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# Technical Efficiency Estimates for Sarawak Pepper Farming: A Comparative Analysis

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**ABSTRAK**

Menganggar kecekapan teknikal teknologi pengeluaran adalah penting untuk tujian polisi. Empat fungsi sempadan (frontier) pengeluaran terdiri dari fungsi berparameter dan tidak berparameter dianalisis untuk menganggar kadar kecekapan teknikal ke atas sampel ladang lada hitam di Sarawak. Metadologi yang digunakan memberi anggaran taburan dan 'ranking' kadar kecekapan yang berbeza. Anggaran fungsi tidak berparameter adalah lebih tinggi berbanding anggaran fungsi berparameter kecuali di bawah kaedah stokastik berparameter. Disebabkan oleh perbezaan yang ketara didalam keputusan kecekapan teknikal, cadangan untuk tujuan polisi tidak boleh dibuat tanpa terlebih dahulu dibuat analisis terperinci bagi setiap kaedah yang digunakan.

**ABSTRACT**

Estimating technical efficiency of production technology is important for policy purposes. Four production frontiers consisting of parametric and nonparametric functions were analysed to estimate technical efficiency ratios on a sample of pepper farms in Sarawak. The methodologies employed produced different estimates, distributions, and rankings of efficiency ratios. The nonparametric estimates were greater than parametric estimates except under stochastic parametric method. Due to the large differences in technical efficiency results, recommendation for policy purpose should not be made without prior detailed analysis of each method.

## INTRODUCTION

The modeling of production activities has long occupied a central role in applied economic research, both as an area in which existing statistical estimators may be applied and in providing a stimulus for the development of new methods. In standard microeconomic theory, production technology is represented by transformation (production) function that defines the maximum attainable outputs from different combinations of inputs. Hence, the transformation function describes a boundary or a frontier. Given that the production function to be estimated had constant returns to scale, Farrell (1957) assumed that observed input per unit of output values for firms would be above the so-called unit isoquant. The unit isoquant defines the input per unit output ratios associated with the most efficient use of inputs to produce the output involved. The deviation of observed input per unit output ratios from the unit isoquant is considered to be associated with technical efficiency. On the other hand, technical inefficiency is defined as a firm's failure to produce maximum output from a given set of inputs (Forsund *et al.*, 1980).

A more general presentation of Farrells' concept of production (or frontier) is depicted in Fig. 1 involving the original input and output values. The observed input-output values are below the production frontier, given that firms do not attain the maximum output possible for the inputs involved, for a given technology. A measure of technical efficiency of the firm which produce output, y, with input, x, denoted by point A, is given by $y/y^*$, where $y^*$ is frontier

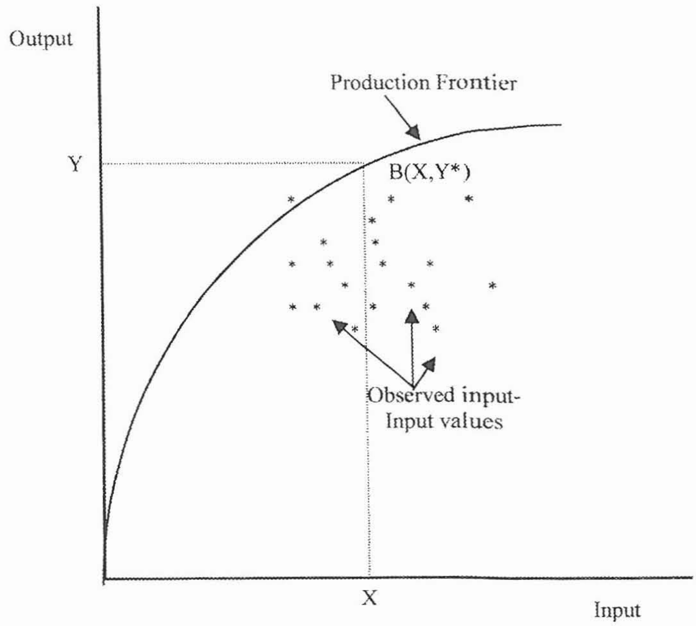


*Fig. 1. Technical efficiency of firms in input-output space*

output associated with the level of input, x, (point B). Thus, the ratio of observed output and frontier output is a measure of technical efficiency for the input involved.

In recent years, many empirical studies using frontier function methodologies have been undertaken with the purpose of measuring farm efficiency. Recent differences in farm efficiency measurements may have been the result of numerous factors, including the time period analysed, the degree of sample homogeneity, output aggregation and the method employed (Neff *et al.,* 1991). For example, Bravo-Ureta and Rieger (1990) examine New England and New York farm efficiency using four production frontier methods. The result of their analysis indicates that, while large differences exist between estimated average firm efficiency ratios, all four sets of efficiency ratios are highly correlated within two time periods.

Kalaitzandonakes *et al.* (1992) examined the relationship between firm size and technical efficiency on a sample of Missouri grain farms using three production frontiers. There are strong differences between estimated average efficiency ratios from the three methods. Byrnes *et al.* (1987), using a nonparametric radial output efficiency measure, find that south-central Illinois grain farms are producing only four percent below their efficient levels. However, Aly *et al.* (1987) and Neff *et al.* and Hornbaker (1991) using a deterministic parametric frontier, find that farms are producing at approximately 60-65 percent of their efficiency level. Finally, Grabowski *et al.* (1990) employing a stochastic parametric frontier, find that a sample of Illinois grain farms are producing at 82 percent of their efficient levels.

Given the result of previous studies, the purpose of this paper is to provide a comparison of the most commonly used frontier methods utilizing four production frontier methods, namely:

a. Deterministic Parametric Frontier (COLS)
b. Linear Programming Parametric Frontier (LP)
c. Nonparametric Frontier (NPAR), and
d. Stochastic Parametric Frontier (SPF)

This paper proceeds as follows. The next section focuses on the methodology that are used in this study. Section three presents the data and estimation followed by the empirical results. The last section concludes the study with the implications of the findings.

## METHODOLOGY

*Deterministic Parametric Frontier*

Let y represent the output of a firm and let x denotes a vector of input utilized in the production of *y*. The deterministic parametric frontier is estimated assuming a conventional Cobb-Douglas production technology:

$$Y = \alpha \Pi X^{\beta} e^{u} \tag{1}$$

where

$\alpha$ = a constant and

$\beta$ = a vector of slope coefficients.

From the output relationship estimated by Ordinary Least Squares (OLS), the frontier production function is derived by a method called Corrected Ordinary Least Squares (COLS). It has been shown that the COLS estimates give coefficients which are unbiased and consistent (Green, 1980). The procedure involves estimating the individual specific error terms from the production function, and revising the intercept by the magnitude of the largest error term. The results in output magnification not only at that point but over the entire production surface. Thus, the frontier function is given by

$$Y^* = \alpha^* \Pi X^{\beta} e^{u} \tag{2}$$

The technical efficiency measure of an individual firm is the ratio of actual output Y, to potential output, Y*

$$TE = Y/Y^* \leq 1 \tag{3}$$

*Linear Programming Parametric Frontier*

A further measure of technical efficiency can be estimated using linear programming methods (Aigner and Chu, 1968; Timmer, 1970, 1971). This approach differs from the Deterministic Parametric Frontiers in that the assumption of linear homogeneity is relaxed at a cost of specifying a functional form for the production function. Again, the Cobb-Douglas specification is used. Using Eq. (1), assume that the disturbance terms are constrained to be one sided, that is, $u_i \leq 0$ so that the function is a frontier one. For an efficient frontier, this should be estimated so that:

$$\sum_{g=0}^{G} \alpha_g X_{gi} = Y_i^* \geq Y_i \qquad 1=1, 2, \ldots, n \tag{4}$$

where

$Y_i = Y_i^* + u_i$

$Y_i^*$ = the frontier estimate of $Y_i$, and

$u_i$ = the residual of farm i

Only efficient farms satisfy the strict equality. In order to determine the unique vector $\alpha_g$ which satisfy (4), Timmer (1970) suggests minimizing the linear sum of residuals rather than minimized the linear sum of square residuals since the latter accentuates the impact of extreme observation. Thus the problem is to find $\alpha_g$, in order to:

$$\text{Min} \sum_{i=1}^{n} u_i$$

st

$$\sum_{g=0}^{G} \alpha_g X_{ig} \geq Y_i \tag{5}$$

$$\alpha_g \geq 0$$

To solve this using LP method, $\Sigma u_i$ is expressed as a linear function of $\alpha_g$ and $X_{ig}$. The production function in (1) is then summed over i and $\Sigma u_i$ is solved, that is

$$-\sum_{i=1}^{n} u_i = \sum_{i=1}^{n} \sum_{g=0}^{G} \alpha_{gi} X_{gi} - \sum_{i=1}^{m} Y_i \tag{6}$$

However, for any data set, the last term on the RHS of (6) is a constant, so it can be removed. What remains becomes the objective function. Timmer (1970) suggests that the problem is computationally simpler when the objective function is divided by the number of observations. Thus, the LP problem is to find $\alpha_g$, in order to:

$$\begin{aligned}
&\text{Min} \quad \alpha_0 + \alpha_1 \overline{X}_1 + \alpha_2 \overline{X}_2 + \ldots\ldots\ldots\ldots + \alpha_G \overline{X}_G \\
&\text{st} \\
&\quad \alpha_0 + \alpha_1 X_{11} + \alpha_2 X_{21} + \ldots\ldots\ldots + \alpha_G X_{G1} \geq Y_1 \\
&\quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&\quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&\quad \alpha_0 + \alpha_1 X_{1n} + \alpha_2 X_{2n} + \ldots\ldots\ldots + \alpha_G X_{Gn} \geq Y_n \\
&\quad \alpha_g \geq 0
\end{aligned} \tag{7}$$

Having estimated the production frontier, the efficiency ratings are calculated for each farm in each year as $Y_i/Y_i^*$. Thus, that LP measure of technical efficiency for farm i is given by exponential of these ratio, that is

$$TE = \exp\left(\frac{Y_i}{Y_i^*}\right) \leq 1 \tag{8}$$

*Nonparametric Frontier*

Nonparametric frontiers were originally proposed by Farrell (1957). The radial output measure of technical efficiency is estimated by assuming a nonparametric production technology (T) with strong disposable output and inputs, and non-constant return to scale:

$$T = \{(x,y): zY \geq y,\ zX \leq x,\ \sum z_i = 1,\ z \in R^+\} \quad (9)$$

where

x = a (n x 1) vector of inputs
y = a (m x 1) vector of outputs
k = the number of farms
X = the (n x m) matrix of inputs
Y = the corresponding (n x k) matrix of outputs, and
z = the intensity with which any activity (x,y) is utilized.

Technical efficiency i estimated by solving the following linear programming for each farm i:

$$\begin{aligned} &\text{Max} \quad \Theta_i \\ &\text{st} \\ &\qquad zY \geq \Theta_i y_i \\ &\qquad zX \geq x_i \\ &\qquad \sum z_i = 1 \end{aligned} \quad (10)$$

For the single-output nonparametric efficiency measure used here, there is one output constraint in (10). There are six input constraint for the measures. The solution to each programming, Θ, represent the ratio of each farm frontier output to observed output. The efficiency ratio, $TE = \frac{1}{\Theta}$, indicates the percentage (TE × 100) of output achieved by each firm. A primary difference between nonparametric and parametric production frontiers is that the former does not assume any parametric form. Hence, instead of attempting to fit a regression surface through the center of the data, nonparametric procedures lay a piecewise linear surface on top of the observation (Kalaitzandonakes *et al.* 1992).

*Stochastic Parametric Frontier*

Aigner *et al.*, (1977) and Meeusen and Van den Broeck (1977) have specified and estimated a stochastic production frontier which can be written as:

$$Y_i = F(X_i, \beta i)\ e^{\varepsilon_i} \quad (11)$$

where

$Y_i$ = output of ith farms
$X_i$ = a vector of inputs,
$\beta_i$ = a vector of parameters, and
$\varepsilon_i$ = an error terms

The stochastic frontier is also called *composed error* model, because it postulates that the error terms (i is composed of two independent error component:

$$\varepsilon_i = v_i - u_i \quad (12)$$

The error component vi is assumed to be distributed normally with mean zero and variance $\sigma_v^2$ ($v_i \sim N(0,\sigma_v^2)$) and account for variability in the frontier due to random shocks or noise. The error component ui is assumed to be distributed half-normally ($u_i \sim |N(0, ,\sigma_u^2|$) and assumed to capture firm' inefficiency, that is deviation from the stochastic frontier. Equation (4) is estimated using maximum likelihood. The technical efficiency related to the stochastic production frontier is

$$e^u = \frac{Y_i}{F(x_i, \beta_i) e^{vi}} \quad (13)$$

capture by the one sided error component $u_i \geq 0$ (Jondrow et al., 1992).

## DATA AND ESTIMATION

A cross section of 159 sample Sarawak pepper farms was used to estimate the production frontier models discussed in the previous section. Our empirical model consists of a single equation production function, which is justified by invoking expected profit maximization. The Cobb-Douglas functional form was chosen, as has been the practice in most published efficiency studies, because of its well-known advantages. The specific model estimated is:

$$\begin{aligned} \ln Q = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 \\ + \beta_3 \ln X_3 + \beta_4 \ln X_4 \\ + \beta_5 \ln X_5 + \varepsilon \end{aligned} \quad (14)$$

where

Q = pepper production (kg/year)
$X_1$ = the fertilizer used (kg/year)
$X_2$ = the weedicide used (lt/year)
$X_3$ = the chemical used (lt/year)

$X_4$ = labour (manday/year)
$X_5$ = number of vines cultivated
$\beta_0$ = parameter to be estimated, i =1,2..5
$\varepsilon$ = disturbance terms

As the first step, Ordinary Least Square (OLS) is applied for estimation, yielding best linear-unbiased estimates of production coefficients. The scale parameter estimates is then corrected by shifting the function until no residuals is positive and one is zero. In the application of the LP deterministic parametric frontier, equations (7) are used to estimate the parameters.

The nonparametric model derived the efficiency of each farm by comparing its observed use of inputs and produced output relative to all other farms. In the application to the Sarawak pepper farms, 159 farms observations of five inputs and single output are assembled. Therefore, there are five equations for input constraints and one additional constraint that the element of the intensity vector sum to one ($\sum z = 1$). Since 159 farms are present, a series of 159 such linear programming must be solved to determine the technical efficiency of each farm.

Estimation of parameters of stochastic frontier as well as the consequential diagnostics and statistical test was accomplished by using the maximum likelihood method (Greene, 1992).

## RESULTS AND DISCUSSION

Table 1 presents COLS, LP and stochastic estimates of the production function parameters. The adjusted $R^2$ indicates that the fitted regression explain 53.75 percent of the variation in pepper production for COLS model. It is interesting to note that farmers were operating at almost constant return to scale as indicated by the sum of the estimated coefficient. The regression coefficients for all the variables are positive and significant at 1 percent level. However, in the case of LP model, no standard error and $R^2$ can be calculated, but the intercept estimate is higher than the COLS method.

The corresponding stochastic and COLS estimates are quite similar in term of signs. The levels of significant for the corresponding coefficients are largely the same with the exception of the case for chemical. The COLS estimate of the intercept is smaller than the stochastic estimate. This confirms that the average production function (traced by the COLS estimates) lies below the stochastic production function reached by maximum likelihood estimates. The variance ratio parameter

TABLE 1
Estimates of production function

| | Deterministic Parametric (COLS) | LP-Deterministic Parametric | Stochastic Parametric (SPF) |
|---|---|---|---|
| Fertilizer | 0.2364 | 0.1619 | 0.31160 |
| | (7.415)[a] | | (6.234)[a] |
| Weedicide | 0.1151 | 0.1489 | 0.0881 |
| | (4.680)[a] | | (2.138)[a] |
| Chemical | 0.2508 | 0.2391 | 0.2232 |
| | (2.827)[a] | | (1.458) |
| Labor | 0.2048 | 0.2774 | 0.24941 |
| | (2.995)[a] | | (1.984)[b] |
| No. of Vine | 0.1666 | 0.1993 | 0.25180 |
| | (5.527)[a] | | (4.981)[a] |
| Constant | 1.1195 | 1.4066 | 2.0513 |
| | (0.2603) | | (1.661)[b] |
| $R^2$-ADJ | 0.5375 | | |
| $\sigma^2_v$ | | | 0.1068 |
| $\sigma^2_u$ | | | 0.0671 |
| Log-Likelihood | | | -63.7464 |

*Note:* Figures in parentheses are t-statistics
a Significant at 1% level
b Significant at 10% level

$\left(\lambda = \frac{\sigma_u}{\sigma_v}\right)$, a measure to indicate the extent of total variation that is due to differences in production efficiency, is found to be 0.78. This suggests that a high portion of the differences between farmers' realized production and the maximum possible productions are due to farming practices rather than random behaviour.

Table 2 presents the results of the efficiency analyses for four frontier models. At first glance, the results show considerable variability in the value of mean technical efficiency across methods. On average, the mean efficiency ratios of the sample farms are high, over 80 percent for SPF measures. The NPAR measure indicates that the pepper farms are almost 80 percent efficient, which is about 1 - 2 percent lower than average measures for the SPF model. The COLS frontier method has the lowest average efficiency ratio for the pepper farms. The COLS measure indicates that farms are approximately 62 percent efficient on average, about 3 - 4 percent lower than the average measures for the LP method. Both measures are about 20 - 22 percent lower than the average measure for the NPAR and SPF models. Efficiency ratios from the SPF model are higher than the COLS model because modeling the error term in SPF as a composite of random error and inefficiency, rather than solely as inefficiency (Neff *et al.*, 1993).

The nonparametric model tends to result in higher average efficiency measures than the parametric model (except for the SPF model). A significant reason for this is that the NPAR model analyses construct a different frontier for every sample farm. This result is consistent with Neff *et al.* (1993) where the NPAR model is a piecewise-linear, not a smooth function as in the COLS and SPF models.

The standard deviation for SPF model is the smallest compared to other three models. Consequently, the SPF model provides farm efficiency estimates with much lower variability than any of the other methods. For the SPF model, the technical inefficiency of each farm is a point estimate, that is, the mean of the conditional distributions of each farm's inefficiency error component ($u_i$) given its total error term ($\varepsilon_i$). The mean for the conditional distributions ($u_i|\varepsilon_i$) of the sample farms are very similar resulting in low variability in the efficiency ratios.

Table 2 and Fig. 2 represent distributions of farm efficiency ratios. The COLS and LP models is almost normally distributed. Approximately only 8 percent of the farms are very efficient (ER ≥ 90 percent) and 28 percent are inefficient (ER ≤ 50 percent) for COLS model. For LP models, approximately 13 percent of the farms are very efficient and 24 percent are inefficient. The COLS model, which is parametric, results in only one farm being on the frontier (ER = 1) and two farms for LP models.

The distribution of the NPAR model is skewed to the left. This is primarily due to a large number of efficient, or very efficient (ER ≥ 90%), farms associated with the nonparametric frontiers. The results indicate that a large number

TABLE 2
Frequency of efficiency ratio of pepper farming in Sarawak

| | Deterministic Parametric (COLS) | LP Parametric (LP) | Non-Parametric (NPAR) | Stochastic Parametric (SPF) |
|---|---|---|---|---|
| 31 - 40 | 12 ( 7.5) | 11 ( 6.9) | | |
| 41 - 50 | 33 (20.8) | 28 (17.6) | 13 ( 8.2) | |
| 51 - 60 | 45 (28.3) | 40 (25.2) | 17 (10.7) | 1 ( 0.6) |
| 61 - 70 | 23 (14.5) | 26 (16.4) | 25 (15.7) | 2 ( 1.3) |
| 71 - 80 | 13 ( 8.2) | 17 (10.7) | 17 (10.7) | 50 (31.4) |
| 81 - 90 | 20 (12.6) | 16 (10.1) | 20 (12.6) | 104 (65.4) |
| 91 - 100 | 13 ( 8.2) | 21 (13.2) | 67 (42.1) | 2 ( 1.3) |
| Minimum | 0.3398 | 0.3605 | 0.4106 | 0.5878 |
| Maximum | 1.0000 | 1.0000 | 1.0000 | 0.9064 |
| Average | 0.6162 | 0.6415 | 0.7999 | 0.8168 |
| Standard Deviation | 0.1712 | 0.1823 | 0.1923 | 0.0536 |

*Note:* Figures in parenthesis represent percentage of total sample

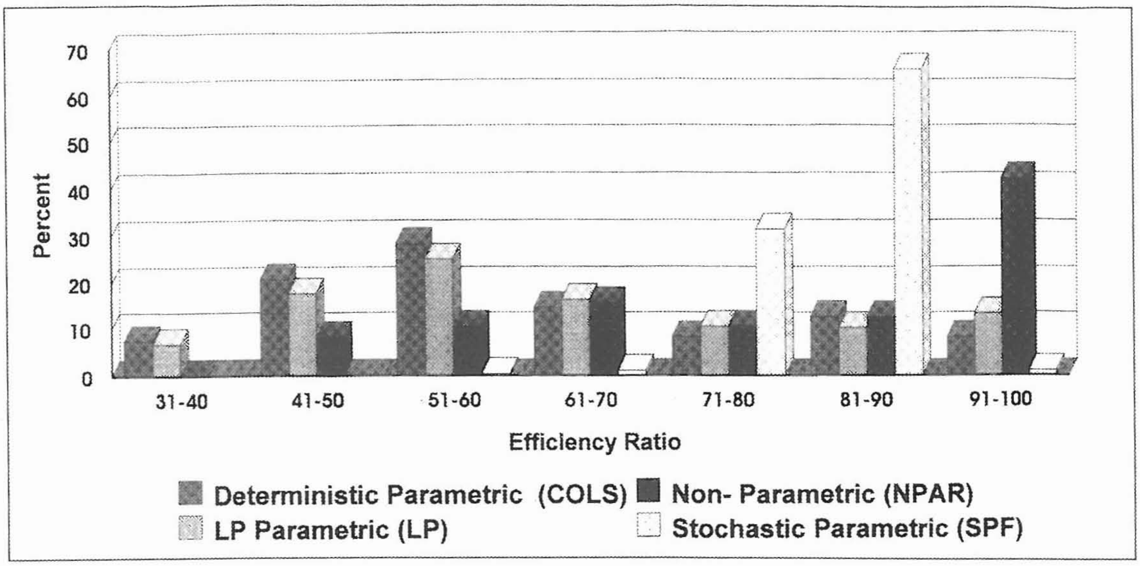


*Fig. 2. Distribution of efficiency ratio*

of farms being on the frontier. For the NPAR model, there are 55 farms with ER = 1. In part, this is a result of piecewise-linear manner in which the nonparametric frontiers are constructed where each farm observation has its own frontier.

The distribution of the efficiency ratio for the SPF model is in contrast to the other three measures. Over 65 percent of the sample farms are concentrated in the 80 - 90 percent efficiency region. On average, it appears that none of the sample farms in the SPF model have efficiency level less than 50 percent and also none are perfectly efficient. This is because the frontier is stochastic, and a portion of the total error is attributable to random behaviour (Neff *et al.*, 1993).

Table 3 presents summary statistics of the differences (DER) between the efficiency ratios estimated by the four frontier methods. A large number positive differences indicate that, in general, the efficiency ratio of four models are ranked as SPF > NPAR > LP > COLS. There are large differences between the efficiency ratios of the COLS, LP and NPAR models. NPAR efficiency ratios are 16 percent and 19 percent higher on average, respectively, than those of COLS and LP methods.

## CONCLUSION

The purpose of this paper is to compare the results derived from alternative production frontier estimation methods. The Cobb-Douglas functional form was used to evaluate the four methods that have been frequently employed in the literature, on a sample of 159 pepper farms in Sarawak.

In general, all the four models indicate that Sarawak pepper farms are producing at 60 - 80 percent efficiency ratio. However, the study

TABLE 3
Summary statistics of difference in efficiency ratio (DER) between four frontier models

| | COLS-LP | COLS-NPAR | COLS-SPF | LP-NPAR | LP-SPF | NPAR-SPF |
|---|---|---|---|---|---|---|
| Der > 0 | 37 | 1 | 20 | 0 | 30 | 74 |
| Der ≥ 0 | 122 | 158 | 139 | 159 | 129 | 85 |
| | Difference in Efficiency Ratio | | | | | |
| Average | -0.03 | -0.18 | -0.20 | -0.16 | -0.18 | -0.02 |
| Minimum | -0.15 | -0.59 | -0.42 | -0.61 | -0.45 | -0.36 |
| Maximum | 0.11 | 0.01 | 0.14 | 0.00 | 0.14 | 0.41 |

revealed that systematic differences in the efficiency measures are attributable to the method used. Differences also exist in the distribution of efficiency measures and the relative rankings of the farms by various models. The distributions of the COLS and LP measures are widely dispersed and more normally distributed. In contrast, the distribution of efficiency ratios from the stochastic parametric method is highly concentrated around 70 - 90 percent efficiency rate. This is in part due to the need to estimate inefficiency using the Jondrow *et al.* (1992) decomposition. However, in the case of nonparametric frontier, the results indicate that 35 percent of the sample farms are perfectly efficient (ER = 1). This is because the frontier is more flexible; that is, it is a piecewise-linear instead of continuous, functional form; and it constructs a different frontier for each observation.

In summary, the results indicate that frontier production functions proved significant in computing efficiency level in pepper production. The results can assist those involved in the industry's decision making to formulate strategy in abating inefficiency in order to enhance productivity. For example, a low level of technical efficiency indicates that increasing production would require new innovations or high-tech farming system. However, the absolute level, the distribution and the relative ranking of farm efficiency as shown in this study are influenced by the method employed. Thus, before any remedies can be suggested, the precision of predictors for individual technical efficiency should be carefully considered.

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