stochastic production functions (North Sylhet + Juri + Lungla + Manu-Doloi + Balisera + Luskerpore + Chittagong) estimated separately.

Here we have observed that the direct effects of area, labor, square terms or second order parameters of area and labor and interaction of area and labor are significantly different from zero in the Translog Stochastic Production function. The values of the log likelihood for the Cobb-Douglas and Translog production frontiers are 18.935 and 25.203 respectively. By employing equation (6) we estimated the value Likelihood-Ratio (L-R) equal to 34.268 and 38.389 respectively. These values are compared with the upper five percent points for the $\chi^2{}_{(3,0.05)}$ and $\chi^2{}_{(9,0.05)}$ which are 3.85 and 10.25 respectively. Finally it is concluded that the null hypothesis $H_0 : \beta_{ij} = 0$ is strongly rejected and indicates that Translog Production Function is more preferable than Cobb-Douglas Production Function.

Estimating the stochastic frontier model

The results of the Ordinary Least Square (OLS) and Maximum-likelihood Estimation (MLE) for the Translog production function described in equation (4) are reported in Table 1. The value of log likelihood function for OLS and MLE allow to test whether technical inefficiency exists or not. In case technical inefficiency does not exist then technically there will be no difference in the parameters of OLS and MLE. From the analysis what we have observed that the coefficients of area, interaction of area and labor, second degree parameters of area and labor are statistically significant in the production process. These results indicate that these input variables significantly affect the amount of production in tea regions of the tea industries. Reasonably enough, for a labor surplus economy, labor has the negative output elasticity and is found to be insignificant in the production process. This implies that labor does not affect the yield of the tea significantly.

The variables labor, time, square terms of time, interaction of time and labor and interaction of time and area are found to be insignificant. However, the negative sign of labor might be due to the reason that the employers of the restricted tea gardens are employing more labors than the recommended level or at a marginal productivity level. However, future research should focus

Table 1. OLS and MLE estimates of Translog Stochastic Production Frontier Model.

Variable	Parameters	Estimated OLS coefficients	Estimated MLE coefficients
Constant	β_0	-3.920@ (10.448)	-8.802* (0.886)
Time	β_1	-0.023@ (0.216)	-0.154@ (0.146)
Area	β_2	4.983*** (3.085)	6.773* (0.685)
Labor	β_3	-1.878@ (1.88)	-1.779* (0.300)
$Time^2$	β_{11}	0.004@ (0.009)	0.005* (0.002)
$Area^2$	β_{22}	-2.16** (1.019)	-2.330* (0.615)
$Labor^2$	β_{33}	-1.808**(0.953)	-1.728* (0.613)
Time*area	β_{12}	-0.079@ (0.212)	-0.084@ (0.073)
Time*Labor	β_{13}	0.071@ (0.211)	0.088@ (0.077)
Area*Labor	B_{23}	1.839** (0.959)	0.999* (0.073)
Sigma-squared	σ^2	0.058	
Log likelihood function		6.009	25.203

N = 105 and *, ** and *** Significance level at 1, 5 and0 % consecutively@ means insignificant, S.E = Standard error given in the parentheses.

Table 2. Region wise Mean Efficiency of Yield for the selected regions in Bangladesh, 1990-2004.

Year	Efficiency							
	North Sylhet	Jury valley	Lungla	Manu-doloi	Balisera	Luskerpore	Ctg. dist	Mean
1990	0.39	0.46	0.42	0.59	0.43	0.86	0.37	0.50
1991	0.43	0.52	0.41	0.67	0.73	0.71	0.38	0.55
1992	0.37	0.49	0.29	0.60	0.67	0.60	0.33	0.48
1993	0.34	0.42	0.32	0.56	0.66	0.60	0.33	0.46
1994	0.37	0.55	0.37	0.65	0.76	0.69	0.38	0.54
1995	0.30	0.47	0.31	0.52	0.58	0.53	0.29	0.43
1996	0.36	0.54	0.38	0.60	0.70	0.60	0.39	0.51
1997	0.31	0.44	0.29	0.47	0.49	0.50	0.31	0.40
1998	0.57	0.83	0.56	0.89	0.91	0.92	0.54	0.75
1999	0.31	0.54	0.37	0.59	0.66	0.57	0.35	0.48
2000	0.39	0.52	0.39	0.60	0.72	0.50	0.47	0.51
2001	0.42	0.54	0.37	0.65	0.67	0.49	0.58	0.53
2002	0.35	0.44	0.32	0.57	0.66	0.43	0.40	0.45
2003	0.40	0.52	0.36	0.67	0.77	0.50	0.44	0.52
2004	0.36	0.47	0.33	0.60	0.70	0.45	0.42	0.48
Mean	0.38	0.52	0.37	0.62	0.67	0.60	0.40	

Source: Author's computation.

on exploring this critical issue.

From the MLE analysis what we have observed independently that all the variables except time and its interaction with area and labor are significant in affecting the yield of tea. It implies that variable time and its interaction with area and labor does not affect the yield of the tea significantly and the variable area, labor are significantly affect the production of tea. We observe that the variable area shows significant affect for both OLS and MLE estimation of the Translog production function.

The efficiency of yield model is depicted in the Table 2. From the analysis it is observed that for yield, the overall mean technical efficiency of Bangladesh Tea industry during the period 1990 to 2004 is found to be 0.51 and the technical efficiencies ranges from a minimum of 0.29 to a maximum of 0.92 for the selected regions in Bangladesh. This implies that 51% of potential yield is being realized by the tea industry of Bangladesh. In the present study none of the estates had achieved 100% level efficiency for yield. The findings also suggest that

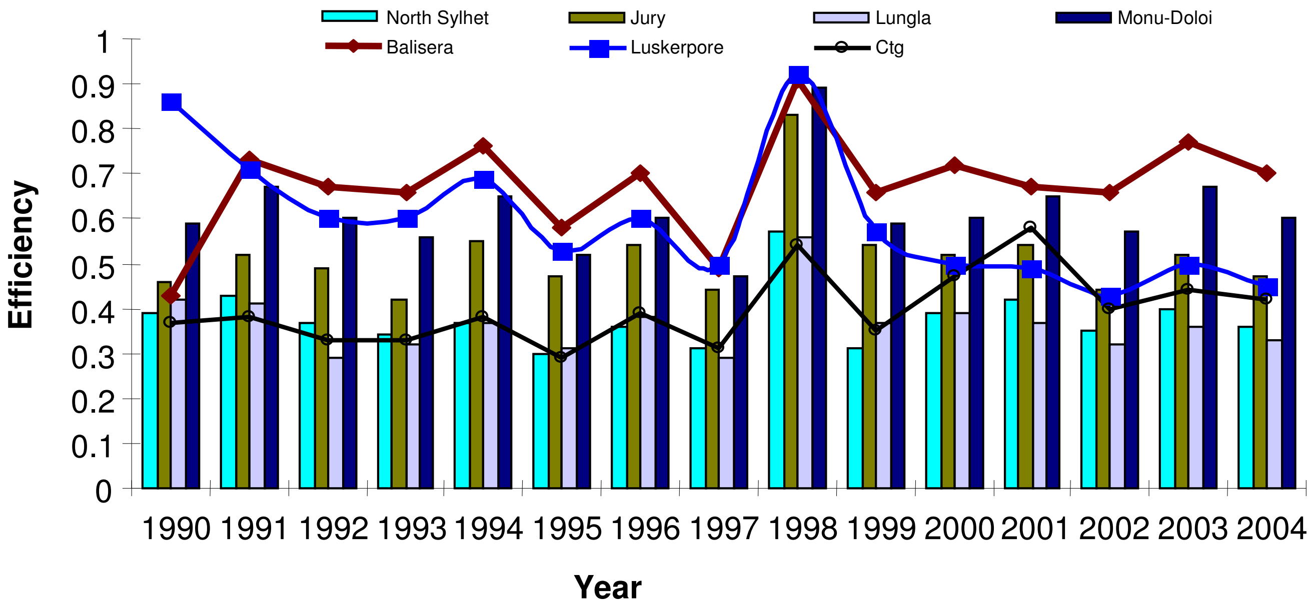

Figure 1. Yield efficiency in tea producing regions in Bangladesh, 1990 - 2004.

49% technical inefficiency exists in the yield of tea. There is wide variation in the technical efficiencies among the different tea producing region. We observed from Figure 1 that the Yield efficiency in tea producing regions (Lungla, North Sylhet and Ctg.) in Bangladesh during the period 1990 - 2004 have lower efficiency comparable to other regions. This may be for the unskilled manpower exists in that region and also the factors (rainfall, temperature, soil conditions, fertilizer, pest management etc) that influenced the growth of tea yield were not in satisfactory level. It ranges from a low mean efficiency of 0.43 in 1995, to a high of 0.75 in 1998 for yield (Figure 2). For the year 1997 the efficiency for yield was least but it reached its highest efficiency for the following year 1998 (Figure 2). It was shown that the region Balisera was the highest efficient tea producing region and Manu-doloi was the second largest efficient region (Figure 3). So, tea garden owners have a wide chance to increase their tea production efficiency through proper utilizing their total assets and labor. Though the efficiency scores are not satisfactory but it is a matter of hope that there has been occurred a gradual improvement over the sample period. Yield efficiency shows a gradual improvement through the first five years and yield efficiency increasingly upward trend over the time period. Herfindahl Index (HHI) has negative signs suggesting that this significantly decrease the inefficiency of a tea producing region.

Estimating the inefficiency effects model

The sign of coefficients of the variables time and HHI are negative impact on tea production, these indicate that time and HHI variables are inversely related with inefficiency (Table 3). The sign of the coefficient of rainfall and temperature indicate that these variables are less efficient although the coefficients are not statistically significant. In addition, inefficiency of the production function in time varying is calculated by the error term. Using the composed error terms of the stochastic frontier model, it is defined by $\gamma = \sigma_{\xi}^2 \big/ \left(\sigma_{\xi}^2 + \sigma_{\zeta}^2\right)$ which is a measure of level of the inefficiency in the variance parameter it ranges between 0 and 1. It is observed that the MLE estimate of γ is 0.999 with estimated standard error of 0.073. The value of γ is significantly different from one indicating that random shocks are playing a significant role in explaining the variation in tea production, which is expected in tea production where uncertainty is assumed to be the main source of variation. This implies that the stochastic production frontier is significantly different from the deterministic frontier, which does not include a random error. In the MLE estimation, γ is positive and significant at 1% level, implying that tea industry specific technical efficiency is important in explaining the total variability of yield produced. However, it should be noted that 99% of the variation in production is due to technical inefficiency and only 1% is due to the stochastic random error.

Hypothesis tests on the estimates

As indicated in the methodology, the results of various

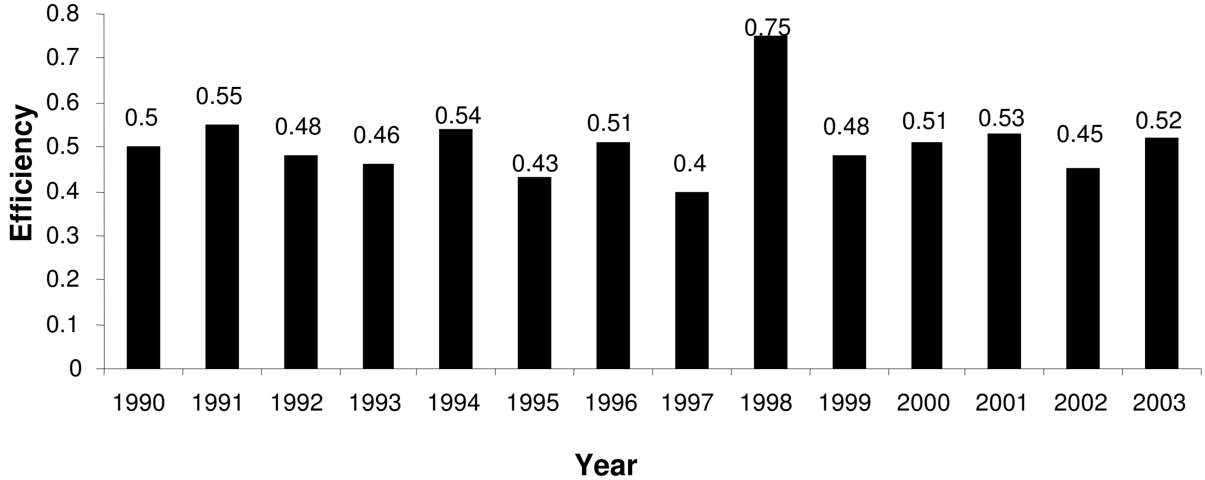

Figure 2. Year wise Mean Yield Efficiency in in Bangladesh, 1990-2004.

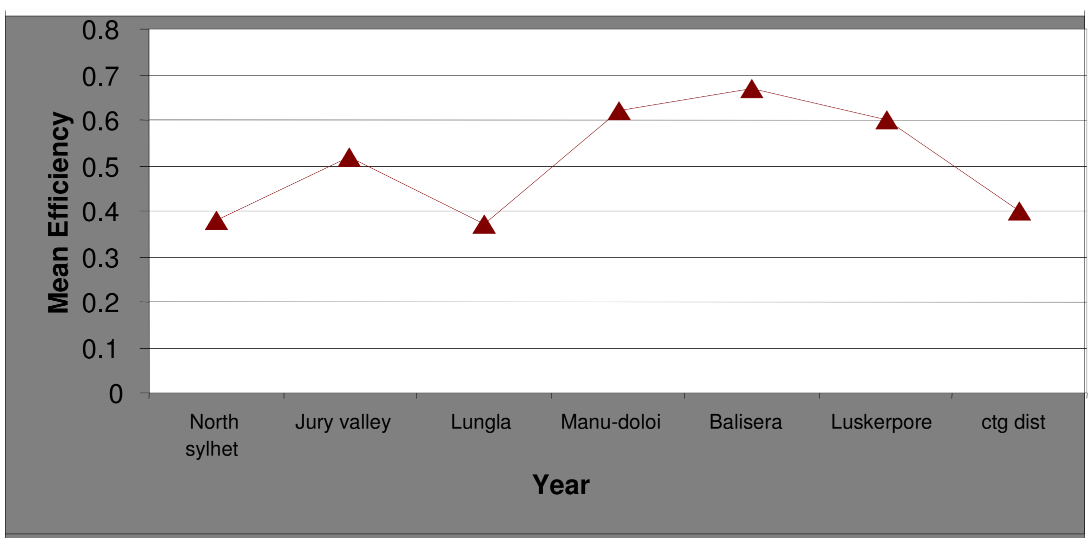

Figure 3. Region wise Yield Efficiency in Tea Industry in Bangladesh, 1990-2004.

Table 3. Estimation of inefficiency effect (Yield) model.

Variable	Parameters	Estimated coefficients
Constant	δ_0	3.405* (0.928)
Time	δ_1	-0.0003$^@$ (0.009)
Temperature	δ_2	-0.072$^@$ (0.241)
Rainfall	δ_3	0.010$^@$ (0.054)
HHI	δ_4	-0.475* (0.042)
sigma-squared	σ^2	0.020* (0.004)
gamma	γ	0.999* (0.073)

Values in the parentheses indicate S.E., $^@$indicate insignificance

Table 4. Likelihood-Ratio Test of Hypothesis of the Stochastic Frontier Production Function for the Yield Model.

Null hypothesis	Log-likelihood function	Test statistic λ	Critical value*	Decision
$H_0 : \gamma = 0$	6.009	97.564	10.25	Reject H_0
$H_0 : \beta_{ij} = 0$	1.812	34.268	3.85	Reject H_0
$H_0 : \eta = 0$	6.009	40.419	5.21	Reject H_0

Notes: All critical values are at 5% level of significance.
*The critical values are obtained from table of Kodde and Palm (1986). The null hypothesis which includes the restriction that γ is zero does not have a chi-square distribution, because the restriction defines a point on the boundary of parameter space.

Table 5. Technical efficiency according to size of tea estates in the region.

Size (hectare)	Technical efficiency level (%)
Below 200	0.912
Above 200 to below 400	0.887
Above 400 to below 600	0.862
Above 600	0.812
Mean	0.868
Standard Deviation	0.213
Correlation Coefficient	-0.005

hypothesis tests for the Yield model is presented in Table 4. Under the null hypothesis, this test statistic (6) is assumed to be asymptotically distributed as mixture of chi-square distribution with degree of freedom equal to the number of restrictions involved. The restrictions imposed by the null hypothesis are rejected when λ exceeds the critical value (Taymaz and Saatci, 1997, p. 474).

For the yield specification model, the first null hypothesis $H_0 : \gamma = 0$ which specifies that there is no technical inefficiency effects in the model. Since the hypothesis is rejected so we can conclude that there are technical inefficiency effects in the model. The second null hypo-thesis is $H_0 : \beta_{ij} = 0$, which indicates that Cobb-Douglas production function is more preferable than Translog production function. From the outcome it is observed that the null hypothesis is strongly rejected and Translog production function is statistically more favorable.

The third null hypothesis is $H_0 : \eta = 0$, which specifies that the technical inefficiency effect does not vary signifi-cantly over time. The null hypothesis is rejected indicating that the technical inefficiency effect varies significantly.

Efficiency size of plantation and productivity

In order to see relationship in between the efficiency and the estate size, Table 5 presents information on means, standard deviations and correlations. Correlation coef-ficients of technical efficiency display negative (-) signs indicating that as estate size increases, these efficiency declines**.** This establishes the fact that efficiencies are higher for the lower estates (Figure 4) that means smaller estates are more efficient technically which is economical.

Conclusion

This study focused on the estimation of the technical efficiency of the tea industries in Bangladesh applying the Stochastic Frontier Approach. We observed that the variables area and labor show significant affects for both OLS and MLE estimation of the Translog production function. These results indicate that these input variables significantly affect the amount of yield in tea regions of the tea industries. The variables labor, time, square terms of time, interaction of time and labor and interaction of time and area are found to be insignificant. It indicates that these variables do not affect the yield of tea significantly. The mean technical efficiency of Bangla-desh Tea Industry during the period 1990 to 2004 is found to be 0.51 and it ranges from a minimum of 0.29 to a maximum of 0.92 in the tea regions. This implies that 51% of potential yield is being realized by the tea industry

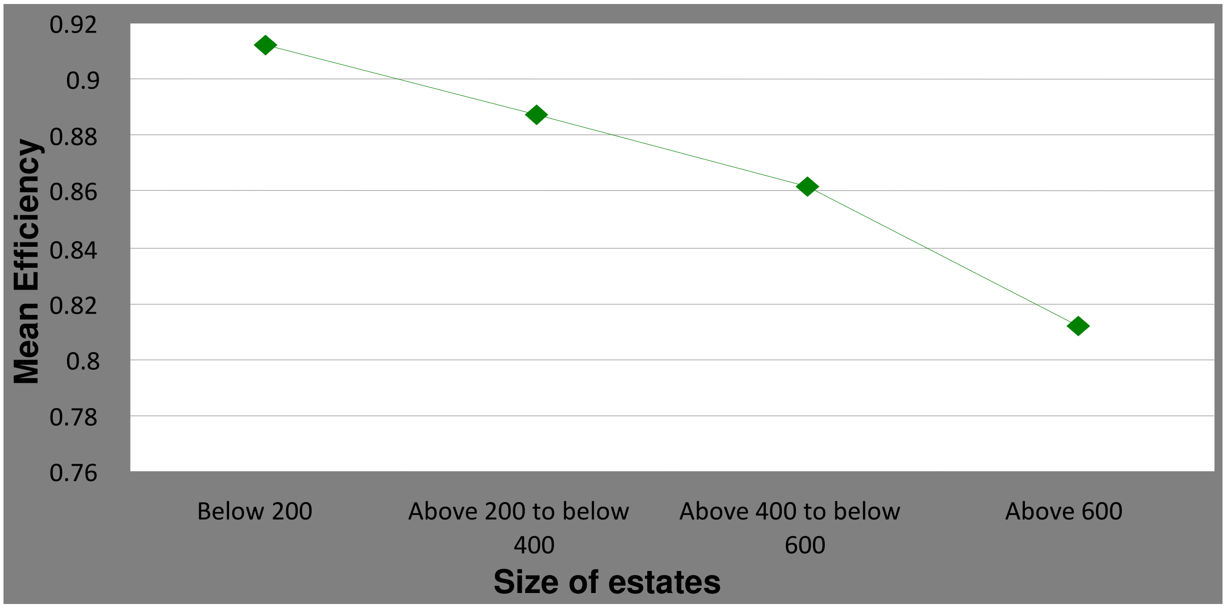

Figure 4. Efficiency according to size of tea gardens in Bangladesh, 1990 - 2004.

of Bangladesh. In the present study none of the estates had achieved 100% level efficiency for yield. In this study we found that Balisera and Manu-Doloi are most efficient in producing tea. This study also revealed that there was a negative relationship between size and yield. For the MLE, γ is estimated at 0.99 which means that 99% of random variation in yield of tea for MLE around in tea industry production due to inefficiency.

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