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Article

Technical Efficiency and Its Determinants of Rice Production in Cambodia

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Abstract: The present study aims to measure the technical efficiency and establish core factors effecting rice production in Cambodia. Four-years dataset generated from the central government document "*Profile on Economics and Social*" of entire 25 provinces between 2012-2015 and the stochastic production frontier model (SFA) was applied. The results indicated that the level of output (quantity) of Cambodian rice production varied according to the different level of capital investment in agricultural *machineries*, total rice actual *harvested area*, and technically *fertilizers* application within provinces. Furthermore, evidence revealed the overall mean efficiency of rice production is 78.4% implies that there is still room to further improve technical efficiency by given the same level of inputs and technology. More importantly, the findings revealed that *irrigation*, *production technique* and amount of *agricultural supporting staffs* are being as the most important influencing factors of rice production's technical efficiency in Cambodia. In conclusion, present study strongly recommends the development of irrigation systems and good water management practices to be considered and bring into more effective actions by the central government as well as related agencies for improving rice production in Cambodia in addition to capital investment and improving technical skills of supporting staffs and rural farmers.

Keywords: technical efficiency; SFA; rice production; Cambodia; agriculture; productivity

JEL Classification: C01; C33; C51; C87; E23; M11; O33

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1. Introduction

Economy of Cambodia is largely dependent on agricultural sector which contributes 27% of national GDP (Gross Domestic Product) in which 65% of the labor force are engaged [1]. Growth in agricultural sector has played a crucial role in the development of Cambodia [2]. Since 2004, garments, construction, agriculture, and tourism have driven Cambodia's growth. Between 2010-2013, GDP climbed more than 7% annually [3], and GDP per capita in purchasing power parity has increased from $2,462 (US Dollar) in 2010 to $3,056 in 2013 [4]. However, although Cambodian's per capita income is rapidly increasing, it still remains low compared to other nations in the region. Most rural households depend on agriculture and its related sub-sectors; and rice, fish, timber, garments and rubber are Cambodia's major export products [3].

Rice production is the central to Cambodian agricultural sector, not only do the majority of Khmer farmers depend both directly and indirectly on the success of the rice crop each year, and as it is the main food staple, rice production is a big factor in the national effort to promote food security. It occupies more than 80% of total cultivated land, and is the most important agricultural export commodity, as well as the main source of crop value added and the major driver of agricultural growth [5]. Being one of the most important staple crops for human consumption, rice plays an unprecedented role in combating food insecurity. Further, rice becomes a key economic crop

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dominated most agricultural economies in the world, particularly in developing countries like Cambodia.

Having similar characteristics to other agricultural crops, nowadays the growth of rice production yield seems to depend on three important aspects: (a) enlarging planting areas, (b) increasing input of material factors, and (c) raising productivity gradually [6]. Due to the limitation of planting area and material input factors, along with the result of rapid population growth from 11.4 million in 1998 to 15.5 million in 2014 [7, 8] and, thus, an increasing demand of land areas and material input factors for non-farm activities, raising productivity of rice production should be the most preferable factor among the three factors previously described.

Khmer farmers have been growing rain-fed rice for at least 2,000 years, possibly longer in the case of upland rice [9]. Today, rice production still serves as the foundation of Cambodian economy. Between 1980-2010, rice production yield has been doubled from 1.21 tons/ha to 2.97 tons/ha [10]. However, productivity of Cambodian rice still has been relatively low compared to other Asian countries, such as Myanmar, Indonesia, Vietnam, Japan, South Korea, and China where rice productivity in 2010 was recorded 4.12 tons/ha, 5.01 tons/ha, 5.32 tons/ha, 6.51 tons/ha, 6.51 tons/ha, and 6.55 tons/ha respectively [11]. Therefore, in order to raise the productivity of rice production in Cambodia, it is important to identify the core factors influencing it.

The main objective of this study was to measure the technical efficiency (hereafter, TE) of rice production in Cambodia. Additionally, the study was also trying to identify core influencing factors of TE in order to explain the possibilities of increasing productivity and profitability of rice by increasing efficiency at provincial level, as well as identify what technical progress policy should be recommended to help decision-makers to increase the rice productivity in Cambodia. The results of this study will be useful for both rice producers and policy makers in government and all other stakeholders along the rice value-chain including development agencies, non-government organizations (NGOs) and many other related parties working towards improving rice production and the agricultural sector at large.

The rest of this article is organized as follows: section 2 presents analytical frameworks and methodology for measuring rice production TE, while in section 3 the data and descriptive statistics of output and input variables is presented. The results are presented, compared, and discussed in section 4. Finally, conclusion remarks are offered in Section 5.

2. Methodology

In the economics literature, productivity refers to the amount of output(s) obtained from given levels of input(s) in an economy or a sector. It is an important topic of study, since productivity is one of the two fundamental sources of larger income streams; the other being savings, which permit more inputs for employment [12]. Coelli, Rao [13] argued that productivity is the ratio of the output(s) that it produces to the input(s) that it uses [Productivity = Output(s) / Input(s)]. In other words, productivity is raised when growth in output(s) outpaces growth of input(s). Productivity growth without an increase in input(s) is the best kind of growth to aim for rather than attaining a certain level of output [14]. Nevertheless, measuring the total input and total output is both conceptually and empirically difficult. Methods to estimate productivity and efficiency that commonly and frequently implement in most of today's empirical works are data envelopment analysis (DEA) and stochastic frontier analysis (SFA), which are non-parametric approach and parametric approach respectively.

Among DEA and SFA, which method should one use often depends on the application being considered. The SFA is recommended by Coelli [15] for use in most agricultural applications. This method has the added advantage of permitting the conduct of statistical tests of hypothesizes regarding the production structure and the degree of inefficiency. However, if an application is using farm level data where measurement error, missing variables (e.g. data on an input is not available or not suitably measured), weather, etc. are likely to play a significant role, then the assumption that all

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deviations from the frontier[1] are due to inefficiency, which is made by DEA, may be a courageous assumption. Thus, only a small percentage of agricultural frontier applications have used the DEA approach to frontier estimation. However, DEA has a very large following in other professions, especially in the management science literature, and in applications to service industries where there are multiple outputs, such as banking, health, telecommunication and electricity distribution, include [16],[17],[18],[19],[20], etc. Another benefit of SFA approach is determinants of inefficiency which allowed external factors affecting efficiency of firms to be determined where unavailable in DEA approach. SFA, hence, was applied by a large number of papers in the recent years, particularly in agricultural researches. For instance, the studies implemented SFA approach include [21],[22],[23],[24], etc. Further detailed discussion of the differences between DEA and SFA has been given in Coelli [15]. Therefore, SFA was also being applied to the present study.

Productivity and efficiency studies have taken the attention of most economists and policy makers in recent years, since there is no meaningful welfare improvement and economic development can take place in the absence of productivity growth [10]. Productivity is a basic and intuitive measure of performance. Furthermore, total factor productivity (TFP[2]) is a method of measuring businesses performance. TFP is used both in competitive and regulated industries, such as electricity distribution companies [26] for instance. It is a method of measuring productivity and growth, which is a productivity measurement involving all factors of production. Other traditional measures of productivity, such as labor productivity in a factory, fuel productivity in power stations, and land productivity (yield) in farming, are often called partial measures of productivity. These partial productivity measures can provide a misleading indication of overall productivity when considered in isolation [27].

However, agricultural productivity and efficiency studies as well as rice production efficiency studies in Cambodia seem to be very poor. Most of research works were conducted by the related government agencies, such as National institute of statistics (NIS), Ministry of agriculture, forestry and fishery (MAFF), Cambodia Development Resource Institute (CDRI), Cambodia Agricultural Research and Development Institute (CARDI), etc. Thus, only a few research works were conducted by the scholars. Given the scarcity of literature on efficiency in Cambodia, the present study therefore seeks to augment literature and contribute in many ways to bridge the gap and supplement the shortage.

The objective of this study was achieved through the estimation and analysis of the stochastic production frontier model (hereafter, SFA model), originally proposed by Aigner, Lovell [28], and Meeusen and Van den Broeck [29]. The most commonly used package for estimation of SFA model is FRONTIER 4.1c, see Coelli [30]. The general form of the SFA model:

$$Ln\, y_{it} = Ln\, f(x_{it}, t\, ;\, \beta) + v_{it} - u_{it} \tag{1}$$

where *Ln* indicates the natural logarithm function form; y_{it} and x_{it} denote rice production output(s) and input(s) within period *t* respectively; β represent estimated coefficients; v_{it} is statistical random error, assumed to be normal distribution, $v_i \sim N(0, \sigma_v^2)$; u_{it} denotes technical inefficiency, assumed to be truncated normal distribution, $u_i \sim |N(0, \sigma_u^2)|$; v_{it} and u_{it} are assumed to be independent; *i*=1,2,…,*N*; *N* is number of measurement unit (MU_i), i.e. total samples; and *t* is time variable measured as year, *t*=1,2,…,*T*.

The present study utilized the logarithmic form of translog production function, thus equation (1) above can be written as:

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[1] According to 15. Coelli, T.J., *Recent Developments in Frontier Modeling and Efficiency Measurement.* Australian Journal of Agricultural Economics, 1995. **39**(3): p. 219-245. "Frontier" refers to a bounding function, which provided benefits of heavily influencing of the best performing firms in in a field (of economics), that always reflect the technology they are using. Additionally, the frontier function represents a best-practice technology against which the efficiency of firms within the industry can be measured.

[2] Also called multi-factors productivity (MFP) in some lectures, like 25. Zheng, S. and H. Bloch, *Australia's mining productivity decline: implications for MFP measurement.* Journal of Productivity Analysis, 2013. **41**(2): p. 201-212.

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$$Ln\, y_{it} = \beta_0 + \sum_j \beta_j Lnx_{jit} + \beta_t t + \frac{1}{2}\sum_j \sum_k \beta_{jk} Lnx_{jit} Lnx_{kit} + \frac{1}{2}\beta_{it} t^2 + \sum_j \beta_{jt} Lnx_{jit} t + v_{it} - u_{it} \quad (2)$$

The technical inefficiency effect can be expressed in following general form:

$$u_{it} = \delta_0 + \sum_{k=1}^{n} \delta_k z_{kit} + \omega_{kit} \quad (3)$$

where ω_{kit} is the stochastic noises; z_{kit} denotes exogenous variables that are factors affecting Cambodia's rice production TE; δ_0 and δ_k are estimated coefficients; if δ_k is negative indicates positive relationship between affecting factor variables and TE of rice production, conversely, if δ_k is positive shows negative relationship between TE and affecting factors.

Followed by equation (2) and (3), the parameters estimation of SFA model can be achieved by applying maximum likelihood estimation method, which estimates the likelihood function in terms of two variance parameters, see Coelli [31]:

$$\gamma = \sigma_u^2/\sigma_s^2 \ ; \quad \sigma_s^2 = \sigma_v^2 + \sigma_u^2 \quad (4)$$

Gamma (γ) takes value between zero and one ($0 \leq \gamma \leq 1$), reflects validity of the random disturbances (v_i,u_i) proportion. If γ is closer to zero, it indicates that the gap between actual output and the maximum possible output mainly comes from other uncontrolled pure random factors, which makes the use of stochastic frontier model meaningless. In contrast, if γ is closer to one, it shows that the gap comes mainly from the effects of one or more exogenous variables z_{ki}, indicates using stochastic frontier production function model is more appropriate.

Rice production TE of every MU_i can be estimated by the ratio of observed output relative to the potential output defined by SFA model, as follow:

$$TE_{it} = y_{it}/f(x_{it}, t) = exp(-u_{it}) \ \leq 1 \quad (5)$$

TE value is always smaller or equal to one. When TE equal to one, indicates MU_i in the samples is fully technical efficiency. Therefore, the closer of TE value to one indicates the higher TE of rice production.

Technical efficiency change (hereafter, TEC) of every MU_i between period *t* and *t+1* is the ratio of TE in period *t+1* to its TE in period *t*, which can be expressed as the following formula:

$$TEC_i^{t,t+1} = TE_i^{t+1}/TE_i^t \quad (6)$$

3. Data and descriptive statistics

The data used for present study were drawn from the document sets of the Royal Government of Cambodia (hereafter, RGC), namely "*Profile on Economics and Social*" of entire 25 provinces in Cambodia (24 provinces and 1 municipality, Phnom Penh) from 2012 to 2015 (4-years dataset) [32, 33]. These document sets were prepared by Provincial Department of Planning of every province based on computer program namely Commune Database (CDB) that provided derived-data from village and commune data books which are annually documented and kept at commune/sangkat and village chief or village representative who is member of Planning and Budgeting Committee.

The SFA model was constructed by one output variable (i.e. *quantity*) and five input variables, included *land*, *labor*, *fertilizer*, *pesticide*, and *machinery*. Output variable was the total provincial un-milled rice production *quantity* (hereafter, *rice output*), which measured in tons. *Land* input was the total area of rice actually harvested within the year, measured in hectares (ha). In many agricultural nations, *land* always plays as an important input in production of agricultural crops like rice. Countries harvested larger land of rice tend to be able to produce higher amount of *rice output*, for example, Thailand and Indonesia where about 10-12 million hectares of rice was harvested annually compared to Cambodia that could harvested only 2-3 million hectares per year. Thus, production of rice in this two countries were respectively recorded around 20 and 36 million tons (of milled rice) annually, compared to only around 4 million tons per year produced in Cambodia [34]. Additionally, provinces of Cambodia that harvested more land of rice were also able to produce more *rice output* compare to provinces with lower rate of rice harvested land. For instance, the province of Battambang

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and Prey Veng where around 279 and 268 thousand hectares of rice area were respectively harvested in 2015 and produced more than 798 and 803 thousand tons of *rice output* (respectively), which was much higher compared to Phnom Penh suburbs that harvested on only 11 thousand hectares and produced about 2 thousand tons within this year [33]. Harvested area (i.e. *land* input), hence, was expected to have positive effect on provincial as well as total *rice output*. *Labor* input, on the other hand, measured as total farmers with rice farming as primary occupation (hereafter, rice farmers), unit in persons. According to dataset from RGC [32, 33], provinces with higher rate of rice farmers tended to produce higher amount of *rice output* since rice remains as their provincial dominant crop as well as the dominant commodity. Thus, *labor* input was also expected to have positive effect on *rice output*. Furthermore, *fertilizer* input measured as total amount of chemical and organic fertilizers' quantity using by total families cultivating rice (hereafter, rice families) in the province (unit in tons), while *pesticide* input also measured as total amount of poisons for insects and grass's quantity (for both chemical and organic poisons) using by total rice families in the province, unit in tons. Followed by the concept of green revolution [35], these two input variables were also expected to be positively related to *rice output*. Additionally, another important input variable was determined as the variable of capital investment on agricultural *machineries* which measured as total amount of tractors, walking tractors (*"koryons"* in Khmer language), and rice transplanting machines existing in the provincial territory. This input variable was also expected to have positive effect on *rice output* as well. Along with the global technological expansion, the development of agricultural sector was inevitably linked to the mechanization improvement as many works/tasks in agricultural production, particularly rice production in Cambodia (which normally is labor-intensive), could be completed faster and greater with the performances of these machineries. **Table 1.** provides summary statistics of the output and inputs of rice production within entire 25 provinces in Cambodia from 2012 to 2015.

Table 1. Input and output summary statistics for 25 rice producing provinces in Cambodia, 2012-2015

Variable	2012		2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Output								
Rice quantity[3] *(tons)*	290,808	52,994	329,872	60,296	391,150	80,437	315,270	57,785
Inputs								
Land[4] *(hectares)*	134,629	23,192	144,944	25,893	212,785	56,497	145,685	26,699
Labor[5] *(persons)*	168,703	27,044	163,805	26,208	160,163	25,683	155,159	24,486
Fertilizer[6] *(tons)*	74,061	13,236	75,027	13,300	160,043	13,436	79,038	13,618
Pesticide[7] *(tons)*	45,116	9,610	47,926	10,021	52,205	10,596	56,117	11,047
Machinery[8] *(units)*	10,196	1,937	12,213	2,135	14,569	2,394	16,762	2,675

Source: Measured by Ms. Excel 2016 using combined datasets of RGC [32, 33]. "S.E." = Standard Error.

Output *quantity* of rice production in Cambodia was higher in 2015 than in 2012 which increased 8.4% in average from 290 thousand tons (2012) to 315 thousand tons (2015). Total area of rice actually harvested in average also increased around 8% from 134 thousand hectares in 2012 to 145 thousand

[3] *Rice quantity* was the total provincial un-milled rice production output quantity, measured in tons

[4] *Land* input was the total area of rice actually harvested within the year (included both in wet and dry season), measured in hectares

[5] *Labor* input measured as total farmers in the province with rice farming as primary occupation, unit in persons

[6] *Fertilizer* input was total amount of chemical and organic fertilizers' quantity using by total rice families in the province, unit in tons

[7] *Pesticide* input measured as total amount of chemical and organic poisons for insects and grass's quantity using by total rice families in the province, unit in tons

[8] *Machinery* measured the capital investment on agricultural machineries was the total amount of tractors, walking tractors (koryons), and rice transplanting machines existing in the provincial territory, unit in units

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hectares in 2015. Total rice families using quantity of chemical and organic fertilizers (i.e. *fertilizer* input), on the other hand, increased in average by 7%, while *pesticide* and *machinery* input (definition same as above) increased greatly between this period. Total rice families using quantity of poison for insects and grass increased by nearly 25% (3-times larger than *land* and *fertilizer* input), while the total capital investment on agricultural *machineries* between this period increased by a huge percentage of 64.4%, indicated a huge improvement of mechanization in Cambodian agriculture, particularly in rice production sector. Nevertheless, along with the improvement of agricultural mechanization, *labor* input which measured as total people with rice farming as primary occupation tended to slightly decrease by 8%, presented the progression of transformation of labor forces out of agriculture to other higher productivity and profitability sectors, such as industries and services.

Figure 1. illustrates the percentage changes of input and output statistics of Cambodian rice production between the study period 2012-2015. A closer look to percentage changes within output and input variables from year to year indicated that from 2012 to 2013, there were not significantly changed within both output and input variables. However, there were a massive change in inputs, particularly in *land* and *fertilizer* between 2013-2014 which caused *rice output* to increased greatly. Unfortunately, the natural disasters (drought, flood, and insects) at the end of 2014 and in 2015 had destroyed a huge percentage of rice cultivated *land* in most leading rice production provinces (totally reduced around 30% of 2014 production) and *fertilizer* input was also decreased greatly (by more than 50%). *Rice output*, therefore, also decreased by a great percentage of 20%. Conversely, development of capital investment in agricultural *machineries* still continued to increase by 15-20% per year, while implementation of *pesticide* by farmers tended to increased 6-9% annually as well. *Labor* input, on the other hand, had the decreasing trend from year to year in the percentage of 2-3%.

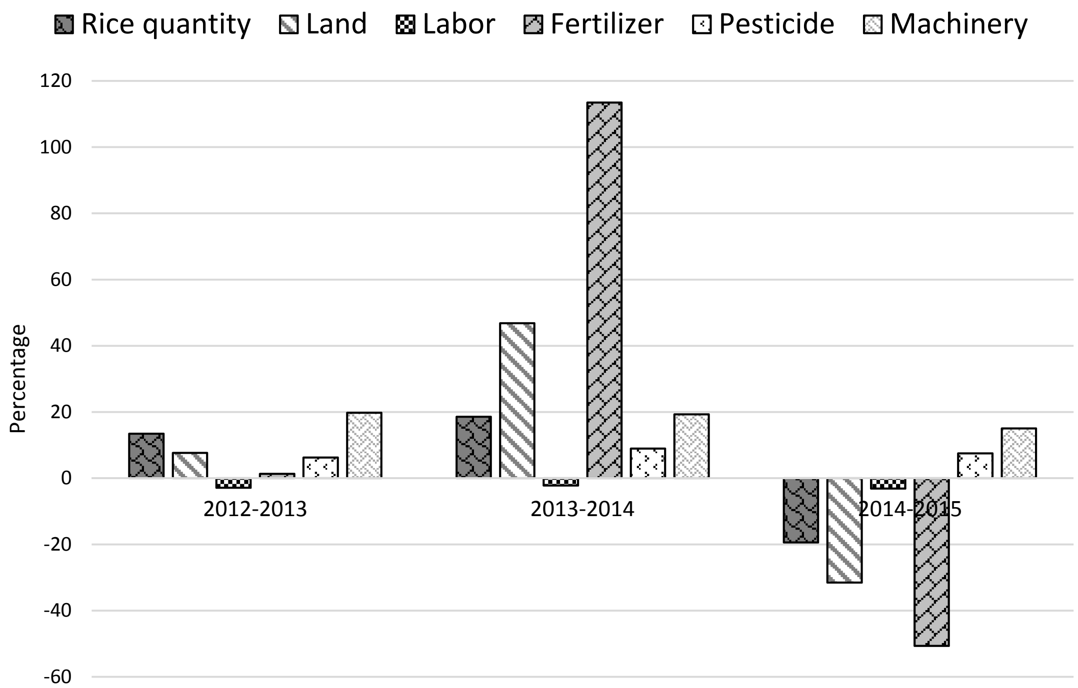

Figure 1. Percentage changes in input and output statistics for 25 rice producing provinces in Cambodia for the periods 2012-2013, 2013-2014, and 2014-2015

In the technical inefficiency model (3), there were seven influencing factors of rice production TE to be considered in the present study. *Disaster* measured as percentage of rice production land damaged by floods, droughts, and insects to total rice production land actually harvested within the year. Apparently, *disaster* always caused the lower of harvested land to cultivated land ratio. Thus, disaster was expected to have negative effect on rice production TE. *Irrigation*, on the other hand, measured as percentage of provincial paddy land having or benefit from irrigation systems (as well as paddy land located near water sources, such as rivers, lakes, ponds, etc.) to total provincial

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cultivated land within the year. Irrigation systems could cause the availability of rice cultivated land expansion by improving multi-cropping[9], hence, irrigation was stalwartly expected to have positive relationship with rice production TE. Additionally, *production technique* measured as percentage of families cultivating rice under the system of rice intensification (SRI) to total families cultivating rice. Under SRI which introduced by MAFF with the supporting of CEDAC[10], various rice cultivation techniques with less utilization of modern inputs and inexpensive method of planting in relatively dry area could result in an average yield of 3.6 ton/ha, while under a similar situation the yield with traditional farming practice is only 2.4 ton/ha [36]. Farmers cultivated rice under SRI were expected to have higher productivity than farmers using traditional techniques for cultivating rice. However, the percentage of families cultivating rice under this system still seem to be very low in Cambodia. Furthermore, farmers living in villages located closer to the center of district/khan might be able to get further and faster market information about rice, hence, this factor of *distant to information sources* was measured as average distance from village center to the center of district/khan (in kilometers). Agricultural staffs, on the other hand, might have played some crucial roles for providing technical supports as well as technical knowledge of rice production to the rural farmers. Thus, number of agricultural supporting staffs existing in province was expected to have positive effects on TE of rice production. The variable of *agricultural supporting staffs* was included in technical inefficiency model (3), measured as percentage of agricultural staffs included both government officers and NGOs staffs (working on agricultural plans or projects) to total rice farmers existing in the province. Likewise, there are two main seasons in Cambodia, i.e. wet season and dry season. Greater availability of water resource during wet season have caused rice crop to be able to grow in every provinces of Cambodia. However, during dry season only some provinces (as well as some parts of a province) where rice fields benefit from irrigation systems or located near water sources could be able to cultivated rice crop. Dry season rice crop always provides higher yield of production, nonetheless it requires plenty of water and utilization of fertilizers, as well as higher commitments to watch over. However, rice production during dry season of Cambodia was still highly depends on availability of water resources during this season. Available land for cultivating rice during dry season sometimes was abundance due to the lack of water. Thus, the improvement of dry season rice was expected to have positive effect on TE of rice production in Cambodia. The factor of *dry-season production* measured as percentage of dry-season paddy land actually harvested to total available land for rice cultivation in dry-season was correspondingly included in the model. Size of farm land owned by farmers was also expected to have positive effect on rice production TE. The great percentage of rice farmers owning farm land less than one hectare, which might cause limited ability for them to improve their rice production. This factor (*small-land farmers)* measured as percentage of families having paddy land smaller than one hectare altogether with families having no paddy land to total rice families. Conversely, some external factors, such as social, economic, demographic, as well as geographic perspectives of each province were omitted from the technical inefficiency model (3), due to un-sufficient availability of appropriated datasets during the study period. Furthermore, the present study utilized only four-years dataset of entire 25 provinces of Cambodia, which limited availability to included too many influencing factors into the model as it might cause unexpected conflicts or correlations among factor variables. Moreover, provinces of Cambodia were quiet tiny in area and normally the local governance as well as economy are still under directly controlled by the central government in Phnom Penh (i.e. provincial local government in Cambodia are not much independence from each other as the situation in other countries like China for instance). Therefore, the present study assumed these external factors to be neutral to rice production TE. Thus, equation (3) can be written as:

$$u_{it} = \delta_0 + \delta_1 Disaster_{it} + \delta_2 Irri_{it} + \delta_3 Tech_{it} + \delta_4 Distant_{it} + \delta_5 Staff_{it} + \delta_6 Dry_{it} + \delta_7 SmallF_{it} \quad (7)$$

[9] Multi-cropping: cropping/cultivating several times of crop on the same plot land

[10] CEDAC: Cambodian Center for Study and Development in Agriculture (Centre d'Etude et de Dévelopment Agricole Cambodgien)

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Table 2. Descriptive statistics of factors affecting the efficiency of rice production in Cambodia, 2012-2015

Variable	2012		2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Disaster[11]	18.86	12.34	5.16	1.12	30.98	26.37	5.20	1.16
Irrigation[12]	21.70	3.49	22.75	3.52	19.94	3.58	22.64	3.54
Production technique[13]	3.04	0.48	2.79	0.47	2.74	0.42	2.44	0.37
Distant info-source[14]	14.92	1.53	14.86	1.22	14.67	1.14	15.01	1.20
Supporting staffs[15]	0.11	0.03	0.10	0.02	0.09	0.02	0.09	0.02
Dry-season prod.[16]	68.47	5.72	58.76	6.33	65.12	5.89	64.91	6.43
Small-land farmers[17]	41.80	3.17	40.99	3.43	40.35	3.45	39.76	3.67

Source: Measured by Ms. Excel 2016 using combined datasets of RGC [32, 33]. "S.E." = Standard Error.

Table 2. presents descriptive statistics of Cambodian rice production efficiency's influencing factors between 2012-2015. Percentage of rice land damaged by floods, droughts, and insects was lower in 2015 compared to 2012. Rice land damaged by disasters in 2012 was 18.8% in average, while in 2015 disasters destroyed only 5.2% of rice production land in average (decreased by 72.4%). However, flooded in wet season of 2014 have still destroyed almost 30% of total rice cultivated land within the year. These percentages still remain huge, which ought to be considered by RGC and the related agencies. Furthermore, from 2012 to 2015, there were also large percentage changes in rural farmers' *production technique* and amount of *agricultural supporting staffs* existing the province. *Production technique* which measured as percentage of families cultivating rice under SRI decreased greatly by 20% within 3 years, while percentage of *agricultural supporting staffs* (to total rice families) also decreased by around 17% during this period, indicated lack of technical supporting techniques as well as technical improvement training for farmers in the purpose of improving the national rice production, particularly for small-land rural farmers which most of them are rice farmers. Although percentage of *small-land farmers* (farmers owned no rice cultivated land or having rice land smaller than one hectare) have been slightly reduced during the study period (less than 5%), in 2015 *small-land farmers* in Cambodia still accounted for 39.8% in average which was still the vast percentage. Moreover, during the dry season, available land for cultivating rice still not fully cultivated yet. In the study period 2012-2015, in average more than 30% of available dry season rice land was abundant annually. During 2012, in average only 68.5% of the total available dry-season rice production land had been actually cultivated and this percentage became worse in 2013 (58.8%). Although situation had been faintly improved in 2014 while this percentage slightly increased to 65.1%, water shortage during the dry season of 2015 had reduced the percentage of dry-season actually cultivated again to around 64.9%. Therefore, there is still a huge gap for Cambodian famers to improve their rice production during dry season as well as total production of rice.

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[11] *Disaster* measured as percentage of rice land damaged by floods, droughts, and insects to total rice actual harvested land within the year

[12] *Irrigation* measured as percentage of provincial paddy land having or benefit from irrigation systems as well as paddy land located near water sources to total provincial cultivated land within the year.

[13] *Production technique* measured as percentage of families cultivating rice under the SRI system to total rice cultivated families

[14] *Distant to information sources* measured as average distance from village center to the center of district/khan (in kilometers)

[15] *Agricultural supporting staffs* measured as percentage of agricultural staffs included both government officers and NGOs staffs (working on agricultural plans or projects) to total rice farmers existing in the province

[16] *Dry-season production* measured as percentage of paddy land actually harvested during dry season to the total available cultivated land for rice cultivation during dry season

[17] *Small-land farmers* measured as percentage of families having paddy land smaller than one hectare altogether with families having no paddy land to total rice families (i.e. families cultivating rice)

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Irrigation plays as a very important role for rice production in Cambodia, particularly in dry-season. Between 2012-2015, irrigation systems were improved gradually by increased the percentage of paddy land having irrigation system from 21.7% in 2012 to 22.6% in 2015 (3.5% increased within 3 years). However, this irrigation rate still seems to be very low compared to other agricultural nations, especially its neighboring countries like Thailand, and Vietnam, since another nearly 80% of total cultivated land still being performance as the rain-fed agricultural land. These statistics reveled that irrigation systems in Cambodia still remain lack, shortage far behind its potential to improve the national rice production. In many developed countries, irrigation systems were not only used for agriculture, but also being used as natural disasters prevention devices. Global climate change had been affecting Cambodia in the latest decade. Natural disasters like floods and droughts occurred more frequently than previous times. Sometimes, within a year, Cambodian people suffered from flood in wet-season, and then suffered again from droughts in dry-season. These could be the results of irrigation systems shortage, which caused Cambodia to had no ability to deal with such frequently-occurred disasters. What if Cambodia could build irrigation and water storage systems in order to store an over-needed water resources during the wet-season keeping for utilization in agriculture during the dry-season?

4. Results and discussion

4.1. SFA model estimation

Table 3. lists the parameters estimation results by implementing the maximum likelihood estimation method in FRONTIER (version 4.1c) econometrics software of Coelli [30]. The variance ratio parameter of gamma (γ) had a value of 1.00 and significant at 1%, shows that the variation of the composite error term was mainly from the technical efficiency (u_i) almost 100%, and the variation of random error (v_i) less than 1%, indicated the efficiency source of Cambodian rice production within the study period came mainly from the production's technical efficiency.

Table 3. Parameter estimates of SFA model

Variables	Coefficient	Standard Error	t-ratio
Constant	-1.1869 *	0.6189	-1.9178
Ln(land)	0.6796 ***	0.2475	2.7458
Ln(labor)	0.0775	0.3279	0.2364
Ln(fertilizer)	0.9245 **	0.4664	1.9820
Ln(pesticide)	-1.8588 ***	0.3565	-5.2139
Ln(machinery)	1.8642 ***	0.2629	7.0914
t	0.0573	0.0369	1.5529
Land x Labor	0.0420 **	0.0197	2.1339
Land x Fertilizer	-0.0771 *	0.0429	-1.7966
Land x Pesticide	0.1680 ***	0.0309	5.4381
Land x Machinery	-0.1210 ***	0.0241	-5.0263
Labor x Machinery	-0.0585 **	0.0271	-2.1577
t^2	0.0013	0.0068	0.1888
Gamma (γ)	1.0000 ***	0.0001	13,538.2280
Sigma-squared (σ^2)	0.0336 ***	0.0062	5.3882
Log likelihood function			75.7787

Source: Estimated by FRONTIER 4.1c. * indicates significant at 10%, ** significant at 5%, and *** at 1%.

Almost all estimated coefficients have the expected signs. Total actual harvested *land* and agricultural *machineries* involved in rice production were both positively related to *rice output* and significant at 1%, while the total amount of chemical and organic fertilizers' quantity using by total families in the province for the production of rice was also positively related but significant at 5%. These results indicated that enlarging in total actual harvested *land*, more capital investment in agricultural *machineries* and technically improvement of *fertilizers* application by smallholder rice producers (farmers) could cause the result in increasing output (quantity) of rice within the province. Moreover, with the estimated coefficient of 1.86, capital investment in agricultural *machineries* was the main input factor driven more output for Cambodia's provincial rice production compared to *land* and *fertilizer* input factor during the study period. This means that the provinces with higher capital investment (in agricultural *machineries*) tended to produce higher level of *rice output* than the provinces with lower capital investment.

Total actual harvested *land* was the second core input factor for increasing output of rice. The provinces which cultivate more additional lands of rice have the ability to maintain reasonable levels of other necessary inputs in order to cause the *rice output* to increase faster than the provinces with low rate of rice cultivated land. This result confirmed the results of several previous studies, such as Yu and Diao [5], Smith and Hornbuckle [37] and some studies of Asian Development Bank [2, 38]. Furthermore, total families using quantity of poison for insects and grass (included both chemical and organic poison) existing in the province, i.e. *pesticides* input factor, was negatively related to *rice output* and significant at 1%, indicated that provinces with more amount of poison (*pesticides*) application tended to produced lower *rice output* than the provinces with smaller amount of poison application. This could be the result of inefficiency used of poison in rice production by farmers. Be noted that most of smallholder rice producers are the farmers with low education. Furthermore, the instruction of product usage for most imported agricultural poison products have not been totally translated into Khmer language yet before imported (to Cambodia), which might cause numerous misunderstanding and leaded to incorrected technical used as well as inefficiency used in field practices by farmers. However, the study established that there was no significant relationship between *rice output* and the *labor* force involved in rice production.

Table 4. Input elasticities of rice production in Cambodia, 2012-2015

Year	Ln(land)	Ln(labor)	Ln(fertilizer)	Ln(pesticide)	Ln(machinery)
2012	0.9898	0.0465	0.0569	0.0317	-0.1701
2013	0.9816	0.0340	0.0559	0.0339	-0.1709
2014	0.9694	0.0248	0.0537	0.0386	-0.1729
2015	0.9632	0.0156	0.0551	0.0356	-0.1687

Source: Calculated by Ms. Excel 2016

Table 4. illustrates the input elasticities of rice production in Cambodia between 2012-2015. From this table, all input factors, except *machinery*, have had increasing return to scale to *rice output*, and elasticity of *land* input was the highest among all input factors, followed by *fertilizer* and *labor* input. Between the study period of 2012-2015, harvested *land* elasticity was 0.976 in average, indicated that 1 hectare increasing in harvested *land* could cause *rice output* to increase by 0.976 tons, while the other input factors just had minor of elasticity value (less than 0.10).

4.2. Technical efficiency analysis

The study indicated that individual provincial-level TE ranged from a low of 49.8% to a high of 99.7% with a mean technical efficiency of 79.5% in 2012. Rice production TE in 2015, on the other hand, ranged from a low of 36.8% to a high of 99.9% with a lower mean technical efficiency of 74% (7% decreased). However, the findings revealed that the overall mean of rice production TE is estimated as 0.784 which indicated that Cambodian produce 78.4% of rice at best practice at the current level of production inputs and technology. It means that *rice output* could have been increased further by 21.6% at same levels of inputs if farmers had been full technically efficient. There were only 10 out of 25 provinces have had TE above the TE overall mean, while TE of another 60% of provinces still ranged below the average mean efficiency.

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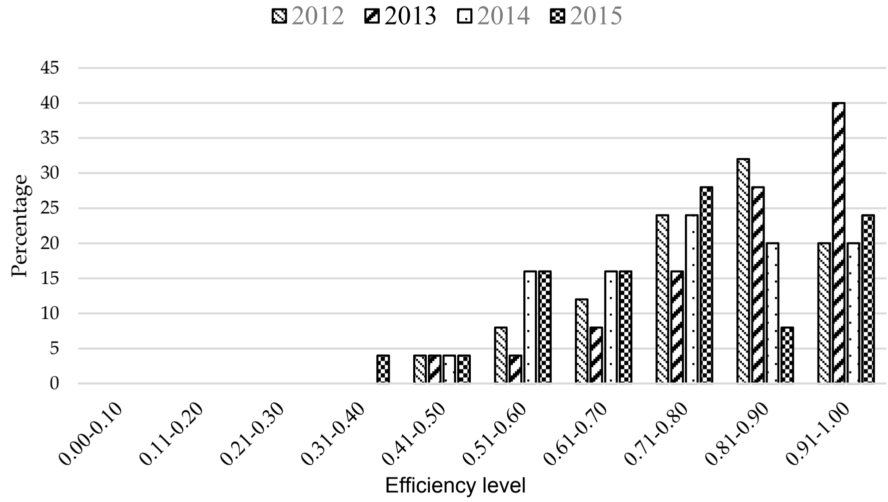

Figure 2. Technical efficiency distribution of rice production in Cambodia, 2012-2015

Figure 2. illustrates distribution of Cambodian rice production's TE from 2012 to 2015. Rice production in Cambodia performed very well during 2013, which 40% of provinces had technical efficiency score between 0.91-1.00, and another 28% had technical efficiency score between 0.81-0.90. Thus, in 2013 nearly 70% of provinces produce more than 80% of rice at best practice at the current level of their production inputs and technology. However, natural disasters in 2014 and 2015 caused the decreased in technical efficiency score in most Cambodian provinces.

Table 5. Regional technical efficiency of rice production in Cambodia, 2012-2015

Regions	2012		2013		2014		2015		TE Change (%)		
	M	*S.E.*	*M*	*S.E.*	*M*	*S.E.*	*M*	*S.E.*	12-13	12-14	12-15
Phnom Penh	0.83	0.00	0.84	0.00	0.81	0.00	0.61	0.00	1.2	-3.4	-26.5
Tonle Sap plain[18]	0.81	0.05	0.87	0.04	0.71	0.05	0.77	0.04	6.8	-12.4	-5.4
Mekong plain[19]	0.86	0.07	0.89	0.10	0.88	0.07	0.88	0.07	3.2	2.6	2.2
Mekong plateau[20]	0.79	0.04	0.79	0.04	0.74	0.06	0.70	0.06	0.0	-6.7	-11.3
Mountain[21]	0.66	0.09	0.76	0.08	0.63	0.09	0.53	0.09	14.6	-5.7	-19.7
Coastal[22]	0.81	0.07	0.84	0.06	0.86	0.09	0.79	0.08	4.7	6.3	-2.0
Cambodia	0.80	0.03	0.84	0.03	0.76	0.03	0.74	0.03	5.4	-3.9	-6.9

Source: Estimated by FRONTIER 4.1c; "M" = Mean; "S.E." = Standard Error; "12-13" = TE change between 2012 and 2013; "12-14" = TE change between 2012 and 2014; "12-15" = TE change between 2012 and 2015

Table 5. shows the rice production TE in different regions of Cambodia from 2012 to 2015. The results revealed that in the study period, *Mekong plain* which is the second-largest rice production region of Cambodia had highest TE score in almost all years from 2012 (0.860) to 2015 (0.878) among all regions, and the only one region have had increasing TE score during the study period 2012-2015 (by 2.2%). In 2015, all provinces in this region, except *Svay Rieng* province, had rice production TE

[18] Tonle Sap plain region included the province of Banteay Meanchey, Battambang, Kampong Chhnang, Kampong Thom, Pailin, Pursat, and Siem Reap. Total area: 61,510 km² (accounted for 34.54% of the total area)

[19] Mekong plain included the province of Kampong Speu, Kandal, Prey Veng, Svay Rieng, and Takéo. Total area: 21,997 km² (12.35%)

[20] Mekong plateau included the province of Kampong Cham, Kratié, Stung Treng, and Tbong Khmoum. Total area: 31,663 km² (17.78%)

[21] Mountain region included the province of Mondulkiri, Ratanakiri, Preh Vihear, and Oddar Meanchey. Total area: 45,016 km² (25.28%)

[22] Coastal region included the province of Kampot, Koh Kong, Kep, and Preah Sihanouk. Total area: 17,237 km² (9.68%)

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more than 91%. *Takeo* province was the most effective province in this region with the highest TE score of 0.999, while *Svay Rieng* province's TE score in 2015 was just 0.599. However, *Tonle Sap plain* which is the largest rice production region of Cambodia in production area had TE score of 0.814 in 2012, but decreased by 5.4% to 0.770 in 2015 as the results of natural disasters at the end of 2014 (flooded) and in 2015 (drought) that affected most provinces in this regions. The province with highest TE score in this region in 2015 was *Kampong Chhnang* province (0.914), while *Banteay Meanchey* was the province that had lowest TE score within the region.

4.3. *Technical inefficiency model and affecting factors*

Table 6. presents the parameters of the rice production's technical inefficiency model estimated by FRONTIER version 4.1c. In the model specification, it is obvious that *irrigation* and *production technique* both had negative coefficient signs and significant at 1%, while *agricultural supporting staffs* had also negative coefficient signs but significant at 5%, indicated positively related of these three factors to TE of rice production in Cambodia. These results revealed that development of *irrigation* systems and good water management practices, development of rice *production technique* to the rural farmers, and increasing the number of *agricultural supporting staffs* in the provincial territory are the three core factors to cause rice production TE to increase. With the highest coefficient of 0.95 and 0.08, the factor of *agricultural supporting staffs* and *production technique* played as the first and second core affecting factors respectively. Provinces with more agricultural supporting staffs existing and higher rate of families using SRI tended to have higher TE score than provinces with less amount to supporting staffs and lower rate of families using SRI, which indicated the important of technical supporting services from agricultural staffs (both government officers and NGOs staffs) and new production techniques implementation in rice production. These coefficient values (0.95 and 0.08 for *agricultural supporting staffs* and *production technique* respectively) indicated that 1% increasing of the percentage of agricultural supporting staffs (to total farmers cultivating rice) within the provincial territory and the percentage of families cultivating rice under the SRI system to total rice cultivated families, could cause the increasing of rice production TE by 0.95% and 0.08% respectively.

Table 6. Rice production technical inefficiency model parameters estimation

Variables	Coefficient	Std. Error	t-ratio
Constant	0.9241 ***	0.1484	6.2261
Disaster	0.0003	0.0005	0.5641
Irrigation	-0.0119 ***	0.0026	-4.5368
Production technique	-0.0841 ***	0.0283	-2.9688
Distant to information sources	-0.0052	0.0060	-0.8703
Agricultural supporting staffs	-0.9530 **	0.4032	-2.3635
Dry-season production	-0.0016	0.0016	-1.0549
Small-land farmers	-0.0007	0.0036	-0.2056

Source: Estimated by FRONTIER 4.1c. * indicates significant at 10%, ** significant at 5%, and *** at 1%.

Irrigation, on the other hand, served as the third core affecting factor of Cambodian rice production TE. With the coefficient of 0.01, revealed 1% increasing of the percentage of provincial paddy land having or benefit from irrigation systems (to total provincial cultivated land) within the year could push TE of provincial rice production to increase by 0.01%. In Cambodia, *irrigation* is mainly used for dry-season rice and to complete wet season rice if necessary. It is also an essential component to ensure that farmers can crop during the dry season. ADB [2] argued rice production's efficiency in Cambodia is always constrained by low-rates of irrigation, while Smith and Hornbuckle [37] suggested that rice yields could be improved by helping to better regulate water inputs. Khmer farmers are mostly able to cultivate rice only once per year because of inadequate irrigation systems and good water management practices.

Rice production in Cambodia still seems to be vulnerable to natural disasters, such as floods and droughts. As being discussed previously, *irrigation* systems and good water management practices was not only the core factors for improving rice production in Cambodia, but also the main disaster prevention devices for protecting Cambodia from natural *disasters*. Although percentage of rice land area damaged by floods, drought, and insects was not significantly affect rice production TE during the study period, frequently-occurred natural disasters still indirectly affect the rice production due to lack of irrigation systems. For instance, disasters occurred in wet season of 2014 (flooded) and in 2015 (drought), had been destroyed thousand hectares of rice fields caused the result of decreasing in total rice actual harvested *land* which was the second core input factor for increasing *rice output* after capital investment in agricultural *machineries*. Although arverage rice yield and rice price still continued to increase between 2014-2015, frequently-occurred of natural disasters still leaded the production of rice to decrease gradually from 2014 to 2015. *Irrigation* systems, therefore, should be the core factor to be considered and bring into actions by RGC and the related agencies. Conversely, the study established that there was no significant relationship between the factors of *distant from information sources*, *dry-season production*, amount of *small-land farmers* and rice production TE.

5. Conclusions

The aim of this paper was to estimate the TE of rice production in Cambodian and determine its main influencing factors by using the SFA model. The present study utilized four-years dataset generated from the central government document "*Profile on Economics and Social*" of all 25 provinces between 2012-2015. The results indicated that the level of *rice output* in Cambodia varied according to the different level of capital investment in agricultural *machineries*, total rice actual *harvested area*, and technically *fertilizers* application within provinces. The mean TE of rice production is 0.784 which means that famers in this region produce 78.4% efficiently rice at best practice, at the current level of production inputs and technology. This means that rice output has the potential of being increased further by 21.6% at the same level of inputs if farmers had been technically efficient. However, during the study periods the TE of rice production recorded a 7% decreasing rate. *Takeo* province was the most effective province nationwide, while another 60% of provinces still had TE below the average mean efficiency in 2015.

Three main conclusions emerged from the study's results. First, based on decomposing the SFA model, enlarging capital investment at provincial level into agricultural *machineries* is the core input factor influencing rice production in Cambodia, while the expansion of total rice land actual *harvested area*, and technically improvement of *fertilizers* application range as the second and third core input factors respectively. These results are not very surprising since they are straightforward techniques for increasing rice productivity in most developing countries in the world. Likewise, these results also confirmed the existing problems in Cambodian rice production sector which were previously addressed by relevant studies like [1],[2],[5],[37] and [38]. However, agricultural mechanization in Cambodia still facing numerous challenges include: 1) national policy on agricultural mechanization is not yet prepared; 2) structure of the Provincial Office of agricultural engineering is still weak; 3) inadequate skilled workforce at both national and provincial level; 4) credit scheme for buying farm machinery and equipment is not existent; 5) most of workshops for repairing and maintenance of farm machinery and equipment are not available at the rural areas; 6) annual budget allocated for the implementation of agricultural mechanization activities fails the nationwide coverage; 7) less activities on research and development on agricultural machinery and equipment and it exists mainly at the national level; 8) external support and cooperation with development partners is still missing; and 9) gap in cooperation with private sector dealing with farm machinery [39]. Local manufacturers of farm machineries and equipment, usually, produce thresher, water pump, local-made truck for transportation, trailer, implements and spare parts such as cage wheel. Nonetheless, they can manufacture only simple machines which do not required sophisticated production process or tools. Normally, they are still small scale and family owned with a few workers and operate seasonally and to supply to local market [40]. Thus, large-scale machineries, such as tractors, walking tractors (*koryons*), etc., still being imported from some major countries, included Belorussia, China, Japan,

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India, US and Thailand. This revealed the lack of ability as well as local technical experts for Cambodia to be able to manufacture large heavy-scale agricultural machineries by itself. Financial institutions (microfinances and commercial banks) are the major sources of credit for making machinery purchases of farmers. Conversely, due of Cambodia haven't had any agricultural bank to support credit scheme for buying farm machinery and equipment yet, hence, farmers have to use their own saving or borrow from existing financial institutions or dealers to buy new machines, where often provided relatively higher interest rate for loan (in average 24% per year) compared to its neighboring countries like Vietnam (less than 1% per year). *Harvested area*, on the other hand, had the highest elasticity among all input factors of rice production in Cambodia. It is clearly indicated that increasing in *harvested area* (i.e. *land* input) could cause the increasing of rice output in higher percentage than all other inputs. However, although the RGC had been trying to increase rice production by enlarging the total area of rice fields annually, this enlargement still remains far behind its enormous potential to increase rice productivity. Therefore, significant commitments and supported actions are required to address the problem.

Second, *production techniques* for rural farmers, technical skills and amount of *agricultural supporting staffs* are being as the most important influencing factors of rice production in Cambodia. Although SRI have been introduced since the prior of 2008, the percentage of farmers cultivating rice under this system still seemed to be low. Enlarging percentage of farmers cultivating rice under the SRI instead of traditional rice cultivating techniques by wider spread introducing of this system to rural farmers, altogether with the strengthening technical skills of agricultural supporting staffs, and building up stronger relationship between rural farmers and supporting staffs, as well as relationship between the related agencies, might be the great solution for this. Likewise, extra researches and developments in new production techniques of rice cultivation still always needed for improving rice productivity. Finally, agricultural sector as well as rice production in Cambodia always inevitably linked to development of *irrigation* systems and good water management practices. Nonetheless, several constraints in *irrigation* development still existing. Irrigation systems in Cambodia are still in development and not coverage for the whole country due to lack of supporting financial resources and technical experts. Moreover, most farmers' paddy fields are small and lack of road access system for the paddy fields far from the road, and lack of drainage systems for paddy field and sometimes rainfall during harvesting still also remains as constrains. Development of *irrigation* systems and good water management practices, is therefore a relevant magnitude to be muscularly considered by policy-makers for developing strategical policies geared towards enhancing rice production.

Therefore, the main factors affecting the output level of rice production in Cambodia appear to be capital investment in agricultural *machineries*, actual *harvested area*, and *fertilizers* utilization while *irrigation* and good water management, *production techniques*, and technical *supporting staffs* serving as main factors affecting TE of rice production in Cambodia.

In conclusion, in addition to capital investment, and improving technical skills for both supporting staffs and rural farmers in order to improve rice productivity in Cambodia, the present study recommends the development of *irrigation systems* and good water management practices should be strongly considered and bring into more effective actions by the central government as well as related agencies for preventing frequently-occurred natural disasters and increasing actual harvested area, particularly in dry-season.

Author Contributions:

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