

Efficiency of Agricultural Production in the Central Region of Thailand

by

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ABSTRACT

A stochastic frontier model incorporating inefficiency effects has been employed to analyse the efficiency of agricultural production in the Central Region of Thailand. The agricultural land area, the number of people employed in the agricultural sector, and the amount of fertilisers used in each province are used to derive the production frontier for the Region, while a dummy variable representing coastal provinces and soil quality index is used to explain inefficiencies of individual provinces. Land area is found to be the most important to agricultural production, labour is found to have zero marginal productivity at current levels of employment, and fertiliser has only a low marginal productivity. Coastal provinces are found to be more efficient than inland provinces, but soil quality does not have significant effects on the efficiency of agricultural production.

1. Introduction

The Thai economy had been enjoying one of the highest growth rates in the world until it was struck by the 1997 financial crisis. Its average annual growth rate for the decade up to 1996 was 9.4%. The crisis, however, brought the economy to a crashing halt and saw it shrink by 10.2% in the following year. The economy is now bouncing back from the crisis, although not completely, and it is growing at around 4.2% per year. The current size of the economy in terms of the nominal GDP is about \$US120b.

Out of the population of 62 million, just over half of them are in the labour force. Although the industrial sector has a larger share of both exports and domestic production, the agricultural sector is still the most important sector in the Thai economy in the sense that more than 48 million people (or 80 percent of the population) live in the rural area and their main source of income is agriculture. The share of the agricultural sector in the Thai GDP is only about 10 percent, but it employs around half of all persons employed in the nation. The agricultural sector used to account for about 50 percent of the total income from exports in the early 1980's, but its share has now reduced to only around 12 percent. The manufacturing sector has overtaken the agricultural sector in both GDP and export shares. During the period since 1990, the Thai agricultural sector has seen a relatively low growth rate of 3~ 5% per year, compared with 10~12% per year for the manufacturing sector.²

Thailand's major agricultural products include rice, rubber, cassava, sugar, and livestock products. These products are produced in about 38 percent of the total land area of 513,115 km². Although its contribution towards the national income is relatively small, a "sustainable development" of the agricultural sector and associated increase in the income of farmers is one of the major targets of the National Plans.³ In this regard, the fact that around half of the labour force accounts only for about 10 percent of GDP

² Data sources: National Statistical Office of Thailand; Labour Force Statistics, the Ministry of Labour and Welfare of Thailand; and the Office of Agricultural Economics, the Ministry of Agricultural and Co-operatives of Thailand.

³ See, for instance, Kuneepong (2001, section 6.1.4).

causes some concern over the efficiency in the use of labour in the agricultural sector. An inefficient use of labour will not only waste the potential to increase national income but also hinder the government's attempt to boost earnings by individual farmers due to a low earnings rate related with low marginal product. For similar reasons, an efficient use of lands would be equally important.⁴

The present paper attempts to shed some light on the efficiency of the Thai agricultural sector using a case study on the agricultural sectors of the individual provinces in the Central/Eastern Region (Central Region, hereafter). It analyses the efficiency in the use of land, labour and fertilisers to produce agricultural products. It also investigates what factors affect the efficiency of agricultural production.

The next section provides economic, geographical and geological information about the Central Region. Section 3 explains the model, and Section 4 describes the data. Section 5 analyses the data and reports the results. Finally, Section 6 draws conclusions.

2. The Central Region

The Central Region, which is also known as the Central Thailand, consists of 26 provinces in an area that occupies roughly one fifth of the total land area of the country; see Figure 1. It lies on the *Chao Praya* river delta that together with regular monsoon rains provides favourable conditions for lowland crops. The clay soil and flat terrain of the delta makes it ideal for traditional rice cultivation.⁵ The most fertile lands in the region are clustered around the middle delta area and the northern part of the region. The western area of the region on the border with Myanmar is mostly mountainous and the remaining areas have soil of a medium or low fertility level; see Figure 2.

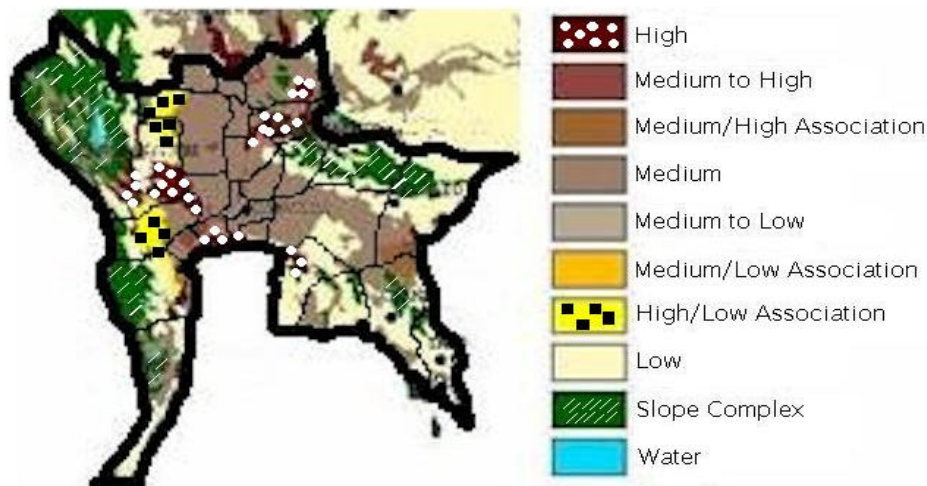
⁴ Historical overviews on the Thai economy and its agricultural sector can be found in Warr (1993) and Siamwalla et al. (1993), respectively.

⁵ Siamwalla and Setboonsarng (1989)

Figure 1: The Central Region of Thailand



Figure 2: Soil Fertility Map



Source: Soil Survey and Classification Division, Land Development Department, Thailand

The region has been the economic and cultural centre of the country due to various reasons. It consists of large plain areas with five main river basins, namely the *Chao Praya*, the *Tha Chin* (or *Mae Klong*), the *Bangpakong*, the *Wae*, and the *Phetchaburi* rivers. These rivers are not only used as the principal means for transportation but also as the main source of water supply for both the agricultural and the industrial sectors. Furthermore, the region has a long coastline embracing the Gulf of Thailand, which provides abundant marine products for the domestic and exports markets. The region also contains Bangkok, the capital city of Thailand, which is the inland and international transport centre.

Figure 3 shows that the Central Region has the largest share of GDP for each of the agricultural, industrial and services sectors. The region's shares for the industrial and the services sectors have increased over time while its share for the agricultural sector has decreased. During the 1990's, the GDP contribution by the Central Region was 1.84 trillion *baht* per year,⁶ which accounted for about two thirds of the national GDP. About 30 percent of the population live in the region.

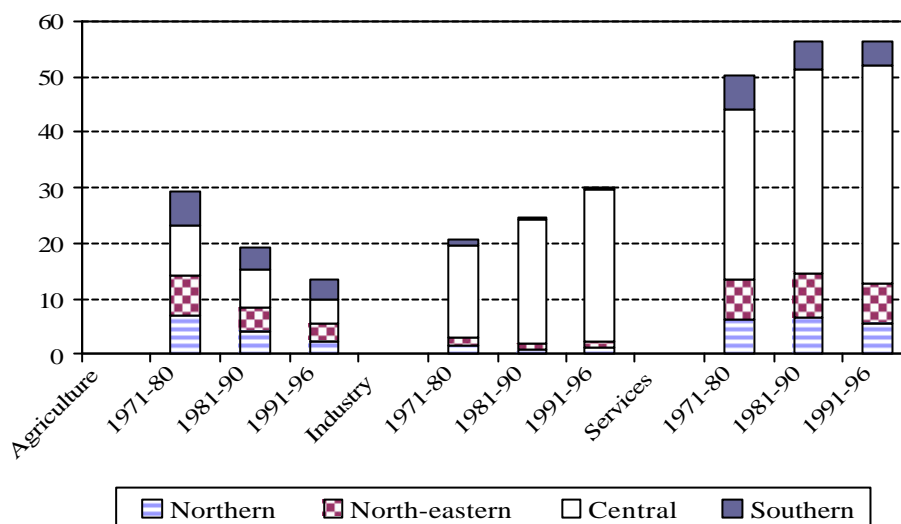
3. Definition of Efficiency and Empirical Model for Its Measurement

The productive *efficiency* of a production unit refers to the ratio of actually-achieved aggregate output to optimal aggregate output it can achieve with the same level of aggregate input, while its *productivity* refers to the ratio of actual aggregate output to aggregate input that is used to produce the output.⁷ A change in productivity can be caused not only by a change in efficiency but also by a change in the production technology and the environment in which the production unit operates (Lovell [1993]).

⁶ The exchange rate for the Thai *baht* is currently around 42.6 *baht*/\$US, but up until the financial crisis the *baht* had been pegged to the US dollar at 25 *baht* per \$US.

⁷ This is an *output-oriented* definition of efficiency, and it can also be defined as *input-oriented*. The present paper will only concentrate on the output-oriented definition of efficiency since it will use that definition for the empirical analysis.

Figure 3: GDP Shares of Each Region by Sector



Source: Office of the National Economic and Social Development Board, Office of the Prime Minister

The efficiency of a production unit can be divided into two components – *technical efficiency* and *allocative efficiency*. Technical efficiency is concerned with how closely the production unit operates to the *frontier* of the production possibility set, while allocative efficiency refers to how close the point on the production frontier, that is projected by linearly extending the vector of actual outputs, is to the point where the relative output price plane is tangent to the production frontier. When the production unit produces only one output, however, a technically efficient point always coincides with the allocative-efficient point. Hence, in such cases, the productive efficiency equals the technical efficiency.⁸

Lovell (1993, p10) considers two different definitions of technical efficiency – one by Koopmans (1951) and the other by Debreu (1951) and Farrell (1957). In fact, as Lovell noted, Koopmans provides a definition of efficiency while Debreu and Farrell provide a

⁸ For the input-oriented definition of efficiency, this will be the case when there is a single input. The present paper analyses the output-oriented efficiencies of the production units that produce a single output, and hence efficiencies only refer to technical efficiencies. (However, if output is measured in value, rather than physical quantity, allocative inefficiency may exist.)

measure of efficiency. According to Koopmans (1951), a production procedure is technically efficient if it cannot increase one output without decreasing another output or increasing at least one input. Debreu (1951) and Farrell (1957) define a measure of efficiency as one divided by the maximum of a scalar value by which the input vector can be proportionately deflated (through division of the input vector by the scalar that is greater than or equal to one) and still produce the same level of output. The output-oriented version of this definition can be stated as the minimum of a scalar value by which the output vector can be proportionately inflated (through division of the output vector by the scalar that is less than or equal to one) to an output level that is still feasible with given inputs.

The two definitions will be identical if the production frontier is strictly concave towards the origin, that is, when there is no part on the frontier that is parallel to an output axis (or input axis for the input-oriented definition). A production unit is efficient by the Debreu and Farrell's definition as long as it operates on the production frontier, but not necessarily by the Koopmans' definition. If a production unit operated on a part of the production frontier that is parallel to an output axis, it would be able to increase the output associated with the axis without decreasing any other output. Hence, the production unit is not efficient in the Koopmans' definition although it is so in the Debreu and Farrell's definition. Lovell (1993, pp13-14) and Coelli et al. (1998, p176) note that this difference between the two definitions is not so important. In particular, when an econometric approach is adopted, the restriction imposed by the chosen production function usually assumes such odd cases away.⁹

There are two main approaches to estimating production frontiers and measuring efficiency scores. One is based on a parametric specification of an econometric model that allows for stochastic disturbances (*stochastic frontier approach*) and the other uses a nonparametric mathematical programming technique to envelop data set (*data*

⁹ The econometric approach is explained below.

envelopment analysis: DEA).¹⁰ The present paper uses the stochastic frontier approach based on a production function to estimate the frontier of the production possibility set, and then calculates output-oriented, Debreu-Farrell type, efficiency scores for individual production units. For agricultural production, especially when there exists excess supply of labour, output-oriented measures of efficiency would be more appropriate than input-oriented measures because the quantities of most inputs are exogenously given and beyond the control of farmers. Unlike the DEA approach which is deterministic in the sense that it assumes that all deviations from the frontier are only due to inefficiency, the stochastic frontier approach allows for random disturbances, such as weather conditions, the effects of pest and diseases, and measurement errors in the output variables.¹¹ As Coelli et al. (1998, p219) observes, stochastic frontiers are more likely to be appropriate for agricultural applications, especially in developing countries, because of these reasons.

For the empirical analysis in the present paper, each province of the Central Region of Thailand is assumed to be a production unit that produces agricultural output (Y) using land, labour and fertiliser as inputs. The production technology is assumed to be represented by a Cobb-Douglas production function. Furthermore, two *environmental variables*, a dummy variable for coastal provinces (COAST) and an index for the quality of soil (SQI), are assumed to have effects on the mean inefficiency of each province.

The *stochastic frontier model* then can be specified as follows:

$$(1) \quad \ln Y_i = X_i' \beta + \varepsilon_i$$

and

$$X_i = [1 \quad \ln \text{LAND}_i \quad \ln \text{LABOUR}_i \quad \ln \text{FERTILISER}_i]'$$

$$\beta = [\beta_1 \quad \beta_2 \quad \beta_3 \quad \beta_4]'$$

$$\varepsilon_i = v_i - u_i \quad \text{for } i = 1, \dots, n$$

¹⁰ More detailed discussions on these two alternative approaches can be found in Lovell (1993) for an overview, Greene (1993) for the stochastic frontier approach, and Ali and Seiford (1993) for the DEA approach.

where Y_i is the agricultural output, $LAND_i$, $LABOUR_i$, and $FERTILISER_i$ are inputs for province i . The slope coefficient β_2 , β_3 and β_4 are input elasticities, and $\ln(\cdot)$ is the natural logarithmic function. The v_i 's are random errors that are independently and identically distributed as $N(0, \sigma_v^2)$, and the u_i 's are non-negative values representing inefficiency of the production procedure used by province i . The inefficiency measures, u_i 's, are assumed to be independent from v_i 's and to be independently (but not identically) distributed as

$$(2) \quad u_i \sim \frac{1}{1 - \Phi(-m_i / \sigma_u)} N(m_i, \sigma_u^2) \quad \text{for } u_i \geq 0,$$

that is, truncated (at zero) normal distribution where $\Phi(\cdot)$ is the cumulative distribution function (cdf) of the standardised normal distribution, and the mean, m_i 's, are determined by

$$(3) \quad m_i = Z_i' \delta$$

and

$$Z_i = [1 \text{ COAST}_i \text{ SQI}_i]'$$

$$\delta = [\delta_1 \ \delta_2 \ \delta_3]'$$

$\text{COAST}_i = 1$ if i is a coastal province and $= 0$ otherwise, and

$\text{SQI}_i =$ soil quality index for province i .

While equation (1) represents the production frontier, equation (3) describes how the mean inefficiency for each province is determined (the *inefficiency effects model*). The right-hand-side variables of the inefficiency effects model are out of control of farmers (*environmental variables*).

¹¹ Some attempts have been made to incorporate stochastic features into the DEA analysis; see Lovell (1993, pp34-35) for a brief overview of them.

Given the above production frontier and inefficiency effects models, the (gross) efficiency score can be defined as:

$$(4) \quad E[Y_i|X_i \text{ and } Z_i, u_i \geq 0] / E[Y_i|X_i \text{ and } Z_i, u_i = 0]$$

$$= E[\exp(-u_i)].$$

Note that the above value lies between zero and one for $u_i \geq 0$, with one being the highest efficiency. The formula that will be used to predict these values in the present analysis is given by Battese and Coelli (1993) and reproduced in Coelli et al. (1999, p255):

$$(5) \quad TE_i = E[\exp(-u_i|\varepsilon_i)]$$

$$= \left\{ \exp\left[-\mu_i + \frac{1}{2}\sigma_*^2\right] \right\} \cdot \left\{ \Phi\left[\frac{\mu_i}{\sigma_*} - \sigma_*\right] / \Phi\left[\frac{\mu_i}{\sigma_*}\right] \right\}$$

and

$$(6) \quad \mu_i = (1-\gamma) \cdot (Z_i' \delta) - \gamma \varepsilon_i,$$

$$\sigma_*^2 = \gamma(1-\gamma)\sigma^2,$$

$$\sigma^2 = \sigma_u^2 + \sigma_v^2, \text{ and}$$

$$\gamma = \sigma_u^2 / \sigma^2.$$

As Coelli et al. (1999, p256) point out, the efficiency score defined by (4)-(6) is a gross measure in that it includes the effects of environmental variables. A measure net of the environmental effects can be obtained by substituting the $Z_i' \delta$ in (6) with $\min_i[Z_i' \delta]$ so that efficiency scores are computed under the assumption that all production units have identical (the most favourable) environmental conditions. The difference between the gross efficiency score and the net efficiency score can then be interpreted as the efficiency component that can be attributable to the environmental influences. The net efficiency score can then be interpreted as a measure of the skills of farmers.

4. The Data

The data set contains 24 cross-sectional observations in year 1998. Out of the 26 provinces in the Central Region, *Prachinburi* and *Sa Kaeo* in the north-eastern area are combined as one province (*Prachinburi*) since they had been a single province until 1996; and, *Singburi* which is located in the middle-north area is not included as the data for soil quality is unavailable. Each province is regarded as a single production unit producing an aggregate agricultural output (Y) using LAND, LABOUR and FERTILISER.

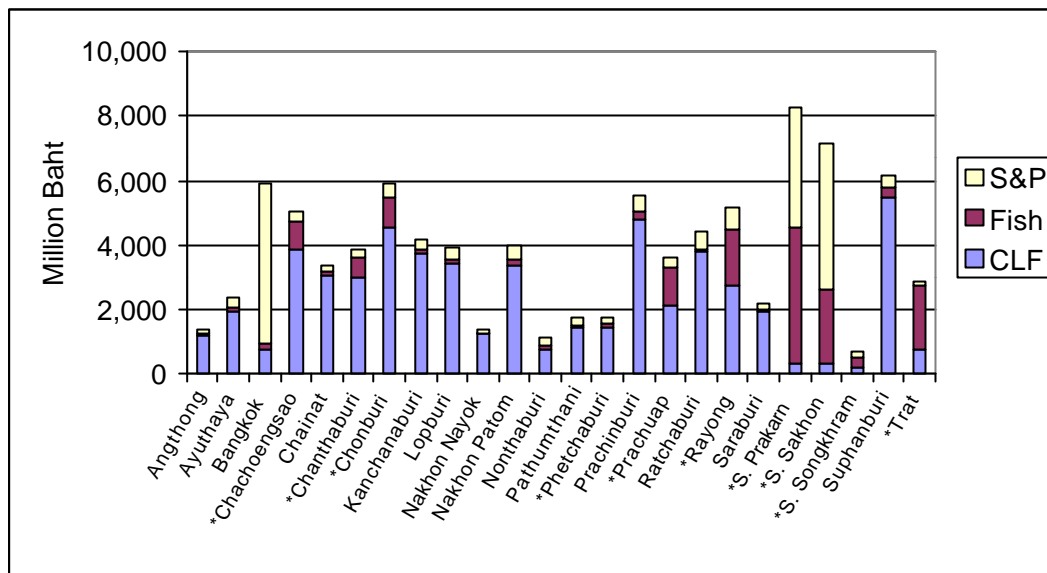
Agricultural outputs are measured as the 1988-price value in million *baht*.¹² They only include crops, livestock and forestry products (CLF), and do not include fishery products (FISH), processed agricultural products, and income from agricultural services (S&P). In 1998, average Gross Provincial Product (GPP) in the Central Region was 79,866 million *baht*, and average agricultural product was 3,847 million *baht*. No province's agricultural product accounted for more than 40% of GPP (data not shown). The size of agricultural product for each province and its breakdown into the CLF, FISH and S&P components are shown in Figure 4. *Samut Prakan* has the largest agricultural product in the region, but most of the income is from FISH and S&P with only a fraction from CLF. The province that has the largest CLF component in the region is *Suphanburi* with CLF of 5,500 million *baht*.

The LABOUR includes people employed in the non-fishery agricultural sector in each province and measured in thousand persons.¹³ The LAND only includes farm-hold land areas classified as "Paddy Land", "Under Field Crops", "Under Fruit Trees and Tree Crops", "Under Vegetables and Flowers", "Livestock Farm Area", and it excludes those used for housing and other purposes, and idle land. The LAND is measured in thousand *rais* (1 *rai* = 0.16 hectares). The FERTILISER is the amount of fertilisers distributed to each province during the year. Its unit of measurement is metric tons.

¹² As Coelli et al. (1998, p213) and Coelli and Battese (1996, p107) point out, using the value, rather than quantity, of output may cause the inefficiency effects to be influenced by allocative inefficiency in addition to the technical efficiency.

¹³ Separate data for the processed agricultural products and agricultural services sectors are not available.

Figure 4: Agricultural Products by Province



S&P = Agricultural Services and Processed Agricultural Products
 Fish = Fishery
 CLF = Crops, Livestock, and Forestry
 The provinces marked with an asterisk (*) are coastal provinces.

Out of the 24 provinces included in the analysis, 10 provinces are coastal provinces.¹⁴ In Figure 4, those provinces are marked with an asterisk (*). It can be seen that for the coastal provinces fishery product occupies a relatively large proportion of agricultural product. Inland provinces also have a positive share of fishery product. That part of income is generated from river fishing and fish farming. It can be envisaged that the classification between people employed in the FISH sector and those in the CLF sector would not be clear-cut when a large proportion of fishery product is from non-professional fishermen. Many of those classified as a FISH employee in a coastal region may also work as a CLF employee, and vice versa. To capture this effect, a dummy variable (COAST) is generated so that it takes value one for a coastal province and value zero for an inland province. It is assumed that this dummy has effects not only on the inefficiency effects model but also on the labour elasticity in the production frontier function. The observations on these variables are shown in Table 1.

Table 1: Data Set (1998)⁺

PROVINCE	COAST [#]	Y	LAND [§]	LAB. ^{&}	FERT. [@]	SQI
	dummy	M baht	'000 rais	'000 persons	tonnes	index
Angthong	0	1,196.5	459.665	44.729	999.50	0.4
Ayuthaya	0	1,923.0	1,038.712	75.470	5,154.75	0.8
Bangkok	0	771.6	138.943	47.110	492.00	0.8
Chachoengsao	1	3,861.3	1,628.432	117.592	4,582.24	1.0
Chainat	0	3,063.8	1,108.413	109.613	8,731.10	0.2
Chanthaburi	1	3,020.2	1,324.580	113.578	1,993.90	0.4
Chonburi	1	4,577.5	1,166.092	78.004	938.45	0.6
Kanchanaburi	0	3,767.1	1,886.516	220.432	1,176.25	0.4
Lopburi	0	3,423.4	2,155.336	210.794	6,509.65	0.8
Nakhon Nayok	0	1,243.7	475.343	41.478	2,215.55	0.6
Nakhon Patom	0	3,380.6	602.368	109.824	1,171.75	0.6
Nonthaburi	0	767.5	179.342	16.182	195.00	0.6
Pathumthani	0	1,433.5	511.367	47.909	1,762.50	0.8
Phetchaburi	1	1,482.0	587.034	80.241	5,525.90	0.6
Prachinburi	0	4,827.3	3,165.509	245.349	6,863.70	0.8
Prachuap	1	2,148.5	1,091.364	101.029	290.40	0.8
Ratchaburi	0	3,779.4	1,060.498	162.641	4,052.85	0.8
Rayong	1	2,740.1	1,230.286	97.684	1,018.10	0.4
Saraburi	0	1,976.9	899.748	60.598	2,550.05	0.6
Samut Prakarn	1	320.0	97.429	3.385	0.00*	0.8
Samut Sakhon	1	347.2	89.955	39.815	0.00	0.6
Samut Songkhram	1	232.5	76.899	26.992	0.00	0.6
Suphanburi	0	5,495.9	1,977.132	227.887	3,372.25	1.0
Trat	1	796.2	448.320	35.870	0.00	1.0

+ : Sources are various publications by the National Accounts Division (Office of National Economic and Social Development Board), the Office of Agricultural Economics (Ministry of Agriculture and Cooperatives), and the National Statistical Office (Office of the Prime Minister). The data needed for the soil quality index are from the Soil and Water Analysis Group (Ministry of Agriculture and Cooperatives).

: Bangkok is not classified as a coastal province for the too short coastline.

§ : In excluding land areas used for housing, idle land, and others, from farm holding land, the data for land for housing, idle land, and others are those for 1999.

& : The third-round observations in 1998. The labour data for *Trat* is for 1999.

@ : The amount distributed to each province during the year by the Agricultural Cooperatives for Marketing and Thai Agribusiness Ltd.

* : The values marked as zero are replaced with one so that the log value becomes zero.

In addition to the dummy variable representing coastal provinces, the quality of soil is believed to have effects on the inefficiency of agricultural production. Five soil attributes, namely acidity (pH), organic matter (OM), phosphorus (P), potassium (K), and electrical conductivity (EC), have been combined to construct an index to represent the soil quality

¹⁴ *Bangkok* has coastline, but it is not classified as a coastal province for the purpose of the current analysis as the coastline is too short.

of each province. The data used for this purpose are collected in 1998 by the Soil and Water Analysis Group in the Ministry of Agriculture and Cooperatives of Thailand.

The pH scale is a measure of the concentration level of hydrogen ions (H^+) in aqueous solution. The scale ranges from 1.0 (highly acidic) to 14.0 (highly alkaline). The neutral level is pH 7.0. A suitable level of pH for agricultural cultivation is 6.0–7.0. Excess use of commercial fertilisers, especially NH_4N based ones, and increasing rainfall (with pH being lower than 5.7) increases soil acidity; see Tisdale et al. (1993, pp370-1).

Soil organic matter (OM) is the fraction of soil that is composed of anything that once lived. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Well-decomposed organic matter forms humus, a dark brown, porous, spongy material that has pleasant, earthy smell. Organic matter is an essential component of soil not only for plants but also for soil organisms as it stores and provides vital nutrients and energy source. Continuous cultivation without returns of adequate crop residues leads to a decline in the humus content of soil; see Tisdale et al. (1993, p127). In most types of soil, organic matter accounts for less than 5 percent in volume. If the proportion of organic matter in the volume of soil is more than 2 percent, the soil is suitable for plant growth.

Phosphorous (P) exists in soil in both organic form (from natural mineral or organic matter) and inorganic form (from chemical fertilisers). Although phosphorous helps plants' growth, plants' speed to absorb available phosphorous is very slow and limited. Plants can only absorb 15-20 percent of available phosphorous, and fixation occurs to the remaining phosphorous so that it becomes unavailable to plants. The speed of fixation depends on the pH level and other attributes of soil. A suitable level of available phosphorous for plant growth is 13-25 ppm (parts per million); see Tisdale et al. (1993, p205).

Potassium (K) is soft alkali metal that is highly reactive. Potassium is an essential element for living organisms and it helps plants produce and transport sugar and

carbohydrate. It also helps plants' respiration and photosynthesis. If available potassium is greater than 80 ppm, the soil is suitable for plant growth. Most provinces in the Central Region have a potassium level greater than 80 ppm (data not shown).

Soil electrical conductivity (EC) does not have direct effects on crop growth or yield, but it is an indicator that shows the levels of attributes that affect crop growth, especially soil salinity. The higher soil EC, the higher the salinity in the soil. If EC is greater than 2 dS/m (deci-siemens per meter = one hundredth of milli-siemens [mS/m]), growth of sensitive plants, such as corn and sunflower, may be restricted. In the Central Region of Thailand, all provinces except *Samut Sakhon* have EC level lower than or equal to 1.0.

Based on the above discussion, the soil quality index (SQI) has been constructed by the following method.¹⁵

$$(7) \quad SQI_i = (DPH_i + DOM_i + DP_i + DK_i + DEC_i)/5$$

where

$$DPH_i = 1 \text{ if } pH_i \geq 6.5 \text{ and } = 0 \text{ otherwise,}^{16}$$

$$DOM_i = 1 \text{ if } OM_i \geq 2 \text{ and } = 0 \text{ otherwise,}$$

$$DP_i = 1 \text{ if } P_i \geq 20 \text{ and } = 0 \text{ otherwise,}$$

$$DK_i = 1 \text{ if } K_i \geq 80 \text{ and } = 0 \text{ otherwise, and}$$

$$DEC_i = 1 \text{ if } EC_i \leq 2 \text{ and } = 0 \text{ otherwise.}$$

So, SQI is bounded between 0 and 1, and the higher the SQI the better the quality of soil. The last column of Table 1 shows the soil quality indices constructed using (7).

¹⁵ Similar methods are widely used for soil quality indices; see, for example, Brejda and Moorman (2001, p536).

¹⁶ In no province, pH is greater than 7.5, and thus high alkaline level is not a concern.

5. Estimation and Analysis

Stochastic frontier production functions, similar to the one given by (1), were first estimated independently by Aigner, Lovell and Schmidt (1977), Battese and Corra (1977), and Meeusen and van den Broeck (1977) by adding the stochastic term, v_i , to the deterministic frontier model that was introduced earlier by Aigner and Chu (1968). A single-stage ML estimation of the both stochastic frontier model and inefficiency effects model were implemented by Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991). The computer program FRONTIER (version 4.1) by Coelli (1996) employs the above single-stage ML estimation method, and the program has been used for the estimations in the present paper.

The production frontier model, (1), is modified to include the dummy variable for coastal provinces (COAST).

$$(8) \quad \ln Y_i = \beta_1 + \beta_2 \ln \text{LAND}_i + (\beta_{30} + \beta_{31} \text{COAST}_i) \ln \text{LABOUR}_i + \beta_4 \ln \text{FERTILISER}_i + \varepsilon_i$$

The estimation results are reported in Table 2. The estimated coefficients have the expected signs in both the production frontier and the inefficiency effects model. The elasticity of output with respect to each of the three inputs has the expected positive sign, and higher soil quality reduces inefficiency given inputs. The effect of being a coastal province seems in accordance with our earlier expectation. The labour elasticity for coastal provinces is lower than that for inland provinces on average. This may reflect that some of the people in a coastal province who are classified as an employee in the CLF sector do not work full time in that sector, but divide their working time between CLF works and FISH works. However, this effect is insignificant both in its size and in the statistical sense.

Table 2: ML Estimates and Efficiency Scores%

Coefficient	Variable	Estimate	t-ratio	Province	Efficiency Score
b₁	Constant	2.969	8.730	Angthong	0.825
b₂	lnLAND	0.561	5.699	Ayuthaya	0.823
b₃₀	lnLABOUR	0.135	1.342	Bangkok	0.853
b₃₁	lnLABOUR*COAST	-0.033	-0.727	Chachoengsao*	0.992
b₄	lnFERTILISER	0.072	2.421	Chainat	0.832
				Chanthaburi*	0.992
d₁	Constant	0.194	1.632	Chonburi*	1.000
d₂	COAST	-0.740	-2.538	Kanchanaburi	0.834
d₃	SQI	-0.031	-0.131	Lopburi	0.824
s²		0.060	3.040	Nakhon Nayok	0.828
g		0.083	2.867	Nakhon Patom	0.879
LLF		1.64557		Nonthaburi	0.853
LLF(OLS)		0.07305		Pathumthani	0.840
				Phetchaburi*	0.991
				Prachinburi	0.831
LLF(b₃₁=0)		0.08893		Prachuap*	0.992
LLF(CRS)		-5.41316		Ratchaburi	0.862
				Rayong*	0.992
				Saraburi	0.831
				Samut Prakarn*	0.992
				Samut Sakhon*	0.992
				Samut Songkhram*	0.991
				Suphanburi	0.866
				Trat*	0.992
				Average	0.904

#: The computer program FRONTIER (version 4.1) by Coelli (1996) has been used.

*: Coastal provinces.

In fact, the effect of labour on agricultural output in general is statistically insignificant. This is consistent with the proposition that the use of labour in the agricultural sector is inefficient. Agricultural output is responsive only to the land area and the amount of fertilisers used, but not to the number of persons who work in the sector. This implies that

a significant number of people working in the CLF sector could be diverted to other sectors without affecting CLF output.

Land is the most important factor in the production of CLF products. A one percent increase in the land area will lead to a 0.561 percent increase in the CLF output on average. And this effect is highly significant in the statistical sense. It contrasts with the meagre effect of a change in the amount of fertiliser and the statistically insignificant effect of a change in labour. A one percent increase in fertiliser leads only to a 0.072 percent increase in CLF output on average. As it is known that excess use of commercial fertilisers can damage the quality of soil and thus reduce potential future output, the above finding implies that farmers should consider more carefully, when they decide to increase the use of fertilisers, whether it is worthwhile to risk potentially-more-costly soil damage for such a modest return.

The environmental factor that a province has coastline significantly reduces inefficiency in agricultural production. Compared with the inland provinces, the coastal provinces' inefficiency component in the error term (u) has a mean value (of the untruncated distribution) that is lower by 0.74. However, this should be interpreted with care because the two groups of provinces have different production frontiers. The inefficiencies for inland provinces are measured against one frontier while those for coastal provinces are measured against another frontier. The difference occurs as the difference in labour productivity is allowed for. So, the above interpretation is valid when the fact that the two groups have different labour productivity is taken into account.

The sign of the estimated coefficient for soil quality is correctly negative, but it is statistically insignificant. The insignificance might be due to the relatively small variation in the soil quality index between provinces. Sample standard deviation of SQI is 0.21, and two thirds of the provinces have an SQI within 0.6~0.8; see Table 1. Furthermore, as noted earlier, most provinces have a suitable level of potassium and electrical conductivity.

The last column of Table 2 reports the efficiency scores computed by the computer program FRONTIER Version 4.1 which uses the formula given by (5). The scores are consistent with the findings from the coefficient estimates for the inefficiency effects model. Namely, all coastal provinces are highly efficient when the low labour productivity is taken into account. *Chonburi*, which is a coastal province, has the highest efficiency score, 1, while *Ayuthaya* is the least efficient. However, even the least-efficient *Ayuthaya* is not much behind the most efficient province. Its efficiency score is 0.825 and it is lower than other inland provinces' only by a fraction.

Some hypotheses of interest are tested. Firstly, the hypothesis that inefficiency effects are not present ($H_0: \gamma = \delta_1 = \delta_2 = \delta_3 = 0$) is tested against the alternative ($H_1: \gamma > 0$ and/or at least one of the three δ_i 's $\neq 0$), using a likelihood ratio (LR) test. The test statistic is given by

$$(9) \quad LR = -2 [\ln L(H_0) - \ln L(H_1)]$$

which has a "mixed" Chi-square distribution with 4 degrees of freedom under the null hypothesis (because γ is non-negative). The $L(H_0)$ and $L(H_1)$ denotes the values of the likelihood function for the restricted model and the unrestricted model, respectively. When there is no inefficiency effect ($u = 0$ for all i), then the production frontier is a simple mean response function and it can be estimated using the OLS method. The log-likelihood value from the OLS estimation is 0.07305 while the log-likelihood value from the ML estimation of the full model is 1.64557; see Table 2. So, the observed value for the test statistic is 3.145. The critical value is obtained from Table 1 of Kodde and Palm (1986). In the present case, there is only one inequality and hence there is no distinction between the upper bound and the lower bound. The 5 percent critical value for the mixed Chi-square distribution with 4 degrees of freedom is 8.761 which is greater than the observed statistic. So, the null hypothesis that no inefficiency effects exist cannot be rejected at 5%. This implies that all deviations from the production frontier are mostly due to random factors (such as the effects of weather, pest, diseases, or measurement errors) rather than inefficiencies. Hence, all provinces' agricultural productions are

largely efficient, and the production frontier given by (1) is simply a mean-response production function. Not surprisingly, the OLS coefficients (data not reported) are not much different from the ML estimates reported in Table 2.

Another hypothesis of interest is whether the production frontier exhibits the property of constant returns to scale (CRS). This hypothesis is tested on the model with the restriction that $\beta_{31} = 0$ imposed (i.e., the model given by (1) and (3) rather than (8) and (3)). The null hypothesis of CRS can then be stated as $H_0: \beta_2 + \beta_3 + \beta_4 = 1$. So, the restricted model is given by

$$(10) \quad \ln(Y_i/\text{FERTILISER}_i) = \beta_1 + \beta_2 \ln(\text{LAND}_i/\text{FERTILISER}_i) \\ + \beta_3 \ln(\text{LABOUR}_i/\text{FERTILISER}_i) + \varepsilon_i.$$

The log-likelihood value for the unrestricted and the restricted models are 0.08893 and -5.41316 , respectively. Hence, the observed value of the test statistic is 11.00, which should be compared with a critical value for Chi-square with one degree of freedom. The 1 percent critical value is 6.63. So, the null hypothesis of CRS is strongly rejected. The sum of the estimates for β_2 , β_3 and β_4 in the unrestricted model is roughly 0.75 (data not shown). So, it implies that the agricultural production frontier exhibits decreasing returns to scale.

6. Conclusions

Efficiencies of the procedures used for the production of crops, livestock and forest products in the provinces of the Central Region of Thailand have been analysed. The stochastic frontier approach with an inefficiency effects model incorporated has been used for the analysis. The results obtained by the one-stage ML estimation of the model show that output is irresponsive to changes in labour input. This most likely implies that labour in the agricultural sector is oversupplied and it is not used efficiently. It also has an implication for average earnings rates for farmers. In such circumstances, farmers will have to work at a very low rate of earnings. As changes in labour input does not have

significant effects on agricultural output, government policies directed towards diverting labour to other sectors would not induce an immediate reduction in agricultural output, hence without hindering its policy for self sufficiency of food.

The effect of using fertilisers on agricultural output is found to be only minor. As excessive use of commercial fertilisers is known to damage soil, the result implies that the government may have to reconsider its policies encouraging the use of commercial fertilisers, such as price subsidies for fertilisers, because it may not be worthwhile to risk soil damage for such minor returns.

The LR test on the existence of inefficiency effects implies that there are no inefficiency effects and hence an OLS estimation of the production frontier would not lead to a bias in the estimates. This also implies that most provinces are operating around the production frontier without significant differences in their efficiencies, and hence the estimated frontier is a mean-response function. Not much weight should be given to this result though as the sample size is relatively small. The efficiency scores are a measure of performance relative to the best performers in the sample. The result simply shows that the provinces' efficiencies are not much different from each other within a group of 24. It would be interesting if the performance of these provinces were compared with the performance of the provinces in other regions. If the hypothesis of no inefficiency effects were true for a national data, then the only way to increase agricultural output would be through a technology improvement (such as introduction of new farming skill or new seed/breed) because inefficiency is not a reason for low output, agricultural land area is largely fixed, and the elasticities of the other inputs are low.

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