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# APPLICATION OF STOCHASTIC FRONTIER FOR THE MEASUREMENT OF TECHNICAL EFFICIENCY OF PADDY CROP GROWN UNDER LAND RECLAMATION TECHNOLOGY

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ABSTRACT

The study of technical efficiency as to how with the existing production technology farmers can achieve maximum crop output without any additional cost, is of vital importance to planners, administrators and research scientists. The construct of production frontier provides sufficient economic rationale for measurement of technical efficiency. This paper attempts to measure technical efficiency and its related parameters on paddy farms under newly developed Land Reclamation Technology using the concept of stochastic frontier production function. The results reveal that sample farmers, on an average are successful in achieving 81.79 per cent technical efficiency.

## 1. Introduction

The technical efficiency can be derived from the production function which refers to maximum possible output that can be produced from given quantities of a set of inputs. The higher level of output reflected by increased level of technical efficiency refers to a reduction in the quantities of all factors used in the production of unit output. This in other words means that application of better techniques results in the reduction of cost.

The study of technical efficiency is important. For example, it measures the productive contribution of intangible factors like management, education and technology. The increased level of technical efficiency is reflected by homothetic shift in the isoquant. In the context of production function, the increased level of technical efficiency is measured by the shift in the constant term.

Very recently, a new school of thought has emerged that utilises the production disturbances for interpreting technical efficiency. The "Marschak-Andrews" model (1944) in the literature admits the stochastic nature of production function due to production disturbance but fails to derive technical efficiency. The beginning point of discussion of frontier continues with the interpretation of disturbance in production. There is a frontier in each production process because a given function sets a limit to

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the range of possible observations. Like production function, frontier can be studied under the deterministic and stochastic framework. Deterministic frontiers are modelled with one-sided errors while stochastic frontiers are specified with two sided errors.

Under idealistic production and market situations, output would completely be deterministic and farm is said to be cent percent efficient. In actual practice, the output is not exactly determined. Disturbance in the production is common owing to external shocks such as weather, machine performance, input supply breakdowns, incidences of pests and insects, attack by wild animals, etc. Since, a deterministic frontier does not take into account the effects of external shocks which a farm may experience during a given production process, the introduction of stochastic frontier assumes significance. As the deterministic frontier fails to answer the role of exogenous factors satisfactorily, the theory of stochastic frontier along with econometric models employed in empirical investigations is explained in the following section.

## 2. Theory and empirical model

The need to provide frontier a simple mathematical form is first attempted by Aigner and Chu (1968) with the imposition of restriction in implicit manner that one-sided error is responsible to force the frontier for the ith firm to satisfy the condition,

$$Y_i \leqslant f(X_i, \beta) \qquad \ldots(1)$$

where, $Y_i$ is the observed output (maximum) obtainable from $X_i$, a vector of non-stochastic inputs, and $\beta$ is an unknown parameter vector to be estimated. To realise maximum output the mathematical programming procedure employs the minimisation of

$$\sum_{i=1}^{N} [Y_i - f(X_i, \beta)] \qquad \ldots(2)$$

Incidently, this estimation procedure under the constraint given in (1) becomes a linear programming problem if $f(X_i, \beta)$ is linear in $\beta$. If linearity of $f(X_i, \beta)$ subject to the above constraint in (1) is retained, the alternate estimation procedure becomes a quadratic programming problem which must minimise the sum of squares of expression given by (2). Under the pure deterministic framework, the one-sided error representing technical inefficiency, can directly be computed from vectors of residuals subject to constraint that each residual be non-positive while applying either linear programming or quadratic programming. However, this constraint makes data extremely sensitive to outliers which need to be deleted in a given sample.

The other serious objection raised against deterministic frontier is that it makes hypothesis testing impossible without considering the statistical properties of the estimates. Thus, introduction of stochastic frontier becomes imperative. Cobb-Douglas frontier with the condition that all observations to be on or beneath, can be written as

$$Y_i = f(X_i, \beta)e^{-ui} \quad ...(3)$$

Under the conventional OLS procedure, the assumptions associated with X and u are that the observations on u are independently and identically distributed and there is independence between X and u. As such, any number of distributions for $e^{-ui}$ or $(-U_i)$ can be specified. Pursuing the research of Aigner and Chu while proposing explicitly a two-parameter beta distribution for $e^{-ui}$, Afriat (1972) applies maximum likelihood estimator (MLE) model. In an exclusive manner, this amounted to gamma distribution of u as shown by Richmond (1974). Further Schmidt (1976) notes that assumption of exponential distribution leads to linear programming technique, while assumption of half-normal distribution leads to quadratic programming technique. Therefore Aigner and Chu's estimates can be viewed as MLE under particular error specification. It implies that under appropriate assumptions, linear programming and quadratic programming can provide estimates of MLE. Moreover, the assumption that observations must be beneath the frontier creates serious problem in adoption of MLE procedure. Since $Y_i \leqslant f(X_i, \beta)$ and $f(X_i, \beta)$ involves estimated parameters, this very assumption violates one of the regularity conditions which is used to prove general theorem that the estimates of MLE are consistent and asymptotically efficient.

Based on OLS residuals, the corrected ordinary least squares (COLS) technique is an alternative method of estimation of deterministic statistical frontier, first noted by Richmond. He shows that except for the constant term, the OLS estimator is unbiased and consistent. As the bias of the constant term is the mean of one-sided error term, we can correct the constant by adding the negative of estimated bias to OLS estimated constant term. Certainly, COLS can be preferred over MLE because it provides the computational simplicity and removes one of the serious objections regarding the consistency of MLE estimates as discussed earlier.

**Composed Error Model and Measurement of Technical Efficiency**

As suggested by Aigner, Lovell and Schmidt (1977) [referred to hereafter as ALS] and Meeusen and van den Broeck (1977), the stochastic frontier model can be specified with the composed error term $(E_i)$ as given by

$$E_i = V_i - U_i \quad ...(4)$$

where $U_i$ (truncated normal random variable) and $V_i$ (symmetric random variable) are normally and independently distributed. With the introduction of composed error term, the frontier production can be specified in its simplest form as

$$Y_i = X_i \beta + E_i \qquad \ldots(5)$$

The first term ($V_i$) of the composed error ($E_i$) captures the effects of random shocks outside the firm control, observation and measurement error on dependent variable, and usual statistical noise in any empirical relationship. The other independent error component $U_i$, is a non-negative term representing technical inefficiency in the sense that it measures shortfall of output ($Y_i$) from its maximum possible value given by stochastic frontier.

Since $V_i$ is unobservable, it is not possible to draw inference of technical efficiency for individual firm (farm) easily. However, when a model corresponding to (4) and (5) is estimated, we can measure the mean technical efficiency of an industry. Considering half-normal case of a truncated random variable of one-sided component of the composed error model, ALS, from practical point of view, provide a methodology to compute statistical parameters associated with random disturbances influencing a given production process as follows :

$$\text{Var}(E) = [(\pi - 2)/\pi]\,\sigma^2_u + \sigma^2_v \qquad \ldots(6)$$

$$\lambda = \sigma_u/\sigma_v \qquad \ldots(7)$$

$$f(E)\,{}^1\mu{=}0 = \frac{1}{\sigma^2}\sqrt{\frac{2}{\pi}}\ \exp\{-\tfrac{1}{2}(E^2/\sigma^2)\}\,[1 - \phi\,(E\lambda/\sigma)] \qquad \ldots(8)$$

where $\sigma^2_u$ and $\sigma^2_v$ are the variances of truncated random variable and symmetric random variable, respectively ; $\lambda$ is the relative variability of two sources of random errors ; f(E) is density function of E ; $\phi$ is normal distribution function and

$$\sigma^2 = \sigma^2_u + \sigma^2_v .$$

The equation (8) as suggested by ALS is quite useful and convenient to draw conclusion regarding the size of the two sources of variation caused by the two error components. For example, if $\sigma^2_v \rightarrow 0$ the one-sided error becomes the dominant source of random variation and as such its distribution can be regarded as negative half-normal. Since $\lambda$ is $\infty$ in this case, the equation reduces to

$$f(E) = \frac{\sqrt{2}}{\sqrt{\pi}\,\sigma_u}\ \exp\left[-\frac{E^2}{2\sigma^2_u}\right], \text{ for } (E \leqslant 0), = 0, \text{ otherwise} \qquad \ldots(9)$$

Clearly, when $\lambda^2 \rightarrow 0$ implies that $\sigma^2_v \rightarrow \infty$ and $\sigma^2_u \rightarrow 0$. This means that in absence of effects of $\sigma_u^2$, the symmetric error dominates in the determination of E and the equation (8) becomes the density of a N (O, $\sigma^2$).

If the frontier production is defined for the logarithm of production, then the measure of technical efficiency suggested by Battese and Coelli (1988) for the ith farm can be given by

$$TE_i = \exp(-U_i) \quad \ldots(10)$$

For the production of a given farm, the measurement of technical efficiency necessarily involves the comparison of $\exp(Y_i) = \exp(X_i \beta + V_i - U_i)$ to the frontier production. This is the greatest advantage over the earlier measures of technical efficiency because it is capable of removing a serious fallacy which takes into account $\exp(X_i \beta - U_i) / (X_i \beta)$. Other than farmer's will and effort, the luck of a farmer plays an important role in influencing the level of technical efficiency. Farmer's bad luck cannot be made responsible for his failure in achieving efficiency because bad weather, incidence of pests and diseases, drought, famine and several other external unfavourable exogenous factors can adversely affect the output levels considerably. Efficiency measure corresponding to (10) facilitates economic interpretation without any blemish because the observed output in presence of random shocks experienced in the production mechanism outside the farm control compares with the maximum output.

If we consider the measure of technical efficiency as developed in (10), we find that the technical efficiency is independent of the levels of factor inputs in the production scenario of a given farm. This removes one of the stock objections that the OLS estimates are biased and inconsistent because of the correlation between the random error and explanatory variables, with reference to single equation estimation.

Once a model of the farm corresponding to equations (4) and (5) is estimated, one can consistently estimate variances of $\sigma_u^2$ and $\sigma_v^2$ by utilizing appropriate mean corrected moments from computed least squares residuals.

**Recent Methodological Development**

Since the introduction of composed error model in 1977, econometric research has gained considerable momentum with increased interest for its applications and modifications especially in the context of specification and estimation of frontier production function. The stochastic frontier has been considered by a host of researchers starting from Lee (1978) to Schmidt (1988) (for studies in between see the references). Although the composed error model has all round advantages over deterministic models originally developed by Aigner and Chu (1968) and Timmer

(1971), still it suffers from inadequacy of precise and accurate distributional assumptions associated with one-sided component predicting firm level technical efficiency.

ALS consider the half-normal case with a little discussion of exponential distribution. However, they conclude that there is little difference between half-normal and exponential distributions. Since technical efficiency is bounded between 0 and 1, there is every reason to believe that distributions other than half-normal can be theoretically feasible as long as they are restricted with the values of non-negative one-sided term. Hence, half-normal distribution is not unique. Several studies have considered possibilities other than the popular half-normal case of ALS. For example, Richmond (1974) considers Gamma, Greene (1980) assumes log-normal and Meeusen and van den Broeck (1977) attempt exponential distribution of non-negative component. It can be noted that both mean and mode can be used as point estimates of $U_i$. Stevenson (1980) provides a generalised ALS specification in which there exists a possibility of other than non-zero mode for density function of $U_i$. Extending the work of ALS and Schmidt and Lovell (1980) and suggesting a procedure for measurement of firm level technical efficiency, Jondrow *et al* (1982) also consider half-normal and exponential distributions. They argue that it is possible to draw information about one-sided term predicting technical efficiency from the total disturbances in production with the conditional distribution of U | E as

$$f(U \mid E) = \frac{f(U \mid E, E)}{f(E)} \qquad \dots (11)$$

where f (U | E, E) is the the joint density function.

The methodology for estimating firm level technical efficiency with an estimate of conditional expectation of the one-sided component conditional on total disturbance proposed by Jondrow *et al*, (1982) has its own shortcomings. The assumption that the variability due to sampling error disappears asymptotically is a matter of great concern to econometricians. This is consistent with the intrinsic variability to the conditional distribution of U given E which is independent of sample size and draws imperfect information about U from total disturbance [Jondrow *et al* (1982; p. 235)]. Waldman (1984) attempts to resolve this difficult task and suggests conditional expectation function; linear unbiased estimator and best linear prediction as alternative estimators. It is difficult to generalize statistical properties of the three estimators inferred, under the conditions suited to his observations. However, he concludes that in either the case of conditional expectation or exponential model, the gain appears to be marginal. This is because of the difficulty faced in the decomposition of unobservable variable into sum of two unobservable variables. [Waldman (1984, p. 360)].

Realising the gravity of the situation associated with severity of the distributional assumptions giving rise to composed error, Schmidt (1986, p. 308) argues: "In my opinion the only serious intrinsic problem with the stochastic frontiers is that the separation of noise and inefficiency ultimately hinges on strong (and arbitrary) distributional assumptions". Thus, the one-sided component predicting technical efficiency continues to have an appeal but the suitability of its distribution is something of an enigma. Research in this area is on but the development for the future line of action is still awaited.

Thus, ALS model still dominates empirical analysis. In the absence of an appropriate distributional assumption associated with one-sided component, the scope of present paper is limited to estimation of mean technical efficiency and its related parameters of practical importance. More specifically, we assume the half-normal case of truncated random variable for the distribution of one-sided component.

## 3. Model Specification and Estimation

The Cobb-Douglas type of stochastic frontier production function is specified as

$$Y = A^{*} L^{\alpha_1} N^{\alpha_2} B^{\alpha_3} I^{\alpha_4} F^{\alpha_5} Z^{\alpha_6} \ \mathrm{Exp}\,(E) \qquad \ldots (12)$$

where output Y and inputs X per farm are defined as :

Y = output of paddy in quintals;

A* = constant term of corrected ordinary least squares;

L = land measured in hectares;

N = labour measured in man days;

B = flow of bullock labour in animal days;

I = water in gallons;

F = fertilizers (N+P+K) in kilograms;

Z = zinc applied as zinc sulphate in kilograms and

E = defined earlier.

Under the framework of ALS model, Corrected Ordinary Least Squares (COLS) estimator is applied to (12) on the same lines as suggested by Richmond (1974). Mean technical efficiency (MTE) is estimated in same spirit which has been earlier employed by Lee and Tyler (1978) and discussed thereafter by Battese and Coelli (1988) as

$$MTE = 2 \exp(\sigma^2_u / 2) [1 - \phi(\sigma_u)] \quad \text{... (13)}$$

The ratio of standard error of one-sided component to symmetric component ($\lambda$) is estimated, employing (7). Finally, the discrepancy parameter ($\theta$) which is of great practical importance is estimated as

$$\theta = \sigma^2_u / (\sigma^2_u + \sigma^2_v) \quad \text{... (14)}$$

**Empirical Application**

The multi-disciplinary research of Central Soil Salinity Research Institute (CSSRI) has resulted in developing a package of technology popularly known as land reclamation technology (alkali soils). In order to study mean technical efficiency and its related parameters, a sample of 110 farmers growing paddy on reclaimed soils of Moonak and Rair Kalan in the block of Gharaunda are selected randomly.

The research findings of crop management practices of land reclamation technology introduced in 1978-79 reveal that reclaimed soils take about 3 years to achieve desired level of results comparable to normal soils. Therefore, primary cross-sectional data for year 1983-84, is collected through survey methods. Pre-tested interview schedules are prepared for purpose of data collection. Input-output data, resource availability, input-output prices and other relevant informations have been collected by personal interview.

**4. Model Results**

The estimated coefficients of Cobb-Douglas stochastic frontier function are presented in table 1. The results of estimation show that every coefficient of production elasticity is less than one. Hence all the input factors show diminishing returns to scale. The sum of the production elasticities which denotes returns to scale, indicates that the production technology in the sample exhibits increasing returns to scale.

In the sample farms, both labour and fertilizer inputs have negative signs Considering positive sign in the sample farms, the elasticity of output with respect to land, irrigation, bullock labour and zinc assumes same order of importance in production process. The output elasticity of land input is found to be highly significant at 1 percent level. It implies that increase in yield may be achieved potentially due to increase in area under crop.

**Table 1. Estimates of COLS Stochastic Frontier for Paddy crop grown under Land Reclamation Technology**

| Variables | Estimates | | |
|---|---|---|---|
| | Coefficients | Variables | Coefficients |
| Intercept | —0.1593 | ln I | 0.5503 (0.0289) |
| ln L | 0.2661 (0.0363) | ln Z | 0.3782 (0.0271) |
| ln N | —0.0388 (0.0055) | Sum of elasticities | 1.1631 |
| ln B | 0.0174 (0.0100) | $R^2$ | 0.9977 |
| ln F | —0.0101 (0.0106) | | |

Note : The figures in parentheses are standard errors of estimates.

In the sample, most of the farms belong to holding sizes less than 10 acres. In the context of land reclamation environment, the positive contribution of land input establishes a strong conviction that newly developed high yielding varieties highly resistant to factors responsible for salt-affected soils, display their significant performance on a well prepared reclaimed land as a consequence of adequate measures of proper levelling, drainage, bunding and treatment of suitable amendment to such soil. Keeping the levels of given inputs constant, this research finding reveals that there is sufficiently a large scope to increase paddy production on reclaimed soils, if efforts are made to increase area of paddy.

The package of land reclamation technology (alkali soils) recommends higher doses of fertilizers for crops grown on reclaimed soils. In order to yield good results of crop production, it demands that farmers should add 25 percent more nitrogen that what is required for crops grown on normal soils. The negative response of fertilizer input to output which is not found to be statistically significant at 1 percent level may be due to the reason that farmers are not able to follow recommendations of package properly. Further, it can be added that low response of fertilizer input in paddy farms may be due to lodging and incidences of pests and diseases.

The package of land reclamation technology (alkali soils) suggests that salt-affected soils are deficient in zinc nutrient. In order to overcome this deficiency, the package of technology recommends that on average 20-25 kg/ha of zinc as zinc sulphate should be supplied alongwith required doses of fertilizers. This research finding is supported by the fact that while keeping other factors fixed, a one percent change in zinc leads to corresponding change in paddy output by 0.38 percent. This contribution by zinc indicates that farmers follow recommendations of package of technology for its timely application in desired manner.

Among all the components of the package of technology, the availability of good quality water is one of the most important pre-requisities. Water, can become a curse especially when proper irrigation management is not accompanied by soil management. We should not forget that the appearance of salt-affected soils in world is due to faulty irrigation management without considering the interaction of water to soils. The use of water input should be carried out in such a way that it must ensure the fulfilment of irrigation requirements of particular crop in short run without deterioration of soils in the long run. The soils in the region of most of sample farms have already undergone appropriate soil tests in soil testing laboratory of CSSRI before initiating land reclamation programme. There are no reasons to believe that farmers lack any knowledge in meeting water requirement of paddy crop grown on reclaimed soils. These facts are supported by evidence that among all factors, water input contributes the highest to output and is found to be highly signficant at 1 percent level. It is observed that a one percent increase in water input is accompained by 0.55 percent increase in output of paddy. The estimated water input coefficient, therefore, indicates that farmers in sample farms apply water resource judiciously in accordance with recommendation of package of technology already available for alkali soils.

It can be noted from table 2 that estimates of $\sigma^2_u$ and $\sigma^2_v$ are 0.076804 and 0.082949, respectively. It implies that variance of symmetric error term and variance of one-sided error term are almost equal. It is also evident from the table that the estimates of ratios of standard error ($\lambda$) of one-sided error term to symmetric error term is 0.962246. Evidently, it can be stated that standard error of symmetric error term is slightly greater than standard error of one-sided error term.

**Table 2. Estimates of related parameters of Technical Efficiency**

| Parameters | Estimates | Parameters | Estimates |
|---|---|---|---|
| $\hat{\sigma}^2_u$ | 0.076804 | $\hat{\theta}$ | 0.480767 |
| $\hat{\sigma}^2_v$ | 0.082949 | MTE | 0.817976 |
| $\hat{\lambda}$ | 0.962246 | | |

Using (14), the estimates of discrepancy parameter ($\theta$) is 0 480767. This means that almost half of the discrepancies between observed output and frontier (maximal) output is due to technical inefficiency in sample farms. In other words, the shortfall of observed output from frontier output can be minimised with efficient utilization of factors which are within the control of farmers.

The estimate of mean technical efficiency in sample farms which is estimated on the basis of (13) comes to be 0.817976 showing that actual output is about 18.2 percent less than maximal output. This clearly shows that there is reasonably a good scope to increase the output in paddy farms even with existing level of use of inputs.

We observe that there is a little question of the dominance of an error variance concerning to the two types of error components. The paddy production process under land reclamation technology (alkali soils) indicates that these errors as reflected in their estimated values incidently appear alike in influencing the output levels Contrarily we may conclude that the size of symmetric error is not big enough in determining the one-sided error term and the resulting placement of the frontier in relation to the size of one-sided error. Consequently, this provides a little evidence that normal errors have the turbulent production disturbances in combination with the size of the errors associated with the one-sided error. In otherwords, we are not able to confirm a situation of production technology which tends to appro..ch the extreme value ($\lambda \rightarrow \infty$ or $\sigma^2_u = O$ or $\sigma^2_v = O$) of the parameters as can be applied to (8). The relative sizes of standard errors of the two error components is also not big enough to conclude that one component captures the production disturbances forcibly as compared to the other component almost with the same size.

## 5. Conclusions

The present research study has been conducted using paddy data under land reclamation technology for the measurement of technical efficiency and its related parameters. The methodology consisted of application of stochastic frontier with composed error model. The paddy production scenario under land reclamation technology reveals that farmers are successful in achieving a level of technical efficiency on an average by 81.79 percent. In terms of input application, about 18 percent shortfall of output from frontier output may be due to negative signs of the estimated coefficients of labour and fertilizer. This confirmed that farmers could not apply these inputs in a manner needed by an efficient production plan. On the other side, irrigation and zinc appear to play a positive role in increasing levels of output. The study strongly suggests improvement in the utilisation of labour and fertilizer, particularly by "bajigars" who are new to crop cultivation.

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