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Measurement and Comparison of Rice Production Efficiency in Thailand and India: An Efficient Frontier Approach

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Abstract : The main objective of this research is to measure production frontiers and technical efficiencies of a whole rice production in Thailand and India which are two of the major exporters in the global rice market. In addition, we attempt to investigate the development of technical efficiencies of rice productions in both countries between 2002 to 2014. Due to the limitation of the available time-series, an efficient frontier model (EFM) has been chosen because it is more efficient than the traditional stochastic frontier model (TSFM) in the case of small size of data both theoretically and practically. The results show that the EFM gives us better performances than the TSFM. Almost all inputs have positive relations with rice outputs as we expected. The considered factors of seed and pesticide have negative effects on Thailand and India's rice outputs. Concerning the technical efficiency development, the experiment reveals that the technical efficiencies in utilizing resources of Thailand and India are in high level. Furthermore, the technical efficient score of India increased from 0.87 in 2002 to 0.98 in 2014 whereas that of Thailand decreased from 0.96 to 0.94 during the same period. Therefore, we conclude that India had more developments in technical efficiencies than Thailand. In a conclusion, we have policy recommendations of (1) increase more research on the usage of the inputs and the vocational trainings than those on the production scale in

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order to enhance the efficiencies in the production of rice, (2) provide the farmers on the financial access along with the financial education, and (3) implement zoning on the country-wide agricultures.

Keywords : entropy; support point; prior information; technical efficiency.
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1 Introduction

Thailand and India are the biggest and the second biggest exporters in the world. The challenges for Thai rice come from domestic and external factors. For more than two decades, domestic agricultural policies in Thailand have aimed at supporting rice price and farm income. The policies have not concentrated on enhancing rice productivity. Accordingly, Thai farmers have attempted to increase their rice outputs by using more inputs such as seed, fertilizer, and pesticide. Planted areas have dramatically been expanded with an increase of rice cultivation in the once forest covered areas. It is because no matter how much rice the farmers produce, the Thai government always subsidizes them with a large budget. Consequently, domestic rice output has increased (Figure 1) and so has production cost but low productivity. Figure 2(b) demonstrates that the yield of Thai rice has been lower than those of other major rice exporters for a long time.

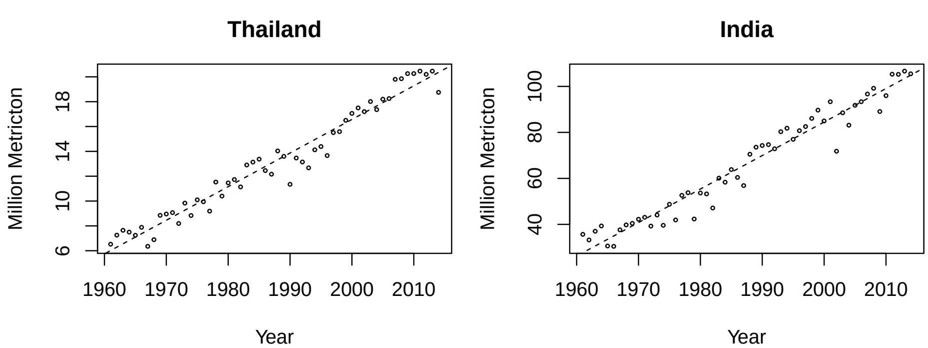
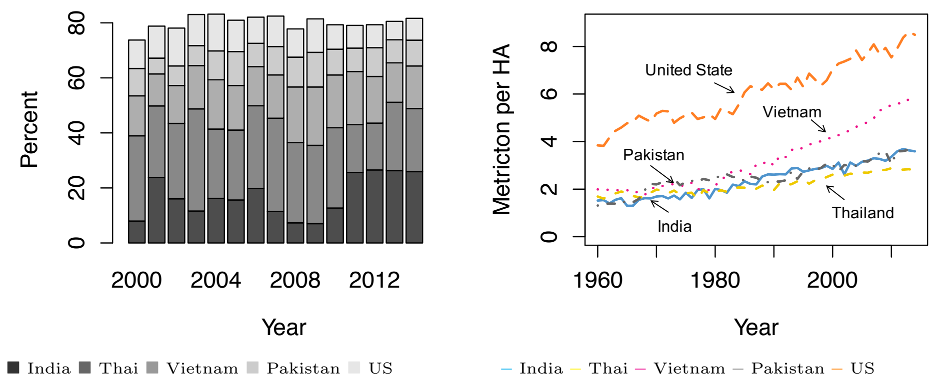


Figure 1: Thailand and India rice productions from 1960 to 2014. Source: U.S. Department of Agriculture.

Likewise, India has faced this phenomenon–slowing growth in rice yield similar to Thailand. Although India has become the largest rice exporter in the international market since India canceled ban on non-basmati rice export in 2012 (Figure 2(a)). India has exported more than ten million metric tons a year or around one-third of the total trade. However, the rice yield of India still stays at the low level (Figure 2(b)). Thus, measuring the rice production efficiency is necessary and



(a) Market share (b) Yield

Figure 2: Market share of top five exporters in the global rice market and rice yield. Source: U.S. Department of Agriculture.

profitable for farmers and policymakers of both countries to enhance their productions because, according to economic theory, the benefits of improved production efficiency are the increases in farm income, competitiveness, trade performance, including the function as key driver of sustainable economic growth in the long run.

In recent year, there have a few studies which focus on the measurement of technical efficiency in Thailand and India's rice production. However, most of previous studies used cross section data to analyze technical efficiency such as Fuwa et al. [1], Krasachat [2], Rahman et al. [3], and Liu et al. [4]. Hence, their results could not show the performance of production efficiency in each year. The most popular approach for measuring technical efficiency is the stochastic frontier analysis. The researchers usually employ standard maximum likelihood estimation (MLE) and ordinary least square (OLS) to estimate this model. For instance, Rahman et al. [5] applied MLE to estimate the efficiency of rice farmers in Bangladesh; Hossain et al. [6] compared stochastic frontier approach with data envelopment analysis based on MLE to investigate total factor productivity and efficiency scores of Bangladesh rice; and Audu et al. [7] also used this method to analyze the cost efficiency in small scale cassava production in Nigeria. Recently, Liu et al. [4] investigated a Zero Inefficiency Stochastic Frontier Model (ZISFM) to estimate technical efficient of inefficient farmers in Thai rice farms. Nevertheless, OLS and MLE need big sample sizes and have very strong assumptions, especially specified distribution of error term. Golan et al. [8] established the Generalized Maximum Entropy (GME) to estimate with limited data; and the stochastic frontier production function was called Efficiency Frontier Model (EFM). The good aspects for this estimation have been discussed in a great deal of papers such as Zhang et al. [9], Golan et al. [10], Campbell et al [11], Tonin et al. [12], and Macedo et al.

[13]. Camplell et al. [11] stated that we could estimate a frontier that is stochastic by not requiring an ad hoc assumption about the distribution of the efficient component by using GME. Macedo et al. [13] suggested that the GME could be employed in both linear and nonlinear regression models, especially in models with small sample sizes and in models which have the number of parameters to be estimated more than the number of observations available. Zhang et al. [9] studied estimating crop-specific production technologies in Chinese agriculture and found that the GME had better performance relative to other methods. Besides, this estimation can reduce the effect by outlying observations due to the weighting between signal and noise in the objective function. It is also a robust estimator when noise is not normally distributed. Furthermore, this estimation enables the researchers to easily define prior information on parameters [12]. In 1979, Brad Efron invented the bootstrap to set confidence intervals on parameters. The main benefits of the bootstrap are that it allows researchers to set confidence interval on parameters without strong assumptions; and it enables researchers attach limits to very ordinary statistics specially a mean, where central limit theorem can not be assumed to be effective [14]. Therefore, it is of practical interest to employ GME estimation with bootstrap confidence interval for measuring rice production efficiency of Thailand and India.

The objectives of this study are to 1) measure production frontiers and technical efficiency of Thailand and India's rice production by using the generalized maximum entropy estimation, 2) compare the development of technical efficiency of rice production in both countries. The contribution of this research is to show how to use the such approach so that they can obtain more reliable conclusion for their data when compared to the traditional stochastic frontier model (TSFM), and provide information for uses by policymakers, producers, investors, traders, including stakeholders in the rice related industries to allocate investment resources for ensuring the efficient rice production.

The paper is structured as follows: Section 2 contains the material and methodology. Section 3 describes the empirical results. Policy recommendation and conclusion are provided in Section 4 and Section 5, respectively.

2 Material and Methodology

2.1 Material

Dataset in this study was obtained from the FAOSTAT database of the Statistics Division of the Food and Agriculture Organization (FAO) of the United Nations, United State Department of Agriculture (USDA), and the World Bank on the period of years 2002–2014. The five important input variables of seed, fertilizer, pesticide, capital, and land were taken into account in measuring the production frontiers and technical efficiencies. Table 1 presents the descriptive statistics of data of both Thailand and India. We have found that the most important input factors in rice productions of both countries are the pesticides and capitals. These factors are more fluctuate than the others, whereas the usages of the seeds in both countries seem to be stable. The results imply that the farmers intensively use the pesticides to accelerate their outputs. India still has a capacity gap of agricultural areas for expanding the rice production while Thailand's rice producing space are almost fully utilized.

Table 1: Descriptive basic statistics of variables, 2002-2014

Variable	Unit	Thailand				India			
		Mean	Min	Max	Std	Mean	Min	Max	Std
Rice	Mill. MT	19.2	17.2	20.5	1.2	94.8	71.8	106.6	10.2
Seed	Mill. MT	0.8	0.6	1.1	0.1	3.3	3.1	3.4	0.1
Fertilizer	Thsd. MT	1.5	1.1	1.9	0.3	6.3	4.1	7.9	1.2
Pesticide	Thsd. MT	5.4	8.1	88.5	25.4	31.0	14.5	40.1	6.1
Capital	Bill. USD	2.8	2.3	3.2	0.2	38.1	1.3	137.9	53.6
Land	Mill. HA	4.0	3.5	4.5	0.4	11.4	9.6	13.0	1.2

Note: The abbreviations used in this table and their meanings are: Mill.- Million, Thsd-Thousand, MT-Metric ton, Bill.- Billion, USD-US Dollar, HA-Hectare.
Source: Calculation

2.2 Methodology

2.2.1 Stochastic Frontier Production Function

The stochastic frontier production function (SFA) was first developed by Aigner et al. [15] and Meeusen and van Den Broeck [16] to estimate the technical efficiency of production. The SFA treats deviations from production function as comprising both random error and inefficiency. The efficiency score can be measured by applying stochastic frontier to individual samples. It can be expressed as

$$Y_i = f(x_i; \beta) exp(V_i - U_i), \tag{2.1}$$

where Y_i and x_i denote the possible outputs and inputs at time i and a vector; β is unknown parameters to be estimated; V_i is a random disturbance (uncontrollable factors); and U_i is a non-negative random variable and associates with the technical efficiency of production. Hence, the term of stochastic frontier is $f(x_i; \beta)exp(V_i)$. The basic structure of the stochastic frontier model is illustrated in Figure 3.

The technical efficiency (TE) computed in term of the ratio of the observed production values to the estimated frontier value which is bounded by zero and one, is:

$$\begin{aligned} TE_i &= Y_i / Y_i^* \\ &= f(x_i; \beta) exp(V_i - U_i) / f(x_i; \beta) exp(V_i) \\ &= exp(-U). \end{aligned} \tag{2.2}$$

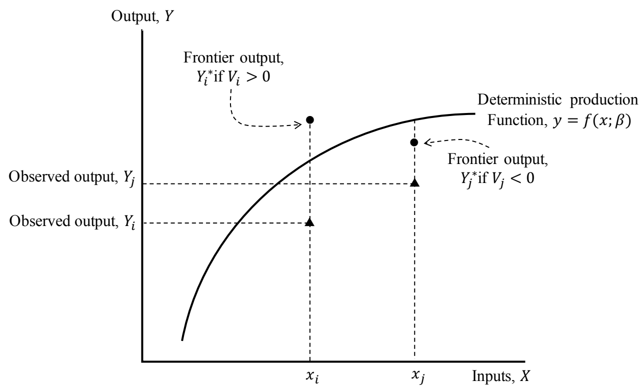


Figure 3: Stochastic frontier production function

2.2.2 An Efficiency Frontier Model

Combination of stochastic frontier and GME is called an efficiency frontier model. The required distributional assumptions are avoided due to the fact that GME estimator is quite robust concerning collinearity [17]. The concept of entropy was introduced by Shannon (1948) to measure the uncertainty of a set of events. The Shannon entropy function is $H(p) = -\sum p_i log(p_i)$, where p_i is the probability of observing outcome i. Golan [8] proposed the GME approach, starting that the probability distribution that best represents the data or available information is the one with the largest entropy. Working on GEM estimator, one will be required to create a set of support points for each parameter and next estimate the probability associated with each support point to get the parameter estimate. GME has been used to combine the prior information of the support points to estimate the associated probabilities and a predicted value of x will be obtained. These points bound the estimated inefficient and are based on theory and prior information. Following Kumbhakar and Lovell [5], a Cobb-Douglas type stochastic frontier in log form and the production frontier in terms of log form can be expressed as

$$lnY_i = f(lnx_i; \beta) + v_i - u_i, \tag{2.3}$$

where u_i is a non-negative inefficiency component and v_i is a producer specific random disturbance. Employed here is the GME methodology as described by Golan et al. [8] to estimate the production frontier given by Eq. 2.3. The coefficient vector is

$$\beta = \mathcal{Z}p = \begin{bmatrix} z_1' & 0 & \cdots & 0 \\ 0 & z_2' & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & z_K' \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_K \end{bmatrix}, \tag{2.4}$$

where the Z_K's and p_K's are both $T \times 1$, so $\mathcal{Z}$ is $K \times KT$ and p is $KT \times 1$. γ_i is the support points and ω_i represents probability weights for each observation, it can be called a set of L with $2 \leq L < \infty$. The random disturbance vector is

$$v = \mathcal{R}\omega = \begin{bmatrix} \gamma_1' & 0 & \cdots & 0 \\ 0 & \gamma_2' & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \gamma_N' \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_N \end{bmatrix}, \tag{2.5}$$

where the γ_i's and ω_i's are both $L \times 1$, so v is $N \times NL$ and ω is $NL \times 1$. The one-sided inefficiency component u, there is a set of $\mathcal{J}$ support points (ϱ_i) for each u_i and probability weights (φ_i) for each observation, with $2 \leq \mathcal{J} < \infty$. It is supposed that zero is the lowest bound of the support points for the one-side inefficient component for all observations. All other support points also are positive: 1) $\varrho_{i1} = 0, \forall i$ and 2) $\varrho_{ij} > 0, \forall i$ and $j \geq 2$. This component vector is

$$u = \mathcal{Q}\varphi = \begin{bmatrix} \varrho_1' & 0 & \cdots & 0 \\ 0 & \varrho_2' & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \varrho_N' \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \vdots \\ \varphi_N \end{bmatrix}. \tag{2.6}$$

Merging, Eqs.2.4, 2.5, and 2.6, the linear model to estimate is

$$Y = X\mathcal{Z}p + \mathcal{Q}\varphi + \mathcal{R}\omega, \tag{2.7}$$

where Y is dependent variable and X is the matrix of explanatory variables. The support points contained in the matrices $\mathcal{Z}$, $\mathcal{R}$, and $\mathcal{Q}$ are established by the researcher using a prior information. GME principle is applied to estimate the unknown vectors of probability weights p, ω, and φ by maximizing

$$H(p, \omega, \varphi) = H^e_{\alpha 1}(\beta) + H^e_{\alpha 2}(v) + H^e_{\alpha 2}(u), \tag{2.8}$$

where $H^e_{\alpha 1}(.)$ and $H^e_{\alpha 2}(.)$ are entropy measures and $\alpha 1, \alpha 2$ represent the order of the entropy measure applied when e denotes the Rényi or Tsaillis entropies. In this work, we use only the Shanon entropy measure. The estimator can be defined as

$$\underset{p,\omega,\varphi}{max} \quad H(p, \omega, \varphi) = -p' ln(p) - \omega' ln(\omega) - \varphi' ln(\varphi), \tag{2.9}$$

and subject to the model constraint and the additive constraints [11, 13];

$$\begin{aligned} Y &= X\mathcal{Z}p + \mathcal{Q}\varphi + \mathcal{R}\omega, \\ &(I_K \otimes i_T')p = i_K, \\ &(I_N \otimes i_J')\varphi = i_N, \\ &(I_N \otimes i_L')\omega = i_N, \end{aligned}$$

where I is an identity matrix. i is a column of ones, and $\otimes$ is the Kronecker product. The first constraint defines the linear production function and the others confirm that each set of probability weights sum to unity. In the inefficiency component of the model, the only prior information needed is the set of support points and the u does not have any assumption about distribution. In this study, we utilize the bootstrap method to estimate the confidence interval.

2.2.3 Model Selection

We use the coefficient of determination (R^2) and root mean square error (RMSE) to evaluate model performance. R^2 is a summary measure that how well the sample regression line fits the data. The calculation of R^2 can be written as:

$$R^2 = 1 - \frac{\sum_{t=1}^{n}(Y_t - \hat{Y}_t)^2}{\sum_{t=1}^{n}(Y_t - \bar{Y})^2}, \tag{2.10}$$

where n is number of observations; Y_t and $\hat{Y}_t$ are the actual and predicted value at time t respectively; $\bar{Y}$ is mean.

RMSE is the differences between predicted and actual value. It can be expressed as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(Y_t - \hat{Y}_t)^2}. \tag{2.11}$$

2.2.4 Model Specification

In this paper, we placed the condition on the Cobb-Douglas production function which is well known and widely applicable in economic literatures (see more details in [18]) with the logarithm-monotonic transformation. The result is a homogeneous function and provides a scale factor enabling one to measure the returns and interpret the elasticity coefficients with the relative case. The model is specified as:

$$\begin{aligned} ln(Rice_t) = \beta_0 + \beta_1 ln(Seed_t) + \beta_2 ln(Fertilizer_t) + \beta_3 ln(Pesticide_t) \\ + \beta_4 ln(Capital_t) + \beta_5 ln(Land_t) + v_t - u_t. \end{aligned} \tag{2.12}$$

Regarding to the number of support points of parameters, Campbell et al. [11] and Macedo et al.[17] suggested the use of the mean of coefficient of conventional SFM estimates to define the supports for the error inefficiency and the statistic noise. The values of the supports in this study are given in Table 2.

Table 2: The values of support points for unknown parameters.

Support points	Thailand	India
z_0	$[-5,-2.5,0,2.5,5]'$	$[-10,-5,0,5,10]'$
z_1	$[-0.25,-0.125,0,0.125,0.25]'$	$[-0.15,-0.075,0,0.075,0.15]'$
z_2	$[-0.01,-0.005,0,0.005,0.01]'$	$[-0.2,-0.1,0,0.1,0.2]'$
z_3	$[-0.05,-0.025,0,0.025,0.05]'$	$[-0.06,-0.03,0,0.03,0.06]'$
z_4	$[-0.5,-0.25,0,0.25,0.5]'$	$[-0.025,-0.0125,0,0.0125,0.025]'$
z_5	$[-0.9,-0.45,0,0.45,0.9]'$	$[-0.15,-0.075,0,0.075,0.15]'$
γ	$[-0.002,-0.001,0,0.001,0.002]'$	$[-0.02,-0.01,0,0.01,0.02]'$
ϱ	$[0,0.02,0.04,0.06,0.08]'$	$[0,0.003,0.001,0.0015,0.2]'$

3 Empirical Results

In this section, we present the parameter estimates and the results of the technical efficiency analyses. Table 3 and 4 show the parameter estimates of the production frontiers by using the TSFM and EFM. The results indicate that the estimation by using the EFM has a better performance than the TSRM since the RMSE of the EFM is smaller than those of the TSFM. The RMSE of the EFM of Thailand and India are 0.0492 and 0.0725 smaller than 0.0526 and 0.0740 of the TSFM respectively. Therefore, we conclude that the EFM estimation is more appropriate for measuring rice production frontier and technical efficiency.

Considering the production frontier estimations (Table 4), the results show that the impacts of all inputs on rice outputs between Thailand and India are different. In the case of Thailand, the coefficients of the fertilizer, pesticide, capital and land appear positive with 95% confident interval as expected. The factor of land seems to create a large effect on rice production compared to other inputs. We found that expanding 1% of area will generate 0.6238% increase in the output. The impact of fertilizer is the smallest while the seed has negative effect on output. For example, an additional 1% of the seed will lead to 0.0789% decrease in the output. In the case of India, almost all inputs have a positive impact on the output, except for the pesticide. The fertilizer has the highest elastic value of 0.1561, implying that 1% increase in the fertilizer allocated to rice production will increase the output by 0.1561%.

Table 3: Parameter estimates of the traditional stochastic frontier model

Parameter	Thailand		India	
	Coefficient	SE	Coefficient	SE
Constant	3.5111*	0.8599	8.3147*	0.9952
ln Seed	-0.2293	0.1534	0.0630	0.4253
ln Fertilizer	-0.0056	0.0601	0.1552	0.1382
ln Pesticide	0.0179	0.0113	0.0339	0.0452
ln Capital	0.2028*	0.0314	0.0195	0.0179
ln Land	0.7592*	0.2072	0.1102	0.4928
σ^2	0.0026*	0.0003	0.0052*	0.0015
γ	1.0000*	0.0929	1.0000*	0.0438
σ_u^2	0.0508		0.0722	
σ_v^2	0.0000		0.0000	
R^2	0.2401		0.5011	
$RMSE$	0.0526		0.0740	

Note: * denoted significant at 1% level ($p < 0.01$)

Figure 4 shows the technical efficiencies based on the TSFM and EFM estimations. The results report that rice productions of Thailand and India are in high level of technical efficiency — TE scores of both countries are above 0.9. On the average, the TE score of Thailand's rice production is equal to 0.9611 which is higher than 0.9532 of that of India's rice production. Nevertheless, the technical efficiency of Thailand's rice production obviously goes down from 0.9641 in 2002 to 0.9440 in 2014 (Figure 4 (b)). Conversely, the technical efficiency of India's production tends to grow up from 0.8669 to 0.9804 during the same period (Figure 4 (b)). However, TE score of Thailand's rice production has a decreasing trend and the TE score of India's rice production is less than one. In the positive aspects, it can be suggested that the Thai and Indian farmers have opportunities to increase their rice productions by improving their technical efficiencies.

Table 4: Parameter estimates of the efficient frontier model

Parameter	Thailand			India		
	Coef.	95% CI		Coef.	95% CI	
		Lower	Upper		Lower	Upper
Constant	4.1063	0.5008	4.8810	8.6920	7.7983	9.8882
ln Seed	-0.0789	-0.1802	0.1321	0.0613	0.0200	0.0896
ln Fertilizer	0.0009	-0.0036	0.0021	0.1561	0.0041	0.1926
ln Pesticide	0.0234	-0.0073	0.0393	-0.0070	-0.0236	0.0345
ln Capital	0.1325	-0.0159	0.4487	0.0172	-0.0131	0.0240
ln Land	0.6238	0.2831	0.8037	0.0874	0.0513	0.1341
R^2	0.3344			0.5232		
$RMSE$	0.0492			0.0725		

Note: Coef. and CI denoted Coefficient and Confidence Interval respectively.

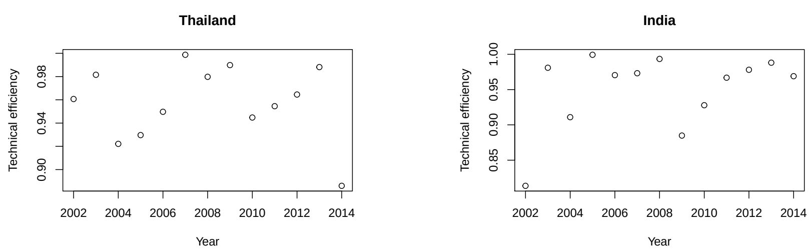
In the lower panel of Figure 4 illustrates the differences of the technical efficiency scores by estimating the TSFM and EFM. We found that the TSFM overestimates and underestimates the technical efficiency of the EFM (Figure 4 (c)). These results of Thailand's rice production show a bigger differences between two methods than those of India. To emphasize, it is recommended that the EFM should be used to measure the technical efficiency behavior of rice production, instead of the TSFM.

4 Policy Recommendation

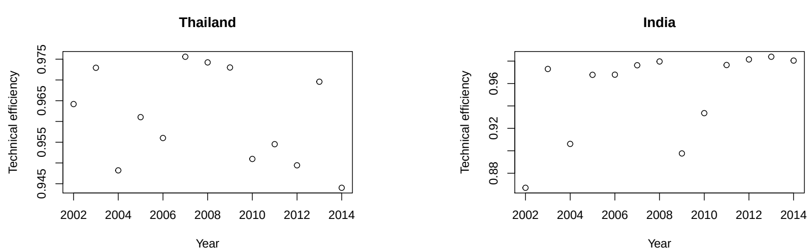
According to our findings (Section 3), we propose the policies and strategies for improving Thailand's and India's efficiencies in rice productions as the followings:

In the case of Thailand, we would like to suggest four improvements. Firstly, this study reveals the strong positive relationships between the cultivating areas and rice productions, thus, zoning and liberalizing land markets for the farmers should be more emphasized. Secondly, the capital is also the major input and has large impacts on rice productions. The government should, therefore, support the farmers on the finance access along with the financial education to the farmer at the same time. Otherwise, household debts would increase because their incomes rely entirely on the local climates and global prices. In addition, this could also lead to increases in the Non-Performing Loans (NPLs) which are the significant risks for financial institutions. Thirdly, there should be more research and development for the usage of inputs; such as seeds, fertilizer, pesticide, etc; that will directly increase the quantity, quality, and efficiency of the production (or decrease waste) as a result. Lastly, the farmers should focus more on the technological improvements than on the production scale.

(a) The technical efficiency by using the TSFM



(b) The technical efficiency by using the EFM



(c) The differences of technical efficiency between the TSFM and the EFM

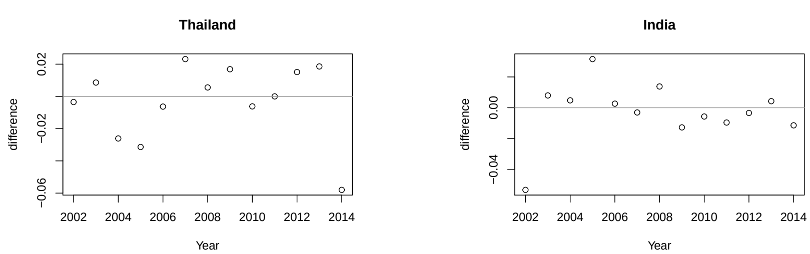


Figure 4: Technical efficiency of the traditional stochastic frontier model (TSFM) and the efficient frontier model (EFM).

In the case of India, there are three suggestions of improvements. Firstly, the responsible organizations should provide the vocational training to enhance rice farmers' efficiencies either higher than, or at least, as high as their current levels.

Secondly, our results suggest that, in order to raise the productivity, the fertilizer should be more utilized but the pesticide should be less used. Lastly, the research should be more invested for the better quality of seeds.

5 Conclusions

This paper applied the generalized maximum entropy estimation to the stochastic frontier model which is called an efficiency frontier model in order to investigate the production frontier and technical efficiency of Thailand's and India's rice productions in utilizing seed, fertilizer, pesticide, capital, and land. We compared the results of estimations between the EFM and the TSFM. The method with better performance was selected to analyze production frontier and technical efficiency.

We firstly found that the root mean square error of the EFM is smaller than those of the TSFM. The TSFM's results revealed that there are some misdirections of the relations between inputs as well as the outputs and the overestimation and underestimation of the technical efficiency relative to the EFM. Hence, it can be concluded that the EFM is more accurate and properer to measure the production frontier and technical efficiency. Secondly, the elasticity of most of the inputs are positive, except for the seed and pesticide. There are negative relations between the seed and rice output of Thailand as well as the relations between the pesticide and the rice output of India. The capital and land are the significant factors for rice production efficiency in both countries. Thirdly, Thailand and India are in the high technical efficiency levels. They ranges 0.9440 to 0.9756 for Thailand and 0.8670 to 0.9839 for India. Fourthly, the development in the technical efficiency of India's rice production is higher than Thailand — the TE scores of India increase from 0.8669 in 2002 to 0.9804 in 2014 as the TE scores of Thailand decrease from 0.9641 to 0.9440 during the same period. All suggestions aim to maintain and enhance their rice production efficiencies, as well as, more emphasize the importance of technical efficiency than increase the production scale.

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