Measurement of technical efficiency in Thai agricultural production

Wirat Krasachat¹

Abstract: The primary purpose of this study is to measure technical efficiency in Thai agricultural production during the period 1972 to 1994. Unlike past studies, this study decomposes technical efficiency into its pure technical and scale components. The data envelopment analysis (DEA) approach and annual data from 1972 to 1994 for four regions in Thailand are used. The empirical results suggest that there are significant possibilities to increase efficiency levels by increasing farm size. In addition, the availabilities of new land and the diversity of climate, natural resources, etc., could have had an influence on technical efficiency in Thai agricultural production.

Keywords: technical efficiency, pure technical efficiency, scale efficiency, data envelopment analysis, Thai agriculture

1 Introduction

Thai agriculture has experienced rapid growth over the past three decades. During the periods 1963 to 1975, 1975 to 1985, and 1963 to 1985, the annual growth rates of gross value added averaged approximately 4 per cent (Onchan and Isvilanonda 1991, p. 60). Although the agricultural sector recorded a negative growth rate of 2 per cent in 1987, due to the drought crisis, agriculture still grew at a high average rate of nearly 4 per cent per annum during the 1980s (Asian Development Bank 1990) and 3 per cent per annum from 1990 to 1995 (Bank of Thailand 1998).

There are at least three causes for worry concerning the future development of the agricultural sector in Thailand. First, in the past, the relatively high growth rate of the agricultural sector in Thailand was achieved mainly through the expansion of cultivated areas (by deforestation). This pattern of growth can no longer continue since Thailand reached its land frontier two decades ago. Therefore, a new strategy for agricultural development has been used in recent years with emphasis placed on increasing agricultural land productivity. New technology inputs, such as modern varieties of plants, fertilisers, irrigation, mechanisation and chemicals, have been widely adopted. Second, although, the contribution of technology inputs towards sustainable output growth has been recognised,

¹ Department of Agricultural business Administration, King Mongkut’s Institute of Technology Ladkrabang, Bangkok 10520, Thailand, Email: kkprimirat@kmitl.ac.th
yield in Thai agriculture has generally been rather low, and declining in some cases such as rice and corn, the most important crops. For example, their yields decreased from 1988 to 1990. Compared with some selected Asian rice-growing countries, the yield of rice in Thai agriculture was the lowest in 1990 (Ministry of Agriculture and Cooperatives 1996). Third, Thai agriculture differs regionally due, primarily, to the differences in geographical area, such as climate and natural resources, and thus production characteristics. For example, as indicated in Puapanichya and Panayotou (1985), mungbeans and soybeans are of particular significance to the Northern Region, while kenaf, rubber, and rice are very important to the Northeastern, Southern and Central Regions, respectively. These regional differences may cause different technical efficiency among regions. This is because most government intervention policies at national level might unequally impact producers in different regions as indicated in Schertz et al. (1979). In addition, Thailand has experienced cheap land and labour, little agricultural research and no shortage of food for many years. Because of the above factors, economists and policy makers have raised the question of the technical efficiency of Thai agricultural production.

The main purpose of this study is to measure technical efficiency (decomposed into its pure technical and scale components) at aggregate level in Thai agriculture. To estimate efficiency scores, the DEA method is applied to panel data comprising 23 years of annual data (1972 to 1994) on the four regions in Thailand. Previous studies have investigated cost efficiency and its components at both the farm and aggregate levels in Thai agriculture (e.g., Tantavaruk 1985, Chayaputi 1993, Krasachat 2000). However, this study, to our knowledge, has been the first application of DEA in order to measure technical efficiency and its components at the aggregate level in Thai agriculture. This enables more detailed understanding of the nature of technical efficiency in Thai agricultural production.

This paper is organised into five sections. Following this introduction, the analytical framework is described. Next, data and their sources are described. The last two sections cover the empirical findings of this study, and conclusions and suggestions for further research.

2 Analytical framework

Coelli. (1995), among many others, indicated that the DEA approach has two main advantages in estimating efficiency scores. First, it does not require the assumption of a functional form to specify the relationship between inputs and outputs. This implies that one can avoid unnecessary restrictions about functional form that can affect the analysis and distort efficiency measures, as mentioned in Fraser and Cordina (1999). Second, it does not require the distributional assumption of the inefficiency term.

According to Coelli, Rao and Battese (1998), the constant returns to scale (CRS) DEA model is only appropriate when the farm is operating at an optimal scale. Some factors such as imperfect competition, constraints on finance, etc. may cause the firm to be not operating at an optimal level in practice. To allow for this possibility, Banker, Charnes and Cooper (1984) introduced the variable returns to scale (VRS) DEA model. In this study, technical efficiency
is calculated using the input-oriented variable returns to scale (VRS) DEA model. Following Fare, Grosskopf and Lovell (1985), Coelli, Rao and Battese (1998) and Sharma, Leung and Zaleski (1999), the VRS model is discussed below.

Let us assume there is data available on $K$ inputs and $M$ outputs in each of the $N$ decision units (i.e., regions). Input and output vectors are represented by the vectors $x_{it}$ and $y_{it}$, respectively for the $i$-th region in $t$-th time period. The data for all regions may be denoted by the $K \times NT$ input matrix ($X$) and $M \times NT$ output matrix ($Y$). The envelopment form of the input-oriented VRS DEA model is specified as:

$$
\begin{align*}
\min_{\theta, \lambda} & \theta, \\
\text{st} & -y_{it} + Y\lambda \geq 0, \\
& \theta x_{it} - X\lambda \geq 0, \\
& N'\lambda = 1 \\
& \lambda \geq 0,
\end{align*}
$$

where $\theta$ is the input technical efficiency (TE) score having a value $0 \leq \theta \leq 1$. If the $\theta$ value is equal to one, indicating the region is on the frontier, the vector $\lambda$ is an $NT \times 1$ vector of weights which defines the linear combination of the peers of the $i$-th region in $t$-th period. Thus, the linear programming problem needs to be solved $NT$ times and a value of $\theta$ is provided for each region in the sample.

Because the VRS DEA is more flexible and envelops the data in a tighter way than the CRS DEA, the VRS TE score is equal to or greater than the CRS or ‘overall’ TE score. The relationship can be used to measure scale efficiency (SE) of the $i$-th region as:

$$
SE_i = \frac{TE_{i,CRS}}{TE_{i,VRS}}
$$

where $SE = 1$ implies scale efficiency or CRS and $SE < 1$ indicates scale inefficiency. However, scale inefficiency can be due to the existence of either increasing or decreasing returns to scale. This may be determined by calculating an additional DEA problem with non-increasing returns to scale (NIRS) imposed. This can be conducted by changing the DEA model in equation (1) by replacing the $N'\lambda = 1$ restriction with $N'\lambda \leq 1$. The NIRS DEA model is specified as:

$$
\begin{align*}
\min_{\theta, \lambda} & \theta, \\
\text{st} & -y_{it} + Y\lambda \geq 0, \\
& \theta x_{it} - X\lambda \geq 0, \\
& N'\lambda \leq 1 \\
& \lambda \geq 0,
\end{align*}
$$

where $\theta$ is the input technical efficiency (TE) score having a value $0 \leq \theta \leq 1$. If the $\theta$ value is equal to one, indicating the region is on the frontier, the vector $\lambda$ is an $NT \times 1$ vector of weights which defines the linear combination of the peers of the $i$-th region in $t$-th period. Thus, the linear programming problem needs to be solved $NT$ times and a value of $\theta$ is provided for each region in the sample.
If the NIRS TE score is unequal to the VRS TE score, it indicates that increasing returns to scale exist for that region. If they are equal, then decreasing returns to scale apply.

Note that efficiency scores in this study are estimated using the computer program, DEAP Version 2.1 described in Coelli (1996).

3 Data

The empirical application in this study considers aggregate data from each of the four regions of Thailand for the period 1972-94. Inputs are classified into six groups: fertiliser, hired labour, capital, operator labour, unpaid family labour and land. The data for quantities of labour are based on annual surveys conducted by the National Statistical Office (1997).

The data for quantities of fertiliser are derived from several occasional publications of the Ministry of Agriculture and Cooperatives. Regional data on fertiliser usage are not available in fourteen of the years. The missing data are extrapolated from the whole Kingdom data.2

Output is aggregated into a single index of agricultural output to avoid any further complexity in modelling. The output index includes the ten major crops. They are rice, kenaf, cotton, cassava, groundnuts, soybeans, mungbeans, sugar cane, corn and sorghum. Livestock is a sector which has been very important for Thai agriculture for a long time. Unfortunately, there are no livestock product data available. Thus, the livestock products are not included in this study. Particular regions have higher livestock output, and thus their low indexes reflect to some extent the problem of undervaluation. The data for quantities and prices of crops are also taken from the Agricultural Statistics of Thailand Crop Year. Note that the actual prices of ten major crops are used. Due to lack of regional price data, the average Whole Kingdom farm price of each crop is used.

Similar to output, capital is aggregated into a single index to avoid any further complexity. The capital index includes the three primary types of capital. They are farm machinery, water pumps and threshers. The figures for quantities of capital are collected from the Agricultural Statistics of Thailand Crop Year published annually by the Ministry of Agriculture and Cooperatives (1996). The imported capital prices are obtained from the Annual Statement of Foreign Trade Statistics (Ministry of Finance 1995).

As mentioned above, pooled data are used for this study. Thus, multilateral comparisons among the four regions are an important issue in this study. However, because of the disadvantage of the Tornqvist index in multilateral comparisons resulting from its failure in the transitivity property, the Caves, Christensen and Diewert (CCD) multilateral index is used to construct any price indexes which involve more than one commodity.3 Following a number

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2 Following Setboonsarng and Evenson (1991), the missing data are acquired by multiplying the national numbers by an average share of numbers of each region to national numbers which are calculated from the data available.

3 See more discussion on index number methods in Krasachat (1997).
of studies (e.g., McKay, Lawrence and Vlastuin, 1980; Wall and Fisher, 1987), implicit quantity indexes are obtained by dividing the current value of each input and output by their corresponding CCD price index.

Land use, in this study, comprises land under rice, field crops, fruit trees and vegetables, grass land, idle land, other land and housing areas. Land use data are available in the Agricultural Statistics of Thailand Crop Year. Eight years of regional land use data are missing. Thus, missing data on land use are extrapolated from the Whole Kingdom data.

4 Empirical results

Technical and scale efficiency scores of Thai agricultural production were calculated using equations (1) and (2) at the sample means of the regional data comprising the two sub-periods of 1972-77 and 1978-94.\(^4\) Table 1 indicates that the mean values of overall technical, scale and pure technical efficiency of all regions are less than one in the two periods and in all regions. The comparatively poor performance in terms of overall technical and scale efficiency is in the Southern Region. This may be due primarily to the differences in soil quality, irrigation and climatic conditions. Most parts of the Southern Region are not irrigated, while large areas in the Central and Northern Regions are irrigated. The mean values of overall technical efficiency range from 0.378 to 0.961 during the period of 1972-77, and they range from 0.214 to 0.962 during the period of 1978-94. The mean values of scale efficiency range from 0.382 to 0.985 during the period of 1972-77 and from 0.270 to 0.988 during the period of 1978-94, while those of pure technical efficiency range from 0.891 to 0.988 during the period of 1972-77 and from 0.781 to 0.973 during the period of 1978-94. These empirical results suggest four important findings. First, there are significant possibilities to increase efficiency levels in Thai agricultural production, especially in the Southern Region. The average overall technical inefficiency for the Whole Kingdom could be reduced by 22 per cent during the first sub-period and by 29 per cent during the latter period by operating at optimal scale. Second, the results also indicate that scale inefficiency for the Whole Kingdom makes a greater contribution to overall inefficiency. Third, because all values of efficiency scores for the Whole Kingdom of the first sub-period are higher than those of the latter sub-period, this implies that the reduced availability of new land (in the latter sub-period) appears to have affected efficiency in Thai agriculture. Finally, the results indicate the diversity of the scores of efficiency among regions. This suggests that the considerable variability of regions in climate, natural resources, irrigation, etc., can have different impacts on efficiency in Thai agricultural production in different regions.

The scale efficiency results are summarised in Figure 1. The DEA results suggest that, of 92 observations, 23 per cent operated at their optimal scale, 23 per cent operated above their

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\(^4\) Patamasiriwat and Suewattana (1990) suggested that the patterns of growth of Thai agriculture can be divided into two periods. As mentioned earlier, before 1978, the relatively high growth rate of agriculture was achieved mainly through the expansion of cultivated areas by clearing the forests. Since 1978, this pattern of growth could no longer continue because Thailand had reached its land frontier. Therefore, new technology inputs such as fertiliser, modern varieties of crops and water have been widely used in this latter period.
optimal scale and 54 per cent operated below their optimal scale. This indicates that the largest increase in overall technical efficiency could be achieved by eliminating the problem of increasing returns to scale, while eliminating the problem of decreasing returns to scale would increase overall technical efficiency to a lesser extent. This implies, from an agricultural policy viewpoint, that if production efficiency of Thai agriculture is to be improved, increasing farm size would be better than decreasing the size of farms.

When comparing the scale efficiency results among regions, the results indicate that, during the 23 years, for 87 per cent or 20 years farms in the Northeastern Region operated above their optimal scale, for 70 per cent or 16 years farms in the Northern Region operated below their optimal scale, for 57 per cent or 13 years farms in the Central Region operated at their optimal scale and for 100 per cent or 23 years farms in the Southern Region operated below their optimal scale. These results indicate evidence of the variation of scale efficiency among regions.

**Temporal Efficiency Changes**

The changes in the efficiencies of Thai agriculture over time are reported in Table 2. They were estimated at the sample means of the periods 1972-77, 1978-83, 1984-89, 1990-94 and 1972-94. The analysis indicates that there is a decline in overall technical, scale and pure technical efficiencies. The reasons for these decreases could be due to the reduced availability of new land since 1978, or may be a consequence of imperfect competition in output and input markets, as a result of intervention by the government in certain markets in Thai agriculture, as mentioned earlier.

Although the analytical results in general indicate that there exist advantages in increasing farm size, it would be better to use them to focus on efficiency improvement at the regional level due to a wide diversity of efficiencies from region to region in Thai agriculture. Jaforullah and Whiteman (1999) indicated that there is a positive relationship between the availability of extension services and farm technical efficiency. An increase in the rate of diffusion of technology and optimal farm management practices encouraged by extension services and programs should increase the technical efficiencies of the inefficient farms in Thailand.

**5 Conclusions and suggestions for further research**

An input-oriented DEA model was used for estimating overall technical, scale and pure technical efficiencies in Thai agriculture.

The results indicate that efficiency scores of some regions were considerably low. This implies that there is significant scope to increase efficiency levels in Thai agriculture. In addition, they also indicate that differences exist in the values of technical efficiency and its components between the periods of 1972-77 and 1978-94 and among regions. This implies that the availabilities of new land and the diversity of climate, natural resources, etc., could have had an influence on technical efficiency in Thai agricultural production.
The results in general indicate advantages in increasing farm size in the Thai agricultural sector. However, extension services should be used to increase the technical efficiencies of the inefficient farms in Thailand. In addition, there exists a decline in overall technical, scale and pure technical efficiencies.

The analysis presented in this paper can be improved in a number of areas. Some areas of further research should be considered. These include: comparing stochastic and DEA frontier analyses; and investigating technical efficiency and productivity changes in Thai agriculture.

References

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Technical efficiency in Thai agricultural


| TABLE 1: MEAN TECHNICAL AND SCALE EFFICIENCY SCORES OF THAI AGRICULTURE |
|-----------------|-----------------|-----------------|-----------------|
| Regions         | Periods         | Overall technical efficiency | Scale efficiency | Pure technical efficiency |
| Northeast       | 1972-77         | 0.836 | 0.937 | 0.891 |
|                 | 1978-94         | 0.735 | 0.779 | 0.947 |
| North           | 1972-77         | 0.961 | 0.978 | 0.982 |
|                 | 1978-94         | 0.912 | 0.981 | 0.929 |
| Central         | 1972-77         | 0.957 | 0.985 | 0.970 |
|                 | 1978-94         | 0.962 | 0.988 | 0.973 |
| South           | 1972-77         | 0.378 | 0.382 | 0.988 |
|                 | 1978-94         | 0.214 | 0.270 | 0.781 |
| Whole Kingdom   | 1972-77         | 0.783 | 0.820 | 0.958 |
|                 | 1978-94         | 0.706 | 0.755 | 0.907 |
TABLE 2: CHANGES IN EFFICIENCIES OF THAI AGRICULTURE

<table>
<thead>
<tr>
<th>Periods</th>
<th>Overall technical efficiency</th>
<th>Scale efficiency</th>
<th>Pure technical efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-77</td>
<td>0.783</td>
<td>0.820</td>
<td>0.958</td>
</tr>
<tr>
<td>1978-83</td>
<td>0.735</td>
<td>0.765</td>
<td>0.949</td>
</tr>
<tr>
<td>1984-89</td>
<td>0.714</td>
<td>0.760</td>
<td>0.907</td>
</tr>
<tr>
<td>1990-94</td>
<td>0.662</td>
<td>0.737</td>
<td>0.858</td>
</tr>
<tr>
<td>1972-94</td>
<td>0.726</td>
<td>0.772</td>
<td>0.921</td>
</tr>
</tbody>
</table>

FIGURE 1: THE SCALE EFFICIENCY OF THAI AGRICULTURE

- Increasing returns to scale: 54%
- Decreasing returns to scale: 23%
- Constant returns to scale: 23%