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A NONPARAMETRIC APPROACH TO ESTIMATING AND TESTING THE PRODUCTIVE EFFICIENCY DIFFERENTIAL

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ABSTRACT

This paper was conceived as an extension of the contribution by Kopp (1981) in developing an approach to efficiency measure that synthesizes. Farrell efficiency measure and the frontier production function. The extension is in the aspect of providing a measure for comparing productive efficiency differential between two groups of firms existing in the same competitive industry. To test the efficiency differential, we proposed the Mann-Whitney Test Statistic. As an illustration of the proposed measure, we used data from three Malaysian agricultural processing industries, that is, rice milling, rubber remilling and oilpalm processing. In the exercise, we estimated and test the technical efficiency differential between private and public firms in each industry and found that in rice milling and rubber remilling, private firms are technically more efficiency than their public counterpart. In oilpalm processing, the two groups of firms are equally efficient (or equally inefficient).

1, INTRODUCTION

The concept of productive efficiency, along with its computational framework, was first introduced by Farrell (1957). Since the pioneering studies considerable amount of theoretical and applied work has been done utilizing the concept introcuced in Farrell (1957) and Farrell and Fieldhouse (1962). The focus of these studies is on establishing measures of technical and/or allocative efficiency of production units within an industry". The works of Aigner and Chu (1968), Afnat (1972), Aigner, Lovell and Schmidt (1977), Schmidt and Lovell (1979), Greene (1980), Mansor Jusoh and Pa Ismail (1983) involved modelling of firm's production technology explicitly recognizing the existence of productive tneificiercy. The approach leads to efficiency measures in production frontier functions. On the other hand, the works of Timmer (1971), Seitz (1971), Fare and Lovell (1978)'extended the approach to efficiency measurement utilized in Farrell (1957).

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Recently. Kopp (1981) proposed an approach to efficiency measurement that synthesizes Farrell efficiency measure and the frontier production function. The approach produced a series of efficiency indexes for each firm in a representative per group. These indexes measure firm's aIlocative and technical efficiency performance as deviations from the efficiency standard, represented by a production frontier function, set by the group. The utilization of a production frontier allows for the relax3tion of homogeneity and homotheticity assumptions on part of technology utilized by production unit (Kopp 1981, p. 488-89).

This paper is an attempt to provide measures that can be used to compare productive efficiency of one group of firms to another within an industry. This subject matter seems to escape the attention of previous writers. For this purpose we extend Kopp's approach to the measurement of productive efficiency differential. The measure of efficiency differential to be proposed has the advantage of being able to be subjected to statistical test, albeit a nonparametric one.

The plan of this paper is as follows. Section 2 reviews Farrel's original approach to the measurement of productive efficiency, focusing on the distinction between the technical and allocative efficiency. In this section we also review farrell-type efficiency measures utilizing production frontier function as efficiency standard. Two proposed measures are discussed: the output-based Timmer measure of technical efficiency and the input-based Kopp's generalized Farrell measures of technical and allocative efficiency. Section 3 proposes a method of constructing measure of efficiency differential, utilizing Kopp's measure of technical efficiency as an illustration. The section also present a nonparametric approach to testing efficiency differential. Section 4 illustrates the empirical application of the proposed measure with data from three Malaysian agricultural processing industries. In the exercise we estimate and test the difference in technical efficiency between private and public firms in each of the industry. The final section offers some concluding remarks.

II. CONCEPT AND MEASUREMENT OF PRODUCTIVE EFFICIENCY

Productive efficiency is defined as the ability of a production organization, e. g., a firm, to produce a well specified output at minimum cost. Farrell (1957) distinguished two sources of inefficiency. One is due to excessive use of inputs, called technical inefficiency, and another is a result of firm employing inputs in the wrong proportion. The latter is called allocative inefficiencies. Both allocative and technical inefficiencies are costly. Furthermore, Farrell assumed that the components of allocative and technical inefficiency are independent and thus could be measured individually

To visualize Farrell's idea consider an industry with several firms, each utilizes two inputs $x = (x_1, x_2)$ to produce a single output y. Assume there exist for the industry an efficiency standard, characterized by an efficient transformation of inputs into output, $y = f(x)$; that is, a production frontier function[2]. Assume also that the function f is linear homogeneous so that the frontier function can also be characterized by a unit isoquant in x_1/y and x_2/y. This efficient unit isoquant is denoted II in Figure I. One should note that points below II are infeasible, while points above are inefficient.

Now, suppose a firm is observed at a production plan (Y_0, x_1^a, x_2^a), shown as point A in Figure I The firm is clearly inefficient as it uses input combination $(x_1^a/Y_0, x_2^a/Y_0)$, which is more than the least combination required, i. e., $(x_1^b/Y_0, x_2^b/Y)$, shown by point B on II. Notice that production plans A and B utilize the same input proportions and is independent of input prices. Therefore, the ratio OB/OA measures the firm's technical efficiency, the physical aspect of productive efficiency.

Given the relative input prices shown by the line ww' in Figure I and the efficient unit isoquant II, the least cost input combination to produce one unit of output is $(x_1^c/Y_c, x_2^c/Y_0)$, which conrresponds to point C. Since D lies on the isocost line ww', input combination at this point also cost the same. Consequently, allocative efficiency can be expressed as one ratio OD/OB[3].

Farrell's measure of efficiency can be generalized to a different efficiency standard. Primarily, the Farrell unit isoquant is quite restrictive in the sense that it requires the technologies employed by the firms being linearly homogeneous. On the other hand, frontier production function is a parametric representation of efficient technology in input-output space. As such, it assumes a specific functional form. However, as an efficiency standard, the production frontier function is considered superior to the Farrell efficient unit isoquant, because a properly specified functional form eliminates the need properly specified functional form eliminates the need for linear homogeneity or homotheticity assumption.

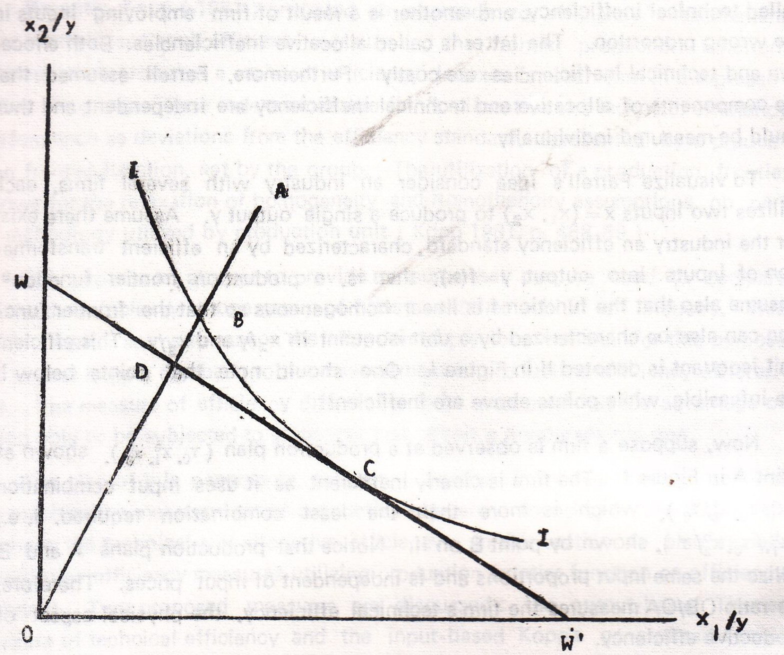

Figure I. Farrell Efficiency Measures

Generalization of the Farrell measures to production function requires the frontier to be of a specific type. In particular, its must satisfy the following three conditions (Kopp 1981, p. 488). First, the function is strictly monotonic, continuous and quasiconcave. Second, the frontier should be a boundary function so that all sample observations (i. e., the firms) must not lie above the frontier. Third, the frontier model assumes all variation in output to be the result of technical inefficiency alone. These compatibility requirements clearly limit the type of frontier function that can be used as the efficiency standard. The frontier function proposed by Afriat (1972), Richmond (1974), Aigner, Amemiya and Poirier (1976). Aigner, Lovell and Schmidt (1977) is not compatible since each of them are 'average" in nature, and thus sample observations can either lie above or below frontier surface. In addition the model attributes some variations in output to random disturbances. Few models that satisfies Kopp's three compatibility requirements are the deterministic frontier functions by Aigner and Chu (1968) and Timmer (1971); another is the maximum likelihood model by Greene (1980).

Timmer's and Kopp's Generalized Farrell Measures

The basic idea underlying Timmer's and Kopp's approach to efficiency measurement can best be illustrated using Figure II. This diagram (redrawn based on Figure II in Kopp 1981, p. 489) depicts the frontier surface OXYZ and the isocost plane JJ 'L' L. In the diagram qq denotes an efficient isoquant.

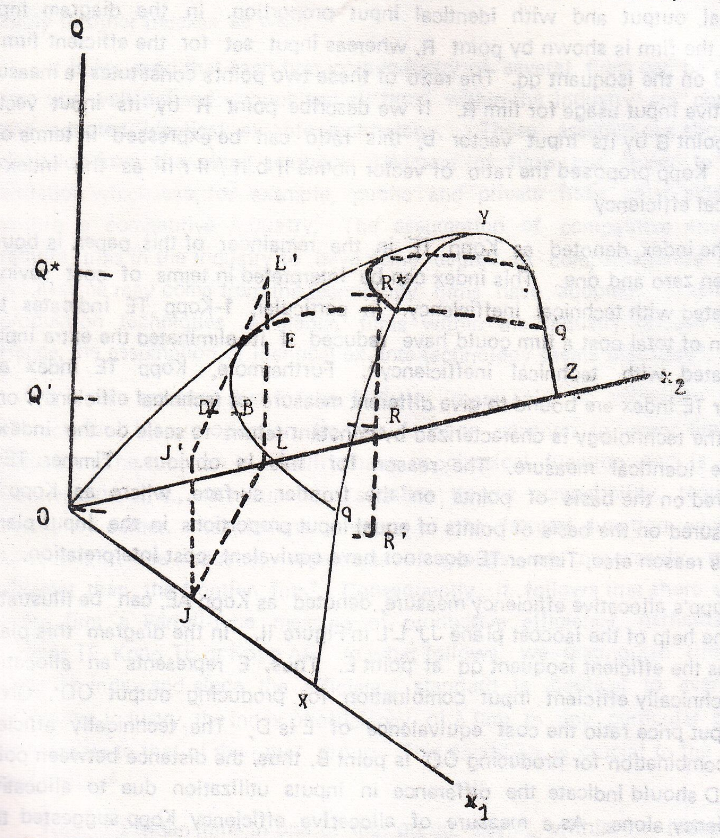

Figure II. Timmer and Kopp Measures of Efficiency

Consider a firm denoted by point R in the three dimensional space. R′ is inefficient since it lies below the frontier surface OXYZ. Timmer (1971) suggested the ration R′ R/R′R* as a measure of firm R′s technical efficiency. This ration reflects the actual output produced by the firm, OQ′=R′ R, compared to the output that could have been produced by an efficient firm, i. e., a firm on the OXYZ surface, using identical inputs.

Another measure of technical efficiency relates actual inputs usage of the firm to the inputs that could have been used by an efficient firm to produce identical output and with identical input proportion. In the diagram input set for the firm is shown by point R, whereas input set for the efficient firm is point B on the isoquant qq. The ratio of these two points constitutes a measure of relative input usage for firm R. If we describe point R by its input vector r and point B by its input vector b, this ratio can be expressed in terms of r and b. Kopp proposed the ratio of vector norms $\|b\| / \|r\|$ as the index of technical efficiency.

The index, denoted as Kopp TE in the remainder of this paper, is bound between zero and one. This index can be interpreted in terms of cost savings associated with technical inefficiency. In particular, 1-Kopp TE indicates the fraction of total cost a firm could have reduced if it eliminated the extra inputs associated with technical inefficiency[5]. Furthermore, Kopp TE index and Timmer TE index are bound to give different measure of technical efficiency; only when the technology is characterized by constant return to scale do the indexes provide identical measure. The reason for this is obvious. Timmer TE is measured on the basis of points on the frontier surface, where as Kopp TE is measured on the basis of points of equal input proportions in the input plane. For this reason also, Timmer TE does not have equivalent cost interpretation.

Kopp's allocative efficiency measure, denoted as Kopp AE, can be illustrated with the help of the isocost plane JJ′ L′L in Figure II. In the diagram this plane touches the efficient isoquant qq at point E. Thus, E represents an allocative and technically efficient input combination for producing output OQ′. Given this input price ratio the cost equivalence of E is D. The technically efficient input combination for producing OQ′ is point B, thus, the distance between point B and D should indicate the difference in inputs utilization due to allocative inefficiency alone. As a measure of allocative efficiency Kopp suggested the ratio Q′ D/Q′ B. Given the input vector d associated with point D, this measure is equivalent to the ratio of vector norms II d II / II b II. A cost interpretation similar to that of Kopp TE applies as well to Kopp AE.

III. MEASUREMENT OF EFFICIENCY DIFFERENTIAL

This section describes a procedure utilizing indexes of efficiency in the preceding section to derive a measure of productive efficiency differential. In the latter part of this section we also present methods for estimation and test of this measure. Description of the procedure is based on Kopp TE index, but apply to other indexes as well.

It is assumed that each firm in an industry of several firms can be classified into two well-defined groups and all firms within the industry are competitive and adopted identical ex-ante technology. These assumptions show slight deviation from the usual textbook treatment of firms but closer to real life situation which see, for example, public and private firms exist side-by-side within a competitive industry. The assumption of competitive environment require firms in the industry to have some degree of competitiveness and this we assume may come from the technology firms have adopted. Given various production techniques available, firms within the industry choose the best. Hence, the assumption of identical ex-ante technology seems plausible[6].

It is also assumed that for the industry, there exist an efficiency standard characterized by a production frontier function common to every firm in the industry. The function is a well-behave neoclassical function and is of a full frontier type, i. e., the function satisfies Kopp's compatibility requirements mentioned earlier. Restrictions on nature of the frontier function ensure that firms within the industry, regardless of groups, are necessarily no more efficient than the frontier firm[7]. Consequently, it follows that there exist for every firm a Farrell-type measure of productive efficiency, particularly the Timmer TE, Kopp TE or Kopp AE. In what follows, we distinguish firm by its Kopp TE index and since the efficiency standard is identical to every group within the industry, the index of efficiency of a firm in any particular group is comparable to that of the other group. This condition is crucial to the analyses that follow[8].

Now, consider firms in one of the group, say A, within the industry and denote X as real-valued function associating each and everyone of these firms with its respective Kopp TE measure. X, then, is a random variable defined over real number between zero and one, corresponding to values taken by the index. The distribution of X is obviously unknown, but we assume that it is symmetric around a location parameter U_A. In like manner, we define a random variable Y over firms in group B and assume it has a location parameter U_B.

Let the location parameters, U_A and U_B, be the means of the random variable X and Y respectively[9]. We then could interpret each of these parameters as representing an average value of the technical efficiency measures of firms in each group. Specifically, U_A describes the average value of Kopp TE measures of firms in group A, and likewise, U_B represents the average for firms in group B, such that U_A and U_B are each bound between zero and one. A value of U_A (or U_B) close to one indicates firms in group A (or group B) are on the average highly efficient, and a value close to zero indicates that they are on the average inefficient. A value of say 0.5 shows that a majority of firms in the group has Kopp TE measures centered around an index of efficiency of 0.5.

Thus, location parameters U_A and U_B, in particular $| U_A - U_B |$, can be used to provide a measure of efficiency differential. The interpretation of this measure is straight forward. If the absolute value of $U_A - U_B$ approaches zero, firms in group A and B are equally efficient, i.e., either they are both equally efficient or equally inefficient. On the other hand, if the absolute value of the difference approache unity, either firms in group A are more efficient than firms in group B or vice versa.

In practice, often U_A and U_B are unobservable and thus have to be estimated from sample observations. Consider taking two independent random samples of size n from group A and size m from group B; and denote $X_1, .., X_n$ as sample from A and $Y_1, ..., Y_m$ as sample from group B. Hence, unbiased estimators for U_A and U_B are the respective sample means :

$$\bar{U}_A = X_i / n,$$

$$\bar{U}_B = Y_i / m,$$

Unbiased estimates of $\bar{U}_A$ and $\bar{U}_B$ are respectively

$$\bar{u}_A = \Sigma x_i / n,$$

$$\bar{u}_B = \Sigma y_i / m,$$

where x_i denote the observed values of the random variable x_i , $i=1, ..., n$ and y_i denote observed values of the random variable Y_i . $i=1, ..., m$.

Furthermore, it follows that an unbiased estimator for the difference $U_A - U_B$ is

$$\bar{U}_D = \bar{U}_A - \bar{U}_B$$

and unbiased estimate of U_D is

$$\bar{u}_D = \bar{u}_A - \bar{u}_B$$

Neither distributions of X and Y nor that of X-Y are assumed known. Thus, a parametric test on $\bar{u}_D$ is not applicable. A nonparametric test, we propose, is based on the Mann-Whitney U Statistic[10]. In the following, we illustrate how the test statistic can be derived.

Recall that $X_1, ..., X_n$ and $Y_1, ..., Y_m$ are samples from group A and group B respectively. Sample observations $x_1 ..., x_n$ and $Y_1, ... Y_m$ are the observed Kopp TE measures for firms in the respective group relative to a common efficiency standard. Thus, each of the observed values are comparable. In particular, if we combine the two samples, all sample observations can be ranked according to the observed technical efficiency measures. Subsequently, combining the two sample observations and ranking $x_1, ..., x_n$; $y_1, ..., y_m$ from smallest to largest and denoting this ordering by $Z_1, ..., Z_{n+m}$, then, rank $(Z_i) = i$ $i = 1, ..., n+m$. In case of tied observations, the mean of the rank positions they would have occupied had there been no ties is assigned to each of the observations.

Denote S as the sum of the ranks assigned to sample observations from group A. When firms in group A are on the average less efficient than firms in group B, i. e., U_A is smaller than U_B, we would expect all observations from this group $(x_1, ..., x_n)$ to rank 1, ..., n, and hence, $S = n(n+1)/2$. Thus, the statistic

$$T = S - n(n+1)/2$$

could be used as a test statistic. As T approaches zero, it signifies U_A is less than U_B and as T becomes large, it signifies U_A is greater than U_B. To determine the critical value of the test, for small n and m, i. e., either n or m is no greater than 20, one could use table of quantile of the Mann-Whitney Test Statistic (e. g., Table 8 in Daniel 1978, p. 408-12).

When n and m are both large and $U_A = U_B$, the test statistic

$$w = \frac{T - nm/2}{\sqrt{nm(n+m+1)/12}}$$

approaches the standard normal distribution. In the above equation, nm/2 and nm (n+m+1)/12 are respectively the expected value and the variance of the statistic W when $U_A = U_B$. Thus for large sample sizes, test on statistic w could be based on the standard normal distribution.

IV. TECHNICAL EFFICIENCY DIFFERENTIAL OF PRIVATE AND PUBLIC FIRMS

The Data

As an illustration of the proposed measure, a sample of cross-sectional data from three agricultural processing industries for the year 1982 were obtained. The three industries are : (1) rice milling, (2) rubber remilling dan (3) oilpalm processing. Each record in the three industries are in average value term and are highly aggregative in nature. The field in each record include : (1) average value of production, denoted by REV, (2) average value of electricity, water and fuel and (3) average number of employees per firm. The latter two are each denoted by UTIL and EMPL respectively. Table 1 provide descriptive statistic of each industry by ownership, i.e., private and public. Each entry in the table is the mean for the sample according to ownership-type. At a glance, it is interesting to note that the average ratio UTIL/EMPL is greater for firms that are privately owned than those that are publicly owned.

The Frontier Function

For the purpose of establishing the technical efficiency standard, it is assumed that firms in each industry have a deterministic frontier function as specified by Aigner and Chu (1968) as follows :

Table I. Average output and input utilization (by ownership)

	Rice		Rubber		Oilpalm	
	Private	Public	Private	Public	Private	Public
Sample Size	29	14	25	15	30	20
REV ($'000)	3,092	2,477	13,090	4,290	4,594	8,793
UTIL ($'000)	64	94	391	149	1,353	68
EMPL (man yr.)	21	40	94	43	95	53
UTIL/EMPL	3048	2350	4160	3465	14232	1283

$$Y = f(x)e^u \quad , \quad (u \leq 0) \tag{1}$$

In the Cobb-Douglas form, equation (1) is

$$\ln Y = \alpha + \sum_{i=1}^{n} \beta_i \ \ln X_i \ + u \quad , \quad (u \leq 0) \tag{2}$$

To estimate equation (2), OLS is applied. The intercept is then shifted such that all residuals are either zero or negative. Such shift will yield a BLU estimate of β_i and a bias but consistent estimate of α (Greene. 1980).

The Estimated Equation

Using the available data, the estimated Cobb-Douglas function is specified for each industry as follows :

$$\ln REV = \alpha + \beta_1 \ \ln UTIL + \beta_2 \ \ln EMPL + u \quad , \quad (u \leq 0) \tag{3}$$

The estimated average Cobb-Douglas for each industry are[11].

Rice : $LREV = 10.2807 + 0.3426 \ LUTIL + 0.2940 \ LEMPL$

$\sum_{i=1}^{2} \beta_i = 0.6366 \qquad \bar{R}^2 = 0.65 \qquad U_m = 1.0875$

Rubber : $LREV = 9.9243 + 0.3599 \ LUTIL + 0.4057 \ LEMPL$

$\sum_{i=1}^{2} \beta_i = 0.7656 \qquad \bar{R}^2 = 0.49 \qquad U_m = 0.8665$

Oilpalm : $LREV = 8.9398 + 0.4922 \ LUTIL + 0.4102 \ LEMPL$

$\sum_{i=1}^{2} \beta_i = 0.9024 \qquad \bar{R}^2 = 0.79 \qquad U_m = 0.6762$

where the capital L in front of each variable name represent natural logarithm and U_m denote the largest positive estimated residual for function in the corresponding industry.

After the appropriate shift in intercepts and denoting REV* as the maximum value of obtainable out put from the given input usage, the frontier functions for each industry are :

Rice : $LREV^* = 11.3682 + 0.3426 \ LUTIL + 0.2940 \ LEMPL$

Rubber : $LREV^* = 10.7908 + 0.3599 \ LUTIL + 0.4057 \ LEMPL$

Oilpalm : $LREV^* = 9.6160 + 0.4922 \ LUTIL + 0.4102 \ LEMPL$

Kopp and Timmer Measure of Technical Efficiency

To generate Kopp TE and Timmer TE measures, denote UTIL* and EMPL* as the optimal usage of input UTIL and input EMPL respectively. Then for each firm in each industry, given REV

$$LEMPL^* = [LREV - \alpha^1 - \beta_1 L(\frac{UTIL}{EMPL})] / (\beta_1 + \beta_2)$$

and

$$LUTIL^* = [LREV - \alpha^1 - \beta_2 L(\frac{EMPL}{UTIL})] / (\beta_1 + \beta_2)$$

where $\alpha^1 = \alpha + U_m$

Thus,

$$\text{Kopp TE} = UTIL^* / UTIL = EMPL^* / EMPL \qquad (\leq 1)$$

and

$$\text{Timmer TE} = REV/REV^* \qquad (\leq 1)$$

Repeating the above calculation for each firm in each respective industry, the technical efficiency indexes (Kopp TE and Timmer TE) is generated and each firm in each industry can thus be ranked, from least efficient to most efficient, according to the observed technical efficiency indexes. Accordingly, the means of Kopp TE and Timmer TE can be calculated for each group (i e., private and public) in each industry and summery of their results are presented in Table II[12].

Test Criterion

As indicated earlier, since the distribution of the observed Kopp TE and Timmer TE indexes are not known, therefore, a parametric test on the efficiency differential, i. e.,

Table II. Sample mean of Kopp and Timmer TE.

	Kopp TE			Timmer TE		
	Private	Public	overall	Private	Public	overall
Rice :	0 25	0.15	0.22	0.40	0.30	0.36
Rubber :	0.42	0.26	0.36	0.51	0.35	0.45
Oilpalm :	0.49	0.51	0.50	0.52	0.54	0.53

$$H_O: \quad u_A - u_B = 0$$
$$H_A: \quad u_A - u_B \neq 0$$

is not applicable. As such, a nonparametric test on the efficiency differential based on the Mann-Whitney U test statistic is derived. Summary of the statistics are presented in Table III.

From Table III, we can safely conclude that in rice milling and rubber remi-lling, private firms are technically more efficient than publics firms, whereas in oil palm processing, private and public firms are equally (in) efficient. While it is interesting to investigate further on the factors that contribute to the technical efficiency differential between private and public firms, such work is beyond the scope of this study.

V. CONCLUDING REMARKS

This paper proposes a method of measuring and testing the efficiency diff-erential of two well defined groups of firms within an industry Each firm in the industry were assumed to have identical ex-ante technologies and there exist a common efficiency denominator for all firms in the industry. In constructing the measure for efficiency differential between the two groups of firms, Kopp's generalized Farrell input-based technical efficiency indexes were extended and since the distribution of these indexes are not known, therefore, a nonparametric test on the efficiency differential were required. The method of testing proposed is based on Mann-Whitney Test Statistic.

The usefulness of the proposed measure for policy purposes is fairly obvious. With its advantage of being able to be subjected to statistical test, the measure, for example, could be used as one of the guiding criterion for privatization policy.

Table III. Estimate of Efficiency Differential

	Kopp TE		Timmer TE	
	Differential	Estimate of w	Differential	Estimate of w
Rice :	0.10	2.37**	0.10	2.36**
Rubber :	0.16	2.81**	0.16	2.81**
Oilpalm :	0.02	0.52	0.02	0.50

Note : **Indicate significant at 5% level.

Furthermore, for firms that exist within a competitive industry and employing identical ex-ante technologies, their technical efficiency are directly related to the same underlying technical and socio-economics factors. As such, with their identification one could readily test for the factors that are responsible for the efficiency differential between groups of firms in the industry.

In the empirical work reported, both Kopp and Timmer technical efficiency differential were estimated for two groups of firms in three different agriculture industries. In all instances, the estimated technical efficiency differentials based on input and output were found to be equal.

NOTES

1. An excellent survey of frontier models and their relationship to efficiency measurement can be found in Forsund *et. al.* (1980).

2. The iudustry, thus could be envisaged as to consist of n firms each having ex-post production function $Y = f_i(X)$, $i =, \ldots n$. The efficient transformation of inputs to output (or the frontier function) for the industry is then $Y = f(X) = \sup_i \{f_i(X)\}$.

3. Notice that point B in Figure I represents a technically efficient input combination, but unlike point C, it is allocatively inefficient. Thus, a movement from B to C should represent an improvement to the firm in terms of allocative efficiency alone.

4. See R. J. Kopp (1981), p. 488.

5. This interpretation is possible only when the measure is made along the input proportion ray and thus independent of input prices (Kopp, 1981, p. 490-91). As such, any reduction in cost associated with the firm moving from point R to point B will be a result of inputs reduction due to increased technical efficiency.

6. Model of this nature, e. g., Kopp (1981), Farrell (1957), assume firms as having already adopted a specific ex-ante technologies.

7. What constitutes a frontier firm is subject to discussion. Farrell (1957) for example consider two alternatives : a hypothetical firm characterized by engineering excellence or a firm showing the best results in practice. For empirical purposes, he suggests the latter.

8. Obviously, one could define a different efficiency standard for each group. But then, measures of efficiency for each firm in one group are not comparable to that of a firm in the other group.

9. One should note that the symmetry assumption is not really necessary. It was adopted so that we could interpret the location parameter to represent the mean or the median of the distribution.

10. The assumptions required to the test are : the two samples are independent, the variables observed are continuous and the distribution functions of the two populations differ only with respect to location, if they differ at all.

(Daniel 1978, p. 82). It seems that all these assumptions are satisfied in this case.

11. We are grateful to Khoo Meng Kian for generating the estimated equation. Through out the exercise, computer program SAS.

12. Individual Kopp TE index and Timmer TE index, and their ranking are not reported. However, they are available upon request.

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