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Efficiency of Rice Production with Environmental Consideration

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ABSTRACT

The present study attempts to investigate the impact of environmental factors on the efficiency of rice production in Malaysia. The Cobb–Douglas stochastic production frontier function is used to estimate the production frontier 'with' and 'without' the environmental variables using primary data from the survey on farmers from two states in Malaysia, which are Kedah and Perlis. The findings from the study indicate that average technical efficiency for the sample farmers is 62.9% which implies that on the average, the farmers are able to obtain 62.9% of potential output from a given mix of production inputs as well as environmental consideration.

ملخص

تحاول هذه الدراسة التحقيق في تأثير العوامل البيئية على كفاءة إنتاج الأرز في ماليزيا. تم استخدام دالة حدود الإنتاج العشوائية كوب-دوغلاس لتقدير حدود الإنتاج 'مع' و'بدون' المتغيرات البيئية باستخدام البيانات الأولية من المسح على المزارعين من ولايتين في ماليزيا، وهما كيدا وبرليس. تشير نتائج الدراسة إلى أن متوسط الكفاءة الفنية للمزارعين في العينة يبلغ 62.9%، مما يعني أن المزارعين قادرون في المتوسط على تحقيق 62.9٪ من الإنتاج المحتمل من مزيج معين من مدخلات الإنتاج وكذلك من الاعتبارات البيئية.

RÉSUMÉ

La présente étude tente d'examiner l'impact des facteurs environnementaux sur l'efficacité de la production de riz en Malaisie. La fonction de frontière de production stochastique Cobb-Douglas est

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utilisée pour estimer la frontière de production « avec » et « sans » les variables environnementales en utilisant les données primaires de l'enquête sur les agriculteurs de deux États de Malaisie, Kedah et Perlis. Les résultats de l'étude indiquent que l'efficacité technique moyenne des agriculteurs de l'échantillon est de 62,9 %, ce qui signifie qu'en moyenne, les agriculteurs sont en mesure d'obtenir 62,9 % de la production potentielle à partir d'une combinaison donnée d'intrants de production et de considérations environnementales.

Keywords: Climate change, Food security, Efficiency, Stochastic frontier, Malaysia.

JEL Classification: C51, Q18, Q54

1. Introduction

Rice production has long been documented as the main economic activity of the rural community in Malaysia, with an average production area of 651,600 ha for the combination of main and off season in the years of 1900's. Yet, there is a steady decline in terms of production area annually. At national level, the production of rice can only accommodate 71.4% of their own domestic needs. Poor productivity compare to other countries has resulted in low incomes for farmers, with average earning of RM1,400 per month. With rural areas accounting for 35 percent of Malaysia's population and agriculture accounting for 43.7 percent of rural employment, improving agriculture productivity is critical to close the rural-urban income gap, which was 1.00:1.82 in 2009.

There are many factors that directly make rice production rate declining. These factors include a variety of aspects such as its fertilizing cycle, soil physical-chemical properties, crop cultivate, pesticide and environment (Toriman et al., 2013). Among all the contributing factors, the environment is a factor that is beyond human control and could only be mitigated after certain events. In Malaysia, among the environmental factors, flood, rainfall, temperature, and humidity are affecting the rice production. In the past 30 years, floods have caused the worst damage to Malaysian economy. In 2007, the economic damage caused by floods amounted to 0.1% of the country's Gross Domestic Products (GDP). UNISDR (2012) reported that during the flood of December 2006, losses in agricultural sector were estimated to amount to USD 18.8 million involving 6,797 farmers and 8,322 ha of arable lands. farmers and 8,322 ha of arable lands. Nonetheless, over the past few decades, Malaysia has experienced a growing warm temperature. The Malaysian Agricultural Research Institute (MARDI) has estimated that a 1°C increase in daily average temperature reduces 10% of the rice yield in peninsular Malaysia (Abdullah, 2007).

Studies on rice efficiency in Malaysia are highly limited (e.g., Ahmed et al., 1999) compared to other developing countries, such as Pakistan (Battese & Coelli, 1995), India (Singh et al., 2019), and Iran (Bakhsoodeh & Thomson, 2001). Masud et al. (2014), for example, only explored the relationship between climate changes and farmer's net income from rice production using the Ricardian model. Toriman et al. (2013) showed the impact of climate change variation on rice production in Selangor, Malaysia but not analyzing the efficiency of production. Zainal et al. (2014) investigated the economic impact of climate change on rice production, again not on the efficiency of production, in Malaysia using the time series data. On the other hand, Mailena et al. (2014), Ghee-Thean et al. (2012) and Radam and Shamsudin (2001) focused on efficiency of rice production using the stochastic frontier model (SFM) and data envelopment analysis (DEA) but with no consideration on environmental factors. No study, to the knowledge of authors, investigates the impact of environmental factors such as soil type, land type, temperature, rainfall and flood on the efficiency of rice production in Malaysia. Thus, the current study is undertaken to fill this gap with the intention to help the farmers to allocate their scarce resources more efficiently and to assist policy makers to design and formulate agricultural policies as regard to rice in Malaysia.

2. Methodology

2.1 Theoretical Background

Two of the most popular functional forms in the economics literature are Cobb- Douglas (C-D) and the transcendental logarithmic (TL) functions. The first one is easy to interpret and estimate but imposes important restrictions on the technology such as scale and output elasticities that do not vary with input or output levels and substitution elasticities among inputs are all equal to unity. The trans log, on the other hand, is a flexible form in the sense that it can provide a local, second order approximation to any function, but it is more difficult to estimate due to the large number of parameters and the problem of multicollinearity among the regressors (Irz & Mckenzie, 2003). In this study, the general form of the Cobb–Douglas stochastic production frontier function is used. The Cobb–Douglas stochastic production frontier function is an extension of the traditional Cobb–Douglas production function, incorporating a stochastic term to account for random errors and inefficiency in the production process. This model is widely used in econometrics to analyze the efficiency of production units, such as firms or industries.

The Cobb-Douglas (C-D) production function is a particular type of production function. Cobb and Douglas (1928) posited that production is determined by the combination of labour and capital. They used the following function:

$$Y(L,K) = AL^{\beta}K^{\alpha} \qquad (1)$$

where, Y is total production (the real value of all goods produced in a year, L is labour input (the total number of person-hours worked in a year, K is capital input (the real value of all machinery, equipment and building), A is total factor productivity, and are the output elasticities of labour and capital, respectively. There are some assumptions of Cobb-Douglas Production Function. They are as follows:

- Constant Returns to Scale occur when the sum of α and β equals 1. The function assumes constant returns to scale, which implies that if all inputs are proportionally increased or decreased, the output will also be proportionally increased or decreased. However, it can also accommodate economies or diseconomies of scale if the sum of α and β is not equal to 1.
- Factor replacement refers to the ability to replace one input (such as labour or capital) with another to a certain degree. In the Cobb-Douglas function, this substitution is assumed to be possible, with a constant elasticity of substitution equal to 1.
- Positive and diminishing marginal returns refer to the phenomenon where each additional input contributes positively to the overall output, but the extent of this contribution gradually decreases. This implies that as the quantity of one input increases,

while keeping other inputs constant, the marginal output generated by each extra unit of input will eventually diminish.

- Technology change is typically captured by the constant A, representing total factor productivity, which can shiftt over time to reflect improvements in technology.

$$Y_i = AL_i^{\alpha} K_i^{\beta} e^{v_i - u_i} \quad (2)$$

where
Y_i is the output of the i-th production unit,
A is the technology parameter
L_i and K_i are labour and capital inputs for the i-th input
α and β are parameters to be estimated.
v_i is a symmetric random error term representing statistical noise (e.g., measurement error, external shocks) and u_i is a non-negative random variable representing technical inefficiency.

2.2 The Empirical Model

In this study, the general form of the Cobb–Douglas stochastic production frontier function is used. In order to determine the consequences of omitting environmental production conditions, we estimate the production frontier 'with' and 'without' the environmental variables. Hence, the conventional specification which omits the environmental variables is written as:

$$ln\, Y_i = \alpha_0 + \sum_{j=1}^{p} \alpha_j\, ln\, X_{ij} + \sum_{j=1}^{p} \beta_j D_{ij} + v_i - u_i \quad (3)$$

and

$$u_i = \delta_0 + \sum_{d=1}^{p} \delta_d Z_{id} + \zeta_i \quad (4)$$

where Y_i is the production of rice, X_{ij} is the jth input for the ith farmer, D_{ij} are the dummy variables used to account for values of input use, value of 1 if the jth input used is positive and zero otherwise, p is the total number of variables of each category, v_i is the two sided random error, u_i is the one sided half-normal error, ln is the natural logarithm, Z_{id} are the variables representing managerial and socio-economic characteristics of the farm to explain inefficiency, Z_i is the truncated random variable, and αs, βs and δs are the parameters to be estimated.

The full specification model which includes variables that represent environmental production conditions can be written as:

$$ln\, Y_i = \alpha_0 + \sum_{j=1}^{p} \alpha_j \, ln\, X_{ij} + \sum_{j=1}^{p} \beta_j D_{ij} + \sum_{k=1}^{p} \varphi_k E_{ik} + v_i - u_i \quad (5)$$

and

$$u_i = \delta_0 + \sum_{d=1}^{p} \delta_d Z_{id} + \zeta_i \quad (6)$$

where E_{ik} are the environmental production condition variables and φ_k is the parameter to be estimated. A total of eight production inputs (X), six environmental production condition variables (E), and eleven variables representing managerial and socioeconomic characteristics of the farmer (Z) are included in the inefficiency effects model as predictors of technical inefficiency in both short and full specifications. Table 1 presents the variables and their units of measurement. Several statistical tests were conducted for stochastic frontier model to select the preferred model. One of the tests is likelihood ratio test. Four model specifications were developed in which the first two equations are the specification models with no environmental variables included. The last two equations are the specification models with environmental variables are considered.

Table 1: Measurement of Variables in the SPF and Technical Inefficiency Model for Rice Production in Malaysia

Variables	Abbreviation	Measure
Input (X) and Output (y)		
Rice Output	Y	kg per farm/harvest
Land area (ha)	Land	Hectare (ha)
Seed	Seed	kilogram (kg)
Irrigation	Irr	time/year
Cost of Mechanical Power/machines	Cap	Ringgit Malaysia (RM)
Fertilizers	Fert	Kilogram (kg)
Cost of Pesticide	Pest	Ringgit Malaysia (RM)
Labour	Labor	unit
Environmental variables (E)		
Land type	Dummy_lndtype1	Indexed (1 = medium high land; 0 = otherwise, high land and low land)

	Dummy_lndtype2	Indexed (1 = high land; 0 = otherwise, medium high land and low land)
	Dummy_lndtype3	Indexed (1 = low land; 0 = otherwise, high land and medium high land)
Soil type	Dummy_soiltype1	Indexed (1= loamy ; 0 = otherwise, peat or organic and clay)
	Dummy_soiltype2	Indexed (1= peat or organic ; 0 = otherwise, loamy and clay)
	Dummy_soiltype3	Indexed (1= clay ; 0 = otherwise, peat or organic and loamy)
Rainfall	Rain	Mililitre (mm)
Average temperature	Temp	Celsius (^{0}c)
Flood	Dummy_flood1	Indexed (1 = 1—10% loss of crop yield, 2 = otherwise)
	Dummy_flood2	Indexed (1 = 11—20% loss of crop yield, 2 = otherwise)
	Dummy_flood3	Indexed (1 = 21—30% loss of crop yield, 2 = otherwise)
Drought	Dummy_drght1	Indexed (1 = 1—10% loss of crop yield, 2 = otherwise)
	Dummy_drght2	Indexed (1 = 11—20% loss of crop yield, 2 = otherwise)
	Dummy_drght3	Indexed (1 = 21—30% loss of crop yield, 2 = otherwise)
Managerial and Household Variables (Z)		
Age	Age	years
Education	Educ	Indexed (1=no formal education; 2=primary; 3=secondary; 4=pre-uni, STPM, diploma; 5=first degree; 6=master; 7=doctorate)
Experience	Exprc	Indexed (1= less than 1 year; 2= 1-2 years; 3= 2-5 years; 4=5-10 years; 5= more than 10 years)
State	Dummy_state	Indexed (1= Kedah; 0=Perlis)
Family size	Farmsize	unit
Marital status	Dummy_married	Indexed (1=married; 0=otherwise, single, divorce)
Gender	Dummy_male	Indexed (1=male; 0=otherwise)
Income per farming	Inc_perfarm	Ringgit Malaysia (RM)
Training	Dummy_notrain	Indexed (1=no training received; 0=otherwise, training

		received in the last 1, 2 or 5 years)
Frequency contact with agricultural officers	Dummy_nolink	Indexed (1=no contact at all; 0=otherwise, contact once a week, fortnightly, once per month and once per 3 months)
Source of agricultural information	Dummy_infoint	Indexed (1=information from internet; 0=otherwise, information from private and public bodies, seminars/workshops, electronic and published media)

2.3 Data

Cross-section data are used in the present study. The study is conducted through survey located in Kedah and Perlis in year 2020, which consists of 27 farmer organizations which is named Pertubuhan Peladang Kawasan,PPK (Regional Farmers Organisation that consist of 55,000 farmers. The survey is confined within Kedah and Perlis as it is the rice bowl of Malaysia. The data was collected through interviews with heads of households who all working as rice farmers. The area is located on the Muda Irrigation Scheme, which covers 125,155 hectares, of which 105,851 hectares are in the north-western part of the State of Kedah and 20,304 hectares are in the southern part of the State of Perlis. An estimated 76% (96,558 hectares) of the land is under rice cultivation. The number of respondents who responded to the survey is 89 based on convenience sampling.

The questionnaire consisted of two sections: A and B. Section A collected information on the farmers' socio-economic characteristics (i.e., household size, gender, ethnic group, religion, education level, income, farm size, family size etc.). Section B enquired as to their farm expenditure, inputs and output in farming activities. In this study, we also used secondary data for environmental condition. Data on environmental condition such as temperature and rainfall data were collected from the meteorological department. Details on the variables are displayed on Table 1.

3. Results and Discussion

Prior to analyzing data empirically, data from the survey are analyzed descriptively. The descriptive statistics are displayed on Table 2 and Table 3. Table 2 shows statistics for continuous data or variables, while Table 3 displays statistics for categorical data. From Table 2, it is reflected that the mean age of respondents or farmers in study is 51 years old with the minimum age is 22 years old and the maximum age is 83. As of family size, on average, farmers have quite big size of family, that is 4.5 or 5 members. Since most of farmers are Malay race which adopt traditional type of family with many children, the result is as expected. The maximum land area possessed by the respondents is 1000 hectare and the minimum is 0.4 hectare. On average, the land size area is 13.84 hectare.

Table 2: Descriptive Statistics of Continuous Variables

Variable	N	Min	Max	Mean	Std Dev	Skewness	Kurtosis
Age	87	22	83	51.31	13.9	0.106	-0.427
Family size (unit)	88	1	8	4.55	1.5	0.088	-0.244
Land area (hactre)	88	0.40	1000	13.84	106.4	9.356	87.67
Income per farming (RM)	89	1500	90000	11179.5	11726.02	4.459	25.726
Rice output (kg per farming)	89	100	52000	8534.83	7932.37	2.534	9.79
Seed (kg per farming)	89	10	2400	375	442.65	2.923	9.357
Machine's cost (RM per farming)	89	0	90950	5064.48	14602.49	4.281	19.155
Pesticide's cost (RM per farming)	89	0	21000	1040.11	24896.90	6.527	48.691
Labour (unit per farming)	89	1	28	2.966	3.284	5.570	39.136
Average temperature (Celsius) monthly	89	29	50	34.21	4.79	1.555	3.058
Rainfall (mm) monthly	81	10	500	180.43	133.68	0.646	-1.130

Having said this, the mean income obtained from the farming activities is RM11,179 per harvest with the minimum and maximum are RM1,500 and RM90,000, respectively. The rice output per farming is 52,000 kg the maximum and 100 kg the minimum, with the average of 8,535 kg per farming. The amount of seed used on average is 375 kg and the number of labour used on average is 3 persons. The minimum number of man-power or labour used is one which probably involve small size of land area. The mean costs of machines and pesticides spent by farmers are RM5,064 and RM1,040 per farming, respectively. The minimum costs on these machines and pesticides are none as some farmers are fully subsidized by government. As for the environmental data, the average temperature of the area of study monthly is 34.2 degree Celsius with the mean rainfall of 180.43 mm. There were cases were the maximum temperature reach 50 degrees Celsius during drought season and rainfall of 500 mm which caused flood.

Table 3: Frequency of Categorical Variables

Variable		**Frequency**	**Percent**	**Valid Percent**
State	Perlis	26	29.2	29.2
	Kedah	63	70.8	70.8
	Total	89	100.0	100.0
Gender	Male	78	87.6	87.6
	Female	11	12.4	12.4
	Total	**89**	**100.0**	**100.0**
Educational level	No formal education	4	4.5	4.5
	Primary	17	19.1	19.1
	Secondary	39	43.8	43.8
	Pre-uni, STPM, diploma	18	20.2	20.2
	First degree	4	4.5	4.5
	Master	7	7.9	7.9
	PhD	0	0	0
	Total	**89**	**100.0**	**100.0**
Experience	Less than 1 year	0	0	0
	1-2 years	1	1.1	1.1
	2-5 years	12	13.5	13.6
	5-10 years	26	29.2	29.5
	More than 10 years	49	55.1	55.7
	Total	88	98.9	100.0
	Missing	1	1.1	
	Total	**89**	**100.0**	
Marital status	Married	75	84.3	84.3
	Single	6	6.7	6.7
	Widower	4	4.5	4.5
	Widow	4	4.5	4.5
	Total	**89**	**100.0**	**100.0**

From statistics on Table 3, the farmers or respondents in study are mainly from Kedah (70.8 percent). The rice farming activities are not only done by male farmers (87.6 percent) but also by females (12.4 percent) and most of them are married (84.3 percent). Majority of farmers have moderate level of education with more than 50 percent of them achieve a maximum of primary or secondary level education. Nonetheless, more than 30 percent of respondents obtain tertiary education as the farming activities might be inherited from parents through land inheritance and difficulties to search for qualified jobs. Surprisingly, 55.7 percent of farmers are having more than ten years' experience in rice farming activities.

3.1. Technical Efficiency of Rice Farmers - The Stochastic Frontier Model

In order to identify the factors affecting rice yield and assess the technical efficiency of rice farmers in Kedah and Perlis, the stochastic frontier production function approach is applied. A Cobb-Douglas stochastic frontier production function is assumed to be the appropriate model for analysis. Several statistical tests of null hypotheses of interest for the stochastic frontier model were conducted using likelihood ratio test. These tests were used to select the preferred frontier models for the presentation of empirical results.

Economic efficiency refers to two components: technical efficiency and allocative efficiency. Technical efficiency can be defined as the ability to achieve a higher level of output, given a same level of production inputs. Both technical and allocative efficiency are necessary and sufficient conditions for achieving economic efficiency. It could be said that the estimated technical efficiency of farm production is able to find out the gap between the actual output level and potential output level.

The estimation is based on strict assumptions and due to limited sample size, precaution on the interpretation to the results of estimation is required. Consider the parameters lamda (λ) or sigma (σ) associated with the variance of the technical inefficiency effects in the stochastic frontiers in Table 4, they are significantly different from zero.

Table 4 shows the maximum likelihood estimates for parameters of the frontier production and inefficiency functions. In the pooled model, the variable of land was highly significant at 1% and showed the strongest positive effect on output per farm/harvest in equation 1, 2 and 4. This clearly shows that land area is an important resource that led to higher technical efficiency to obtain more output. Based on equation 1 and 2, when environmental variables were not included in the model, a one percent increase in the number of hectares of land increased the value of output by 0.39% to 0.48%. Maintaining the same positive sign, however, the response to an increase in one percent of hectare of land only contributed to 0.06% of output with the environmental variables are taken as control variables (in equation 3 and 4). Previous study by Tinaprilla et al. (2013) reported that the level of technical efficiency in rice production in Java was 74.22 percent with the most sensitive land variable affecting rice production. In addition, Kusnadi et al. (2011), Nwaru and Iheke (2010), and Yoko et al. (2014) also marked high and positive elasticity between land area and rice production.

Table 4: Maximum Likelihood Estimates of the Stochastic Frontier Production Function

Variable	(1)	(2)	(3)	(4)
Stochastic frontier (dependent variable = lny)				
lland	0.394*** (1.8e+05)	0.483*** (9.4e+04)	-0.004 (-0.29)	0.062*** (18.26)
lseed	2.071*** (1.4e+04)	5.237*** (1.8e+04)	5.368*** (4.73)	5.086*** (46.33)
lirr	0.285*** 5.4e+04	0.251*** (3.4e+04)	-0.007 (-1.12)	-0.033*** (-6.33)
lcap	-1.927*** (-1.2e+04)	-5.165*** (-1.7e+04)	-5.309*** (-4.63)	-4.996*** (-43.25)
lfert	-0.027*** (-1.8e+04)	-0.004*** (-1524.3)	-0.067*** (-25.07)	-0.083*** (-61.83)
lpest	-0.149*** (-7.8e+04)	-0.022*** (-3498.2)	-0.059*** (-8.25)	-0.191*** (-46.16)
llabor	0.049*** (1.3e+05)	0.043*** (7.1e+04)	-0.045*** (-8.42)	-0.014*** (-7.48)
dum_lndtype3			-0.754*** (-25.71)	-0.477*** (-53.02)
dum_soiltype3			2.072*** (53.54)	1.687*** (83.92)
lrain			1.52e-06 (0.00)	0.009*** (6.03)
ltemp			-0.917*** (-46.07)	-1.457*** (-210.62)
dum_flood3			0.959***	1.157***

			(66.71)	(211.10)
dum_drght3			-0.166*** (-18.93)	-0.321*** (-77.60)
constant	8.978*** (3.6e+05)	8.595*** (2.4e+05)	11.778 (.)	14.194 (.)
Inefficiency model (dependent variable = Mu)				
exprc	-0.519 (-0.86)	-0.855 (-1.14)	-0.697 (-1.57)	-1.337* (-1.78)
lage	-2922 (-1.42)	-3.658 (-1.63)	-0.154 (-0.11)	-4.436** (-2.50)
educ	-1.625* (-1.78)	-1.487* (-1.67)	-0.365 (-0.71)	-0.789 (-1.16)
dum_gender	0.521 (0.42)	0.971 (0.71)	-0.045 (-0.05)	1.287 (1.02)
lfamsize	-0.296 (-0.24)	-1.131 (-0.80)	0.764 (0.75)	0.869 (0.55)
dum_state	10.000* (1.68)	13.322** (1.79)	34.136*** (3.15)	17.788** (2.50)
dum_married	-1.945 (-1.40)	-2.557 (-1.57)	-2.398** (-2.29)	-6.689*** (-2.91)
linc	-0.233 (-0.37)	0.054 (0.09)	-0.763 (-1.49)	-1.026* (-1.66)
dum_notrain		2.598 (1.36)		7.802** (2.48)
dum_nolink		-1.833 (-1.06)		-0.426 (-0.29)
dum_infoint		2.059 (1.39)		1.095 (0.89)
constant	10.934 (1.20)	8.075 (0.84)	-22.414 (-1.95)	10.687 (.)
sigma_u	1.798***	1.829***	1.423***	1.631***
sigma_v	6.44e-09	1.14e-08	0.0001	0.0003
lamda	2.79e+08***	1.60e+08***	13568.82***	5298.74***
Log likelihood	-51.1382	-48.8145	-19.3021	-17.0811
Number of obs	80	80	73	73
Wald Chi-square (prob)	2.21e+11 (0.000)	1.01e+11 (0.000)	2.06e+07 (0.000)	8.19e+06 (0.000)

Note: Standard errors are in parentheses; ***statistically significant at the 1% level; **5% level; *10% level.

Table 5: Descriptive Statistics of Technical Efficiency from Regression (4)

Variable	obs	Mean	Std. Dev.	Min.	Max.
Technical efficiency	73	0.629	0.340	0.0055	0.9993

The rice output per harvest increased by 2% to 5.3% with a 1% increase in seed rate, ceteris paribus. High elasticities were found in models which include environmental variables as compared to baseline models. Increasing the seed rate in a good environment can boost rice production by optimising plant density, improving resource utilisation, minimising weed competition, and enhancing yield components. Nevertheless, it is crucial to determine the ideal seed rate for particular circumstances in order to maximise these advantages while avoiding detrimental consequences resulting from excessive planting density (Sowmyalatha et al., 2011). In a study by Suphannachart (2013), it is also found that the positive determinant of rice production is the superior seed variable. As of irrigation, the positive coefficients are traced in two baseline equations with no environmental variables which indicate that a 1% increase in irrigation number per year, increased the output per harvest by 0.3%. The findings are supported by Puspitasari et al. (2019) which indicated that irrigation has an impact and can increase food crop production, particularly rice. Nonetheless, Muzdalifah (2014) also noted that irrigation has a major impact on lowland rice production. However, the impact was opposite (significant and negative with 0.03 of elasticity value) when the environmental factors were considered in equation 4. This clearly shows that environmental effect is significantly change the technical efficiency of producing the rice from higher production to low production through irrigation. This implies that irrigation procedures should be meticulously tailored to suit certain environmental circumstances to maximise rice production. The statement emphasises the significance of precision agriculture and site-specific water management systems in order to ensure that irrigation has a positive influence on crop output while avoiding any negative effects on the environment (Bouman, 2007).

Similarly, the coefficients of labour switch from positive to negative sign when environmental factors are included in the models. The positive coefficients in equation 1 and 2 of baseline models imply the important of labour in technological efficiency of rice production. While all coefficients in all four equations were highly significant, the negative sign of labour coefficients appeared in equation 3 and 4, with environmental factors were treated as control variables. Since the environmental factors were temperature, rainfall as well as impact from flood and drought, they could indirectly cause negative impact on the productivity of labour toward producing more rice output.

The rice yield decreased by 0.004% (without environmental factors) and by 0.083% (with environmental factors) with a 1% increase in fertilizer dose. The negative signs of all coefficients construe the adverse impact of fertilizers on the technical efficiency of rice production in the Malaysian farms. The result is supported by the findings of Islam et al. (2004), Bäckman et al. (2011), Khan et al. (2010) in case of Bangladeshi farms using cost of fertilizer as an input of rice production and in a study by Gunawan et al. (2022) in the case of farms in Aceh, Indonesia. Government subsidy for fertilizer may encourage the farmers to use too much urea (low-cost fertilizer with the highest Nitrogen content) and it may have long term damaging effects on the long-term productivity of soil. Likewise, some of these studies also found that pesticide cost decreased output of rice including a study by Hasnain et al. (2015). This is similar to the results obtained currently where the coefficients of pesticide cost are negative and inelastic in all four equations shown in Table 4. The results might indicate that pesticides are being overused by the farmers in the study area possibly as an insurance premium against blast and other pests and diseases. It can also influence the environment negatively and therefore; it is suggested that they should use these inputs with appropriate dose. Agricultural policies devised to consider both the production and the environmental efficiency of chemical fertilizer may help the farmers to reduce production costs and conserve the environment (Tu et al., 2018).

The negative coefficients of cost of machines/mechanical power (lcap) in all models imply the higher the cost of machines used in the farming activities did not result in increased rice output yield. The presence of negative coefficients in the models indicates that after reaching a certain threshold, the benefits gained from adding more machinery or mechanical power diminish and may even become detrimental. This aligns with the concept of diminishing marginal returns. When technology is initially introduced in the setting of rice cultivation, it has the potential to greatly enhance output by substituting manual labour and improving efficiency. With the addition of more machinery, the marginal advantage begins to diminish as the maximum level of mechanisation has already been achieved. Past a certain threshold, further investment in machinery can potentially result in inefficiencies, such as equipment congestion, underutilization, or heightened maintenance expenses. Beside this, if machinery is not utilised optimally, the expenses associated with machines can surpass the advantages. This encompasses incorrect functioning, insufficient training, and inadequate upkeep.

In addition, farmers need to choose the most appropriate power source for any operation depending on the work to be done. The level of mechanization should meet their needs effectively and efficiently. Putting together an ideal machinery system is not easy. Equipment that works best one year may not work well the next year because of changes in weather conditions or crop production practices. Decline in rice production due to high cost of machines used might source from the inefficiency use of capital, that is not using it at full capacity. Houssou and Chapoto (2015) also highlighted that in many African contexts, high machinery costs coupled with inefficiencies result in minimal productivity gains.

The inclusion of environmental factors into the basic stochastic frontier model has shown interesting findings in general (refer to equation 3 and 4 in Table 4). Almost all environmental variables are significant at 1 percent level. A dummy variable of land type3 (low land) is significant in both equations with negative sign implying that low land is producing less rice production than other types of land (medium or high land) in the case of Kedah and Perlis rice farms. The positive coefficients of soil type3 (clay) dummy variables, on the other hand, indicate the importance of clay as a soil to produce rice in the study areas as compared to other types of soils such as loamy and peat or organic. Nevertheless, rainfall contributes positively to the rice yield but high temperature decreases the rice production. Since high temperature is parallel to possible drought, a dummy variable of loss crop yield of 21% to 30% (dum_drght3) also show negative sign in both equations. Meanwhile, a dummy variable of loss crop yield of 21% to 30% from flood (dum_flood3) was with positive sign which implies that large volume of rainfall or flood is not giving adverse impact to the rice production as compared to the drought season. Hence, if farmers want to increase technical efficiency in rice production, consideration of environmental issues such as temperature, rainfall, type of land and soil should be taken into account. Less extreme high temperature, probably with more rainfall and clay soil might offers ample opportunities for more efficiency in rice production.

The coefficients associated with age of farmers and farming experience in the inefficiency function were both negative and statistically significant, implying that both older and more experienced farmers contribute to less technical inefficiency. As farmers gained more experience which normally among the older farmers, they became better equipped and more knowledgeable in rice farming. Thus, they were more efficient in the use of labour, seeds, and fertilizer inputs, which were more responsive to output. Similarly, the negative and significant coefficients of education variable in equation 1 and 2 clearly illustrate that those with higher education were performing better with less technical inefficiency. Farmer status of married as well as high income gained per farming also lead to less technical inefficiency and better performance of farmers. The dummy variable of state is significant in all equations with consistent positive sign which illustrates the inefficiency in rice production is obvious in Kedah as compared to Perlis. Nevertheless, the significant and positive dummy variable of ‘no training received’ construes the importance of training to farmers to reduce technical inefficiency in rice production.

The average technical efficiency for the sample farmers, using full specification (equation 4), is 62.9% (see Table 5) with minimum of 0.05% and maximum of 99.9%. This implies that on the average, the farmers are able to obtain 62.9% of potential output from a given mix of production inputs as well as environmental consideration. In the short-run, therefore, there is a scope for increasing rice production by 37.1% by adopting the technology and techniques used by the best practice rice or paddy farms. For farmers in the two states to attain 100% frontier output, they would have to close the gap between their current output and the maximum potential output. This would be plausible by addressing the determinants of inefficiency in rice production. One suggestion is that farmers should engage themselves in activities that would enable them to get more training from public or private institutions to improve rice production which could adopt to environmental changes such as high temperature. No doubt, this is also an indication for the need of governments and other relevant authorities to provide necessary rice production-related information to help reduce the gap (Alem et al., 2019; Lu et al., 2021a;

Manda et al., 2016; Mulungu & Tembo, 2015). Information may be provided through farmer trainings with a focus on relevant rice technologies, especially with the technologies that improve rice varieties, crop diversification, mixed cropping systems, and other sustainable land management strategies (Lu et al., 2021b; Masasi et al., 2020) that are associated with improved rice productivity for environments encountered by the farm areas.

4. Conclusion and Recommendations

The current study attempts to investigate the impact of environmental factors such as soil type, land type, temperature, rainfall and lost from flood and drought on the efficiency of rice production in Malaysia. The general form of the Cobb–Douglas stochastic production frontier function is used to estimate the production frontier 'with' and 'without' the environmental variables. Data were collected through interviews with heads of households who work as rice farmers and the survey is confined within states of Kedah and Perlis as the rice bowl of Malaysia. 89 responses were obtained from the survey at the farm areas. The findings from the study indicate that average technical efficiency for the sample farmers is 62.9% which implies that on the average, the farmers are able to obtain 62.9% of potential output from a given mix of production inputs as well as environmental consideration. There is a scope for increasing rice production by 37.1% in the areas of study. Among environmental variables, high temperature is found as a factor that decreases the rice production. Meanwhile, technical inefficiency in rice production is contributed by less experience and young farmers, no training received, and less educated farmers.

As policy recommendation, the effort by MAFI in drafting initiatives for the comprehensive transformation of the paddy and rice industry through the National Food Security Policy Action Plan (DSMN) 2021-2025, which is aimed at boosting paddy production and farmers' incomes, should be enhanced to encounter the impact of climate change on the nation's food security. The plan currently covers research and development efforts to enhance food production using climate-based technology. Various initiatives including cultivating paddy using the SMART Large-Scale Field concept; applying the site-specific nutrient management system; and utilising modern cultivation techniques such as drones for spraying pesticides and the latest machinery for planting and harvesting purposes (Bernama, 2021). The government has also over the years been providing yearly allocations to build and improve irrigation systems in paddy fields. Tube wells and dams have been built for water storage considering that paddy cultivation is largely dependent on rainfall. Other measures to increase rice production are the implementation of the alternative wetting and drying (AWD) innovation, which is an irrigation scheduling technique to replace the continuous flooding (CF) irrigation system. The development and utilisation of seeds of paddy varieties that can withstand the effects of flooding and droughts (anaerobic and aerobic varieties) are also being done, as well as the introduction of agricultural insurance to mitigate the risks of climate change. MAFI is also supporting the National Water Balance Management System (NAWABS) program by the Ministry of Environment and Water for the effective development and management of the nation’s water resources and which is being used as a reference in paddy cultivation management. Through this program, rain forecast data from Met Malaysia and data from the National Water Research Institute of Malaysia’s Climate Change Impact research have been integrated to provide information on drought forecasts and availability of water resources two months in advance. Warnings will be issued as early as 14 days in advance to the relevant authorities in charge of water management at the state and federal levels. By using this system fully, state water management (authorities) can make decisions pertaining to irrigating paddy fields, such as suggesting procedures like cloud seeding in catchment areas around dams if it doesn’t rain for days and the water level in a dam is decreasing. All these efforts are part of the recent 12th Malaysia Plan to boost the nation’s self-sufficiency level in rice production to 75 percent by 2025. Besides, MAFI is also committed to addressing food security in other agro-food sectors such as fruits and vegetables, livestock, fishery, and aquaculture through the implementation of the National Agrofood Policy 2021-2030 (NAP 2.0) which is driven by five core pillars, including increasing modernisation and smart farming, strengthening the domestic market, and producing export-oriented products. Nevertheless, from factors exerting significant impacts on the performance of rice production, to the extent that these factors are subject to government influence, they can be manipulated to improve overall environmental performance such as introducing some interventions like farmers field schools or other training on how to manage the risk associated with different environmental condition.

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