Estimating Location-Specific and Firm-Specific Technical Efficiency:

An Analysis of Malaysian Agriculture*

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I. The Setting

Decisions about development strategies in agriculture are in part guided by farm level performances. An important measure of such performance is relative economic efficiency, of which technical efficiency is a component. The literature provides a number of different methodologies to measure technical efficiency; of these, the frontier production function approach popularized by Aigner et al. (1977) can generally be considered as an appropriate method.[1] Lee and Tyler used a similar model to estimate average technical efficiency of Brazilian manufacturing firms. However, their approach only allows the measurement of average technical efficiency of a group of firms, and does not provide estimates of firm-specific technical efficiency for individual observations. Recently, Jondrow et al. and Kalirajan and Flinn independently used a similar method to measure firm-specific technical efficiency for individual sample observations. These in-

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[1] A brief but comprehensive discussion on the evolution of frontier production function is given in Forsund et al.

quant. Second, without the assumption of constant returns to scale, specifying a functional form, a smooth curve may be drawn through the lowest of the points in scatter diagrams which would represent the frontier function. The former approach was used by Farrell to measure the technical inefficiency of firms in relation to the function thus estimated. The major criticism of this approach is that it uses only marginal observations and a vast bulk of data does not enter the estimation procedure. But, it is possible to fit a smooth curve showing frontier output, using all observations in the estimation.

Extending the above model of two inputs and one output into one output and m-inputs, the frontier production function is estimated as mentioned below.

Let the production frontier be

$$(1) \qquad y^* = f(x_1, \ldots, x_m)$$

where y^* is the maximum possible output a firm can obtain by using the inputs (x_i's) in a technically efficient way. It is not unreasonable to expect that not all firms may be technically efficient and consequently, not all firms may be operating on their production frontiers. therefore, the prevailing production method which is specific to a particular individual firm at any particular time period can be written as follows:

$$(2) \qquad y = f(x_1, \ldots, x_m) + u$$

where u is the firm-specific technical efficiency parameter. If the firm is technically efficient u takes the value zero, and the firm obtains the maximum possible output, y^*; u takes the value less than zero for those firms which are not technically efficient, and the firms accordingly obtain their outputs $y < y^*$. The negative value of u will vary among firms depending on their technical efficiency according to how close they are to the frontier.[3]

[3] Aigner and Chu estimated such a function using linear programming methods. The major weakness of the approach is that due to the nature of the methodology no statistical tests on the parameters could be carried out.

form, the translog, as introduced by Berndt and Christensen was chosen in the paper.

$$(6) \quad \ln y = a_0 + \sum_i a_i \ln x_i + \sum_i \sum_j b_{ij} \ln x_i \ln x_j + u + v$$

where x and y are as defined in equation (1);
u $\leqslant 0$ and takes a half normal distribution; and
v $\lesseqgtr 0$ and takes a normal distribution.

The density function of u and v can respectively be written as:[4]

$$(7) \quad f(u) = \frac{1}{\sqrt{\frac{1}{2}\pi}} \frac{1}{\sigma_u} \exp(-\frac{u^2}{2\sigma_u^2}) \qquad u \leqslant o$$

$$(8) \quad f(v) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma_v} \exp(-\frac{v^2}{2\sigma_v^2}) \qquad -\infty \leqslant v \leqslant \infty$$

The likelihood function of y is the product of density functioin of each y_k which is equal to the density function of $(u_k + v_k)$.

By convolution formula, the joint density function of $(u_k + v_k)$ can be written as

$$(9) \quad f(u+v) = \frac{1}{\sqrt{\frac{1}{2}\pi(\sigma_u^2 + \sigma_v^2)}}$$

$$\exp\left(-\frac{(u+v)^2}{2(\sigma_u^2 + \sigma_v^2)}\right)\left(1 - F(u + v\frac{\sigma_u}{\sigma_v})\right)$$

where F(·) is the cumulative distribution functioin of the standard normal random variable.

Specifying

4 The validity of these assumptions can be examined by using a family of convolutions. Also, it can be examined by plotting the combined residuals e, the individual technical efficiency u and the output levels.

Now,

$$f(u|u+v) = \frac{1}{\sqrt{2\pi}} \frac{\sigma}{\sigma_u \sigma_v}$$

$$\exp\left[-\frac{\sigma^2}{2\sigma_u^2 \sigma_v^2} (U + \frac{e\sigma_u^2}{\sigma^2}) \right] \frac{1}{1-F}$$

where e = u + v and F(·) is the distribution function of the standard normal variable. Therefore,

$$(12) \quad E(u|u+v) = -\frac{\sigma_u \sigma_v}{\sigma} \left[\frac{f(\cdot)}{1-F(\cdot)} - \frac{e}{\sigma}\sqrt{\frac{\gamma}{1-\gamma}} \right]$$

where f(·) is the standard normal density function.[5] The estimate of u is obtained from replacing e by the residual which is the difference between the estimated and actual frontiers.

IV. The Analysis

The data used in the paper were derived from a sub-sample of a large World Bank sponsored survey completed by Shand et al. The sub-sample consists of 210 and 172 rice farmers respectively operating inside and outside the Kemubu Irrigation Project in Malaysia,[6] during the year 1980. Two sub-groups of farmers were considered viz., tenant operators and owner-tenant operators.[7] It should be noted that farmers outside Kemubu do not use any irrigation at all and their farming entirely depends on rainfall (Shand et al.).

5 The specification of γ here is different from the λ specification used by Aigner et al. (1977). γ may be called as 'intra-class correlation coefficient' of the classical random effects model (Nerlove, 362).

6 For further details of the sample characteristics, see Shand et. al.

7 Owner-tenant operators are farmers who own some proportion of total operational paddy area, i.e., they operate their own land and also some leased-in land.

Table 1

MLE Estimates of Location-Specific Stochastic Production Frontier for Kemubu Farmers

Parameters	ML Estimates		
	Pooled	Inside Kemubu	Outisde Kemubu
a_0	4.3626	5.8848	3.0612
	(1.2912)	(1.1840)	(1.0883)
a_1	0.0312	0.0256	0.0136
	(0.0061)	(0.0056)	(0.0048)
a_2	0.2812	0.2456	0.1985
	(0.1208)	(0.0810)	(0.0620)
a_3	0.4286	0.6582	0.4381
	(0.2012)	(0.2006)	(0.1563)
a_4	0.7260	0.8410	0.6173
	(0.2418)	(0.2253)	(0.2180)
b_{22}	-0.1089	-0.1221	-0.0542
	(0.0412)	(0.0380)	(0.0221)
b_{23}	-0.1126	-0.1811	-0.0873
	(0.0382)	(0.0536)	(0.0324)
b_{24}	0.1008	0.0056	0.0082
	(0.0426)	(0.0123)	(0.0024)
b_{33}	0.0381	0.0690	0.0430
	(0.0120)	(0.0210)	(0.0180)
b_{34}	-0.0298	-0.0897	0.0011
	(0.0082)	(0.0226)	(0.0003)
b_{44}	0.0046	0.0068	0.0024
	(0.0018)	(0.0021)	(0.0010)
Log likelihood function	-48.2640	-28.1672	-31.0829
σ^2	0.3846	0.2916	0.3187
σ_u^2	0.2808	0.2449	0.2486
γ	0.7301	0.8398	0.7800
	(0.2218)	(0.1876)	(0.2103)

Note: Figures in parentheses are asymptotic standard errors of estimates.

Table 2

MEAN PRODUCTION ELASTICITIES FOR INSIDE AND OUTSIDE KEMUBU

Input	Units of Measurement	Production Elasticities at the Mean Input Levels: Inside (e_1)	Outside (e_2)	Test Statistic (Z) for Difference in Elasticities[1]
Labour	man day	0.1518 (0.0212)	0.1089 (0.0187)	1.7229***
Fertilizer	kg	0.1201 (0.0307)	0.0583 (0.0196)	1.7119***
Area	hectare	0.4502 (0.1445)	0.3580 (0.1265)	2.4986**

Notes: ** Significant at the 5 percent level.
*** Significant at the 10 percent level.

[1] Test statistic, $Z = \frac{\hat{e}_{i1} - \hat{e}_{i2}}{\sqrt{Var(\hat{e}_{i1}) + Var(\hat{e}_{i2})}}$ which is N (0, 1) under the null hypothesis (i = 1, 2, 3), and from equation (12), $Var(\hat{e}_i) = Var\ a_i + \Sigma(\ln x_j)^2\ Var\ b_j + 2\Sigma \ln x_j\ Cov(a_i b_j) + 2\Sigma \ln x_k \ln x_j\ Cov(b_j b_k)$.

important, from a policy perspective, it is more useful to estimate technical efficiencies for individual farmers. As indicated earlier, farm-specific technical efficiencies for individual sample farmer were estimated using equation (12), and they are reported in the form of a frequency distribution in Table 3. These results show a wide variation in the level of technical efficiencies across sample farms. Individual technical efficiency ratings range from 0.4182 to 0.9206 for owner-tenant farmers operating inside Kemubu, while for those owner-tenant farmers operating outside Kemubu the range was slightly narrower, between 0.4421 and 0.8929. For pure tenants, individual technical efficiency ratings vary from 0.3927 to 0.8950 inside Kemubu, and between 0.4285 to 0.8792 for tenants outside Kemubu.

Only about 14% of sample participants inside Kemubu and 19% outside Kemubu obtained outputs which were 75% and production technology prevailing in the area. In contrast to most earlier studies, this paper provides a measure of technical efficiency for each observation in the sample.

The stochastic production frontier seeks to estimate the maximum output for a given set of inputs while incorporating the possibility that the frontier shifts randomly due to the influence of unmeasured forces. Also, the frontier could remain fixed with measurement error in output accounting for apparent production beyond the frontier. The assumptions about the structure and distribution of the variables u and v are very important for estimating the frontier production function. The assumption that u and v are independent is absolutely central to the analysis. Unlike most of the econometric analysis, the production frontier methodology assigns behavioural significance to the magnitudes of the error components. The assumption of a truncated normal distribution for u is not without criticism. For examle, when u is assumed to follow a half normal distribution, majority of observations are expected to lie around zero meaning that farms have high technical efficiency. This limitation may be overcome by considering u to have a truncated normal distribution whose mean is different from zero (Stevenson). However, some of the earlier studies have proved that the assumption of half normal distribution is adquate (Lee).

The analysis demonstrates that even in areas well endowed with irrigation and other input facilities, there remains scope for substantial increases in production levels. On average there appears to be 65% (= 1.0 − 0.35) and 69% (= 1.0 − 0.31) technical efficiency with respect to rice production inside and outside Kemubu, respectively. The lower rating of the former case means that production technology inside Kemubu needs more careful attention to improve performance than the traditional production technology outside Kemubu. Thus the analysis reveals that mere promulgation of recommendations for, and broad adoption of, new production technologies may not yield the long term target level of output, and specific measures need to be taken to improve technical efficiency as well.