A Slack Based Enhanced DEA Model with Undesirable Outputs for Rice Growing Farmers Efficiency Measurement

Sahubar Ali Mohd. Nadhar Khan[1], RAZAMIN RAMLI[2], MD Azizul Baten[3]

[1, 2]*School of Quantitative Sciences, UUM College of Arts and Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia.*

[3]*Department of Statistics, School of Physical Sciences, Shahjalal University of Science and Technology, Sylhet, Bangladesh.*

[1]sahubar@uum.edu.my

[3]razamin@uum.edu.my

[3]baten_math@yahoo.com

Abstract **— Agricultural production process typically produces two types of outputs which are economic desirable as well as environmentally undesirable outputs (such as greenhouse gas emission, nitrate leaching, effects to human and organisms and water pollution). In efficiency analysis, these undesirable outputs cannot be ignored and need to be included in order to obtain the actual estimation of firm's efficiency. There are several approaches that has been proposed in DEA literature to account for undesirable outputs. Many researchers have pointed that directional distance function (DDF) approach is the best as it allows for simultaneous increase in desirable outputs and reduction of undesirable outputs. Additionally, slack based DEA approaches considers the output shortfalls and input excess in determining efficiency. The proposed model uses an enhanced DEA model which is based on DDF approach and incorporates slack based measure to determine efficiency in the presence of undesirable factors. Later the proposed increase in desirable outputs and reduction in undesirable outputs can be found for inefficient farmers. The developed model is used to determine rice farmers efficiency form Kepala Batas, Kedah. The study found 13 out of 30 farmers are CRS efficient and 17 out of 30 farmers are VRS efficient. From the basic DEA model, higher number of efficient farmers are identified due to the fact that the effect of undesirable outputs is not included in the model. Generally, DEA models which considers the effects of undesirable outputs produces more robust results.**

***Keywords*—** *DEA, rice farmers efficiency, slack based measure, undesirable output.*

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1. Introduction

Rice is an important agricultural commodity and one of the world's important food source and staple food for more than half of the world population. Most agricultural economies in the world including Southeast Asia are dominated by rice plantation. As the most important staple food in the world, rice is consumed by over 2.89 billion people in Asia, 40 million people in Africa and over 150.3 million people in Latin America [1]. According to Food and Agriculture Organization of the United Nations (FAO) statistics for 2012, there are 1625.3 million hectares of rice planted area in the world with the total production of 738.1 million tonnes.

There are many bio-physical and economic challenges faced by rice production such as water shortage, floods, irregular rainfall, low soil fertility, pest menace, high production cost, labor shortages and fluctuation of paddy price [2]. These uncertainty and climatic challenges has a significant effect in farmers productivity and efficiency. Additionally, rice production activities also produces some negative environmental effects such as greenhouse gas emissions, nitrate leaching, pesticide effects on bio-organisms and water pollution [3].

These negative environmental effects are known as undesirable outputs of a production system. These undesirable outputs are mainly caused by excessive fertilizer and pesticide usage. Farmers often use these two methods to increase production and control pest menace. For example, in rice production the excessive usage of nitrogen fertilizers cause nitrate leaching to water and atmosphere and may harm the aquatic life and biodiversity [3].

2. Efficiency measurement in rice production

Many researchers have focused on measuring efficiency level of rice farmers engaged in agricultural activities and identifying its determinants. If a farmer is operating efficiently, then per unit production cost can be reduced due to increase in yield. So, the determination of existing efficiency level of paddy farmers is an important in order to take necessary actions to improve the efficiency level of the farmers in order to increase production to meet consumption needs. If farmers are technically efficient, then efforts and resources can be focused on improving productivity and production in the long term.

There are numerous techniques that have been employed by researchers to determine the efficiency level of rice farmers. Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are two of the most widely applied techniques utilized for this purpose. DEA is a non-parametric technique whereas SFA is a parametric technique. Both DEA and SFA techniques are derived based on efficiency measurement approach introduced by Farrell [4].

3. Undesirable outputs in efficiency measurement

One of the common characteristic of agricultural production process that is often overlooked by researchers evaluating efficiency is the environmental effects of this production system. These effects are known as undesirable outputs of a production system. There are numerous studies that evaluate the efficiency of rice production that ignores the effects of these undesirable outputs such as by Linh [5], Akighir and Shabu [6], Khai and Yobe [7], Aung [8], Dhungana et al. [9], Krasachat [10], Rahman [11] and Abdulai and Huffman [12].

It is imperative to consider these undesirable output(s) in determining the efficiency of agricultural production systems in order to ensure that the producers are not overly harming the environment by their practices in order to achieve higher output and higher efficiency. Among the factors that had been studied by previous researchers were nitrogen and pesticide pollution [13], greenhouse gas emission [14], pressure on natural resources and biodiversity [15], nitric acid emission [16], pesticide effects on environment [3], methane and nitrous oxide gas emission [17], water source pollution [18], phosphorus emission [19], risk to human health and aquatic life from pesticide runoff and leaching [20] and nitrogen surpluses [21].

There are numerous approaches that have been proposed in the literature to account for undesirable outputs in efficiency measurement which can be broadly classified as direct and indirect approaches. Direct approach refers to approaches that treat the undesirable output in their original form such as parametric output and input distance functions [22, 23, 24] and DEA methods [3, 13, 17, 18, 25, 26].

Indirect approach refers to treating the undesirable output as a classical input. In this approach, the undesirable output is moved to the input side of the model after some transformation imposed and treated as one of the inputs. Seiford and Zhu [27] highlighted that treating undesirable outputs as inputs will distort the actual production process since the relationship between inputs and outputs in the actual production process will be lost.

Färe et al. [28] put forward a direct approach in which both desirable and undesirable outputs are treated in their actual form. Later, Chung et al. [29] and Ball et al. [21] extended the idea of Färe et al. [28] and proposed the use of directional distance functions (DDF) to evaluate efficiency of DMUs in when the production process also produces some undesirable outputs. In this approach, the values of both desirable outputs and undesirable outputs can be augmented simultaneously. Specifically, the desirable outputs can be expanded and the desirable inputs and undesirable outputs can be reduced based on a given direction vector [29].

Later, Zhou et al. [30] proposed a non-radial slacks-based measure (SBM) model extended with the incorporation of undesirable outputs. This model, an extension of Tone’s [31] original SBM model, uses a ratio approach to strike a balance between undesirable output reduction and desirable output increase. In this model the ratio of average reduction in undesirable output to average increase in desirable output is minimized.

4. Proposed model

In this paper we propose an enhanced slack based DEA model which considers desirable and undesirable outputs simultaneously.

Let x, z, and q be the maximum number of variable inputs, risk-adjusted inputs, and fixed inputs used by a firm to produce a set of desirable outputs (y) and undesirable outputs (u). Considering a set of firms N, the production process uses a set of variable inputs, x_i, risk-adjusted inputs, z_r, and fixed inputs, q_f, to produce a set of desirable outputs, y_j, and undesirable outputs, u_k. The DEA efficiency model with slack based directional distance function approach when undesirable outputs are present is as given below. In this model, the input excesses and output shortfalls are modelled in the objective function to determine efficiency. The efficiency score is obtained by computing the ratio of input excesses to the output shortfalls.

$$Min \quad \rho = \frac{1 - \frac{1}{R+I+K}\left(\sum_{r=1}^{R}\frac{\beta_r g_z}{z_r} + \sum_{i=1}^{I}\frac{\beta_i g_x}{x_i} + \sum_{k=1}^{K}\frac{\beta_k g_u}{u_k}\right)}{1 + \frac{1}{j}\left(\sum_{j=1}^{J}\frac{\beta_j g_y}{y_j}\right)}$$

s.to

$$\sum_{n=1}^{N}\lambda_n z_{rn} = z_{ro} - \beta_r g_z$$
$$\sum_{n=1}^{N}\lambda_n x_{in} = x_{io} - \beta_i g_x$$
$$\sum_{n=1}^{N}\lambda_n y_{jn} = y_{jo} - \beta_j g_y$$
$$\sum_{n=1}^{N}\lambda_n u_{kn} = \sigma(u_{ko} - \beta_k g_u)$$
$$\sum_{n=1}^{N}\lambda_n q_{fn} = \sigma q_{fo}$$
$$\lambda_n \geq 0$$
$$0 \leq \sigma \leq 1 \qquad (1)$$

Since model (1) is in fractional form, it can be transformed to linear form by the following procedure to obtain (2). First multiply a scalar variable t ($t > 0$) to both the denominator and the numerator of the objective function in (1). This will not cause any changes to the value of ρ. Then we adjust the value of t so that the denominator becomes 1 and move it to constraints section. The resulting model will be in nonlinear form and can be transformed to linear form using the method proposed by Charnes and Cooper [32]. This produces the following linear program (2).

$$Min \quad \tau = t + \frac{1}{R+I+K}\left(\sum_{r=1}^{R}\frac{\beta_r g_z}{z_r} + \sum_{i=1}^{I}\frac{\beta_i g_x}{x_i} + \sum_{k=1}^{K}\frac{\beta_k g_u}{u_k}\right)$$

s.to

$$t + \frac{1}{j}\left(\sum_{j=1}^{J}\frac{\beta_j g_y}{y_j}\right) = 1$$
$$\sum_{n=1}^{N}\lambda_n z_{rn} = tz_{ro} - \beta_r g_z$$
$$\sum_{n=1}^{N}\lambda_n x_{in} = tx_{io} - \beta_i g_x$$
$$\sum_{n=1}^{N}\lambda_n y_{jn} = ty_{jo} - \beta_j g_y$$
$$\sum_{n=1}^{N}\lambda_n u_{kn} = \sigma t(u_{ko} - \beta_k g_u)$$
$$\sum_{n=1}^{N}\lambda_n q_{fn} = \sigma t q_{fo}$$
$$\lambda_n \geq 0$$
$$0 \leq \sigma \leq 1 \qquad (2)$$

Additionally, the result of model (2) was compared with the results obtained using a basic DEA model given in (3). Model (3) does not considers the effects of undesirable outputs on farmers efficiency.

$$Max \quad z = \sum_{j=1}^{J} v_j y_{j0}$$

s.to

$$\sum_{j=1}^{J} u_j y_{jn} - \sum_{i=1}^{I} v_i x_{in} \leq 0$$
$$\sum_{i=1}^{I} v_i x_{i0} = 1$$
$$v_j, u_i \geq 0 \qquad (3)$$

The dual LP of the model (3) which is given in (4) can be easily solved to obtain the efficiency scores of each farmer.

$$Min \quad z = \theta$$

s.to

$$\sum_{n=1}^{N}\lambda_n x_{in} \leq \theta x_{i0} \qquad i = 1,2,\ldots, I;$$
$$\sum_{n=1}^{N}\lambda_n y_{jn} \geq y_{j0} \qquad j = 1,2,\ldots, J;$$
$$\lambda_n \geq 0 \qquad (4)$$

5. Results and discussion

A survey was conducted on 30 farmers of the Kepala Batas PPK from Kedah, Malaysia. Though the sample was selected randomly, all the selected farmers are male have education up to UPSR and from Malay race and about 83.3% of them are more than 59 years old (Table 2). More than 73% of the farming systems are individual and 26.7% farmers are from estate system.

The input and output variables are classified as variable inputs, risk adjusted inputs, fixed inputs (which are non-discretionary), undesirable outputs and desirable outputs. This classification of inputs and outputs are used to compute the efficiency of rice farmers in situations when the production process also produces some undesirable outputs which values are to be minimized.

Table 1. Input and output variables

	Definition
Variable input:	
Land cost (X_1)	Total cost related to land planted with rice. Includes cost of rental, annual tax and land preparation.
Seed quantity (X_2)	Total quantity (in kg) of seeds used in the planting process
Monetary cost (X_3)	Total cost incurred in rice planting. Includes labor, manhour and equipment rental costs.
Risk-adjusted input:	
Fertilizer (Z_1)	Total quantity (in kg) of fertilizers used for rice planting.
Pesticides (Z_2)	Total quantity if various types of pesticides (in liters) used.
Fixed input:	
Land area (Q_1)	Total area (in hectare) of rice planting.
Desirable output:	
Total production (Y_1)	Total value (in RM) of rice produced from the planted area.
Undesirable output:	
Nitrogen leaching (U_1)	Computed as percentage of nitrogen leached into the environment from the amount of nitrogen fertilizers used in rice planting.
Environmental Impact Quotient [EIQ] (U_2)	Computed using the formula based on the active ingredients of the pesticides used.

Table 2. Background Statistics of the Selected Farmers of Kepala Batas, Kedah, Malaysia

Farming System	**Frequency**	**Percent (%)**
Individual	22	73.3
Estate	8	26.7
Total	30	100.0
Age		
40-49	5	16.7
More than 59	25	83.3
Total	30	100.0
Race		
Malay	30	100.0
Education		
UPSR	30	100.0

Table 3 shows the CRS and VRS efficiency [found using Model (2)] of the selected farmers from PPK Kepala Batas, Kedah, Malaysia. Thirteen farmers are found to be operating efficiently under CRS assumptions and 17 farmers are efficient under VRS assumptions. The average CRS efficiency score is 0.7673 and the average VRS efficiency is 0.8887. It should be noted that all the farmers who are CRS efficient are also VRS efficient while 4 farmers who are inefficient under CRS assumptions were found to be VRS efficient. The results of this analysis confirms with earlier findings in which farmers performance are better under VRS assumptions [Coelli et al., 19].

Table 3. Efficiency score of rice farmers under CRS and VRS assumptions using Model (2)

Farmer (DMU)	**CRS Efficiency**	**VRS Efficiency**
1	1	1
2	1	1
3	0.9963	0.9963
4	0.4090	0.6419
5	0.5886	0.7358
6	0.5505	0.7234
7	1	1
8	1	1
9	1	1
10	0.7439	0.8444
11	1	1
12	0.4750	0.7610
13	0.7078	0.7277
14	0.5298	0.7073
15	0.5062	0.7856
16	0.5397	1
17	0.6782	0.7322
18	0.7566	1
19	0.5954	0.6826
20	1	1
21	0.5745	0.6797
22	1	1
23	0.3137	0.6441
24	1	1
25	0.6007	1
26	0.4532	1
27	1	1
28	1	1
29	1	1
30	1	1
Average Efficiency	**0.7673**	**0.8887**

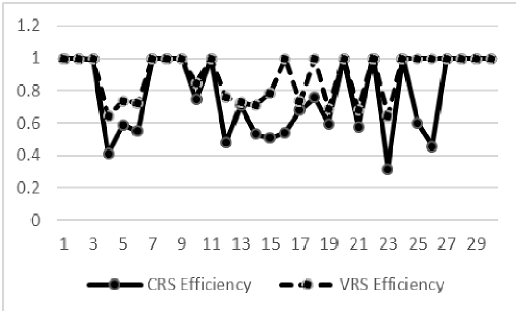

Figure 1. CRS and VRS Efficiency of selected rice farmers using Model (2)

Table 4 shows the CRS and VRS efficiency of the selected farmers using the basic DEA model given in (4). This model does not consider the effects of undesirable output on farmers efficiency. From this analysis, it is found that seventeen (17) farmers are operating efficiently under CRS assumptions and twenty (20) farmers are efficient under VRS assumptions. The average CRS efficiency score is 0.9060 and the average VRS efficiency is 0.9335.

We can note that the number of efficient farmers (under both CRS and VRS assumptions) and their efficiency score is generally higher compared to the results obtained using Model (2). This is due to the fact that a farmer who produces more outputs by using slightly more risky inputs that cause harm such as pesticides and fertilizers will not be penalized in Model 4 and will be found to be more efficient since he produces higher quantity of outputs. In Model (2) these effects are included in the formulation as undesirable outputs which must be minimized. Therefore, farmers who uses higher quantity of harmful inputs such as pesticides and fertilizers will eventually produce higher quantities of undesirable outputs and will be penalized when using Model (2) and will be found less efficient.

This result shows that the proposed Model (2) produces better results since it encourages the farmers to become efficient without unduly harming our environment. The farmers who uses higher quantity of risky outputs will be penalized since they will eventually found less efficient.

Table 4. Efficiency score of rice farmers under CRS and VRS assumptions using basis DEA Model (Model 4)

Farmer (DMU)	CRS Efficiency	VRS Efficiency
1	1	1
2	1	1
3	1	1
4	0.7929	0.8034
5	0.6846	0.7081
6	0.7952	0.8142
7	1	1
8	1	1
9	1	1
10	0.8904	0.9970
11	1	1
12	1	1
13	0.8861	1
14	0.7608	0.7942
15	0.8264	0.9065
16	1	1
17	0.8432	0.8720
18	0.9379	1
19	0.6859	0.7125
20	1	1
21	0.7759	0.7759
22	1	1
23	0.5018	0.6209
24	1	1
25	0.7992	1
26	1	1
27	1	1
28	1	1
29	1	1
30	1	1
Average Efficiency	**0.9060**	**0.9335**

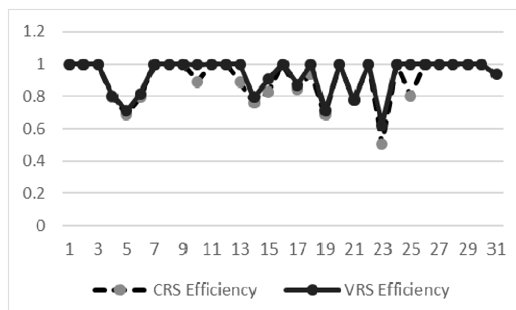

Figure 2. CRS and VRS Efficiency of selected rice farmers using Model (4)

6. Conclusion

This study is concerned with the measurement of efficiency for the rice growing farmers using an Enhanced Slack based DEA Model with Undesirable Outputs. The primary data is collected from PPK Kepala Batas of Kedah, Malaysia with a number of 30 farmers which are randomly selected to estimate CRS and VRS efficiency. The result shows 43% of the farmers operating efficiently under CRS assumptions and 57% of the farmers are VRS efficient. Additionally, when the results are compared with the results obtained using a basis DEA model [Model (4)], it shows that the proposed enhanced model produces more accurate and robust results.

According to the theoretical assumption of the DEA approach, the farm which possesses the highest efficiency score is situated on the production frontier line and so, the estimated results from DEA indicate that the inefficient samples farmers can improve their rice production efficiency to catch up the efficient sample farmers in this northern region, Malaysia. This study suggested that the existence of some inefficiency may be reduced through policy interventions, adoption, and spread of improved agricultural mechanization. In particular, knowledge of factors driving rice production efficiency and contributions of production efficiency to economic performance could provide support for policy makers.

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