 doi:10.20944/preprints201709.0161.v1

Article

Comparison of Cambodian Rice Production Technical Efficiency at National and Household Level

Sokvibol Kea [1,2,*], Hua Li [1,*] and Linvolak Pich [3]

[1] College of Economics and Management (CEM), Northwest A&F University, 712100 Shaanxi, China
[2] Faculty of Sociology & Community Development, University of Battambang, 053 Battambang, Cambodia
[3] College of Water Resources and Architectural Engineering (CWRAE), Northwest A&F University, 712100 Shaanxi, China; pichlinvolak@yahoo.com
* Correspondence: keasokvibol@yahoo.com (S.K.); lihua7485@163.com (H.L.); Tel.: +855-96-986-6668 (S.K.); +86-133-6393-6398 (H.L.)

Abstract: Rice is the most important food crop in Cambodia and its production is the most organized food production system in the country. The main objective of this study is to measure technical efficiency (TE) of Cambodian rice production and also trying to identify core influencing factors of rice TE at both national and household level, for explaining the possibilities of increasing productivity and profitability of rice, by using *translog* production function through Stochastic Frontier Analysis (SFA) model. Four-years dataset (2012-2015) generated from the government documents was utilized for the national analysis, while at household-level, the primary three-years data (2013-2015) collected from 301 rice farmers in three selected districts of Battambang province by structured questionnaires was applied. The results indicate that level of rice output varied according to the different level of capital investment in agricultural machineries, total actual harvested area, and technically fertilizers application within provinces, while level of household rice output varied according to the differences in efficiency of production processes, techniques, total annual harvested land, and technically application of fertilizers and pesticides of farmers. The overall mean TE was estimated at 78.4% (national-level) and 34% (household-level), indicates that rice output has the potential of being increased further by 21.6% (national production) and 66% (household) at the same level of inputs and technology if farmers had been technically efficient. The TE also recorded -7% decreasing rate at the national-level and -14.3% at household-level due to highly affected of natural disasters and various environmental and social factors during the study periods.

Keywords: Agricultural productivity, Cambodia, Rice production, Stochastic Frontier Analysis (SFA), Technical Efficiency

1. Introduction

Agriculture is the long-established foundation of the Cambodian economy. It remains as the foremost sector over the country's narration. In 1985, agriculture accounted for 90% of GDP and employed approximately 80% of the labor force [1]. Although contribution of agricultural sector to national GDP have been decreased gradually, growth in agricultural sector still played a crucial role in the development of Cambodia [2]. The sector grew 4.3% in 2012 and accounted for 4.75 million workers out of a labor force of 8 million in 2011 [3]. Industry, agriculture, and services are three main essential sectors of GDP composition with the share of 24.5%, 34.8%, and 40.7% in 2013 respectively [4].

Rice is one of the world's most important food crops and is the fundamental staple food for more than half of humanity, supplying 20% of the calories consumed worldwide. It is recognized as the « White Gold » for Cambodian people as well as the Royal Government of Cambodia (hereafter, RGC) that has declared that supporting the development of the national rice value-chain is one of its first priorities. Cultivation of rice stands as the most essential segment of Cambodian agricultural sector and plays a major role in the national economic growth (contributing to 15% of the national

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

GDP). Production of rice occupies more than 80% of total cultivated land and is the most essential exported agricultural commodities [5]. With the strongly support from the RGC, rice production has grown rapidly since 2003, which has firmly changed the country's position from rice deficit to surplus [6]. Nonetheless, growth of rice production in Cambodia has decelerated since 2012 and given the land area constraint, its recovery will depend from now on more on increases in rice productivity and quality than on area expansion [7]. Therefore, productivity and efficiency use of existing resources might be another source of rice development potential in Cambodia.

This study attempts to contribute to the productivity literature on Cambodian agriculture by exploring the distribution of technical efficiency (hereafter, TE) and its determinants. The main objective of the current study was to measure the rice production TE in Cambodia. Additionally, the study was also trying to identify core influencing factors of rice TE in order to explain the possibilities of increasing productivity and profitability of rice by increasing efficiency at household level as well as provincial level, and identify what technical progress policy should be recommended to help decision-makers to increase the rice productivity in Cambodia.

The rest of this paper is organized as follows: Section 2 demonstrates the methodology and analytical frameworks used in the study. Section 3 presents data sources and descriptive statistics of input and output variables as well as variables of rice production TE's influencing factors, while the results are presented and discussed in Section 4. Finally, conclusion remarks are given in Section 5.

2. Research Methodology

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 [8] 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 deviations from the frontier 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 [9-13] 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 [14-19] etc. Further detailed discussion of the differences between DEA and SFA has been given in Coelli [8]. Therefore, SFA was also being applied to the current study.

Cogitate a firm that uses amounts of N inputs (e.g. *land*, *labor*, *capital*) to produce a single *output*. The technological possibilities of such a firm can be summarized using the production function:

$$\mathbf{y} = \mathbf{f}(\mathbf{x}) \tag{1}$$

where y represents *output* (dependent variable) and $x = (x_1, x_2, \ldots, x_N)$ is an $N \times 1$ vector of inputs (i.e. explanatory variables). Function $f(.)$ is a mathematical function; reflect the relationship between output and input vector. Different algebraic forms of $f(.)$ give rise to different models of production function. γ, β_n, β_m are unknown parameters to be estimated.

Many functional forms of production function (such as linear, quadratic, normalized quadratic, generalized Leontief, Constant Elasticity of Substitution CES, etc.) are linear in the parameters, making them amenable to estimate using the linear regression technique. The commonly and

 doi:10.20944/preprints201709.0161.v1

frequently uses functional form, i.e. *Cobb-Douglas* and *translog* functions; appear not to satisfy this property at the first glance. However, taking the logarithms of both sides of these functions, resulted as:

Cobb-Douglas: $$\ln y = A_0 + \sum_{n=1}^{N} \beta_n \ln x_n \tag{2}$$

Translog: $$\ln y = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x_n \ln x_m \tag{3}$$

which are both linear in the parameters. Thus, the parameters of *Cobb-Douglas* and *translog* functions can also be estimated in a linear regression framework. More discussion on functional forms is available in [20, 21].

Logarithmic form of *translog* production function was being applied to the present study due to its flexible algebra functional form and fitter with the dataset implemented in the present study than *Cobb-Douglass* function.

3. Data and Descriptive Statistics

The current study is achieved through the estimation and analysis of the *stochastic production frontier* function (called SFA model), which is originally and independently proposed by Aigner, Lovell [22], and Meeusen and Van den Broeck [23]. The most commonly used package for estimation of SFA model, *FRONTIER version 4.1c* [24], was applied. The *FRONTIER 4.1c* was widely applied in different fields of research in the recent years, especially in agricultural studies like [25-32], .etc. The present study utilized the logarithmic form of *translog* production function of SFA model, which can be written as:

$$\mathrm{Ln}\, y_{it} = \beta_0 + \sum_j \beta_j \mathrm{Ln}x_{jit} + \beta_t t + \frac{1}{2}\sum_j \sum_k \beta_{jk} \mathrm{Ln}x_{jit} \mathrm{Ln}x_{kit} + \frac{1}{2}\beta_{it} t^2 + \sum_j \beta_{jt} \mathrm{Ln}x_{jit} t + v_{it} - u_{it} \tag{4}$$

3.1. National Rice Production

The data used for technical efficiency analysis of rice production in Cambodia at the national level were drawn from 4-years dataset (2012-2015) generated in document sets of the Royal Government of Cambodia (RGC), namely "*Profile on Economics and Social*" of entire 25 provinces in Cambodia i.e. 24 provinces and 1 municipality of Phnom Penh [33, 34]. 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.

At the national level, the SFA model was constructed by one output variable (i.e. *quantity*) and five input variables, included *land*, *labor*, *fertilizer*, *pesticide*, and *machinery*. See Table A1 in Appendix for more description of these variables.

 doi:10.20944/preprints201709.0161.v1

Table **1** provides summary statistics of the output and inputs of rice production within entire 25 provinces in Cambodia from 2012 to 2015. Rice output *quantity* was higher in 2015 than in 2012 which increased 8.4% in average from 290 thousand tons (2012) to 315 thousand tons (2015). Total *land* area in average also increased around 8% from 134 thousand hectares in 2012 to 145 thousand hectares in 2015. Total *fertilizers* quantity using by rice families, on the other hand, increased in average by 7%, while *pesticide* and *machinery* input increased greatly between this periods. Total *pesticide* quantity used increased by nearly 25% (3-times larger than *land* and *fertilizer*), 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. Nevertheless, along with the improvement of agricultural mechanization, *labor* input 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 services.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

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

Variable	2012		2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Output								
Quantity (tons)	290,808	52,994	329,872	60,296	391,150	80,437	315,270	57,785
Inputs								
Land (hectares)	134,629	23,192	144,944	25,893	212,785	56,497	145,685	26,699
Labor (persons)	168,703	27,044	163,805	26,208	160,163	25,683	155,159	24,486
Fertilizer (tons)	74,061	13,236	75,027	13,300	160,043	13,436	79,038	13,618
Pesticide (tons)	45,116	9,610	47,926	10,021	52,205	10,596	56,117	11,047
Machinery (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 the RGC [33, 34]. "S.E." = Standard Error.

Figure 1 illustrates percentage changes of input and output statistics of Cambodian rice production 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 and 2014, which caused *rice output* to greatly increase. 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%.

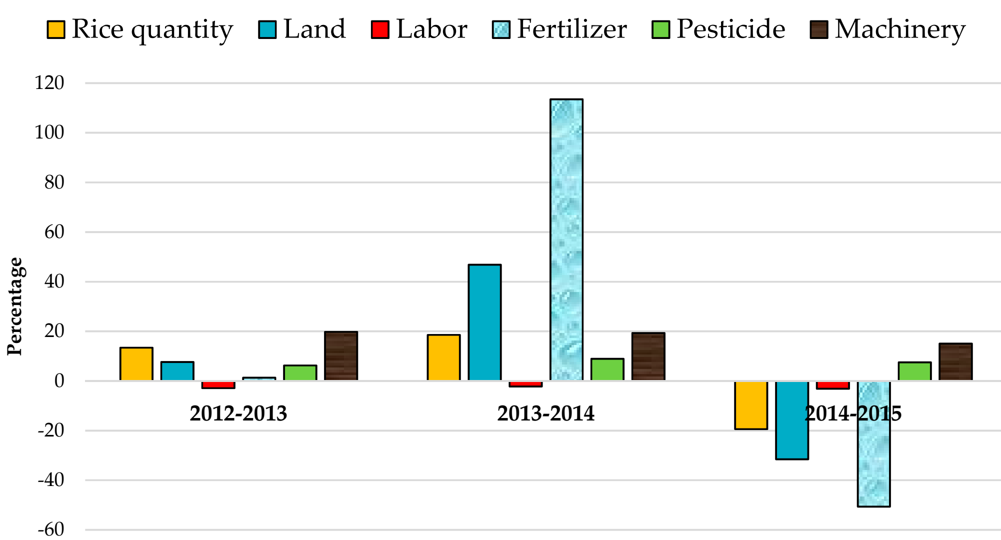

Figure 1. Percentage changes in input and output statistics for 25 rice producing provinces in Cambodia for the periods 2012-2013, 2013-2014, and 2014-2015

In the *technical inefficiency model* (TI model), there were seven influencing factors of rice production TE to be considered in the present study, included *disaster*, *irrigation*, production *technique*, *distance* to information sources, *agricultural staff*, *dry-season* rice production, *small-land* farmers. See Table A2 in Appendix for these variables' description. Some external factors, such as social, economic, demographic, as well as geographic perspectives of each province were omitted from the technical inefficiency model, due to un-sufficient availability of appropriated datasets during the study period. Furthermore, the present study utilized only 4-years dataset of entire 25 provinces of Cambodia, which limited availability to include too many influencing factors into the model as it might cause unexpected conflicts or correlations among factor variables. Likewise, 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, *TI model* for national-level analysis can be written as:

$$\mathbf{u_{it} = \delta_0 + \delta_1 Disaster_{it} + \delta_2 Irri_{it} + \delta_3 Tech_{it} + \delta_4 Distant_{it} + \delta_5 Staff_{it} + \delta_6 Dry_{it} + \delta_7 SmallF_{it}} \quad (5)$$

Table 2 presents descriptive statistics of Cambodian rice production efficiency's influencing factors 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 in average 18.8%, while in 2015 *disasters* destroyed in average only 5.2% of rice production area (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 in 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* 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. During the study period 2012-2015, in average more than 30% of available dry season rice land was abundant annually. In 2012, only 68.5% of 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.

Irrigation plays as a very important role for rice production in Cambodia, particularly in dry-season. Between 2012 and 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

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

dry-season. These could be the results of irrigation systems shortage, which caused Cambodia to have no ability to deal with such frequently-occurred disasters. What if Cambodia could build irrigation and water storage systems in order to store over-needed water resources during the wet-season keeping for utilization in agriculture during the dry-season?

Table 2. Descriptive statistics of factors affecting Cambodian rice production efficiency 2012-2015

Variable	2012		2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Disaster	18.86	12.34	5.16	1.12	30.98	26.37	5.20	1.16
Irrigation	21.70	3.49	22.75	3.52	19.94	3.58	22.64	3.54
Production technique	3.04	0.48	2.79	0.47	2.74	0.42	2.44	0.37
Distant info-source	14.92	1.53	14.86	1.22	14.67	1.14	15.01	1.20
Supporting staffs	0.11	0.03	0.10	0.02	0.09	0.02	0.09	0.02
Dry-season production	68.47	5.72	58.76	6.33	65.12	5.89	64.91	6.43
Small-land farmers	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 the RGC [33, 34]. "S.E." = Standard Error.

3.1. Household Rice Production

At household-level analysis, primary data were collected from a random sample of 301 rice production households from 10 communes (equal to 30 villages) in three selected districts of *Battambang* province by using structured questionnaires. The district of *Thmar Koul*, *Moung Russei*, and *Sangkhae* were purposively selected as the present study's study areas, based on their total rice production area and total number of farmers with rice farming as primary occupation (rice farmers) in 2014, which ranked from the first to the third among all 14 districts of *Battambang* province. The field surveys gathering 3-years data of households' rice production (2013, 2014 and 2015). Structured questionnaire designed to capture information related to the characteristics of rice farmers, their inputs allocated to the rice cultivation and its output(s). Furthermore, the collected primary data were supplemented with secondary data collected from various relevant sources.

The SFA model was constructed by one output variable (i.e. production *quantity* of rice) and five input variables included *land*, *labor*, *fertilizer*, *pesticide*, and *other capital*. See Table A3 in Appendix for variables description.

Table 3 provides summary statistics of the output and inputs of households' rice production in three districts of Battambang 2013-2015. Output quantity of households' rice production increased 8.5% in average from 16.7 thousand kilograms to 18.1 thousand (kg). Nevertheless, household rice output has been decreased by 6.5% between 2013 and 2015 as the results caused by natural *disasters* occurred in wet season of 2014 (flood) and dry season of 2015 (drought) which reduced rice output to 15.6 thousand kg per household (in 2015). Rice area harvested by farmer households ranged from the smallest of 1 ha to the largest of 82 ha annually. During the study period, in average farmers harvested around 7 ha (included for both wet season and dry season) in 2013, and increased by 1.2% from to 7.1 ha in 2014. However, average households' rice harvested area in 2015 has been slightly reduced to 7.05 ha. Furthermore, average annual working days of adult family members (18-65 years old) for both male(s) and female(s) on the rice field(s) was 108 days per person in 2013, and increased to 110.5 days in 2014, then reduced to 106.7 days in 2015. Total quantity of chemical and organic fertilizers using by households in rice production (i.e. fertilizer input), on the other hand, increased by 2.5% between 2013 and 2015 from average of 772 kg (2013) to 791 kg (2015), while pesticide input which measured as total quantity of poisons for insects and grass (both chemical and organic) using by households in rice production also increased by 1.6% between the same period, from 70.8 kg to 72 kg in average. However, during the study period the level of households' capital investment showed the impressively deduction by 4%, particularly between 2014 and 2015 (capital input decreased by 12.6%), indicated the farmers' response to effects of natural disasters that reduced availability of rice area to be harvested.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

Table 3. Output and input summary statistics for households rice production, 2013-2015

Variables	2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Output						
Quantity (kg)	16,651.16	1,244.43	18,065.78	1,422.06	15,569.77	1,235.43
Input						
Land (ha)	6.99	0.53	7.07	0.53	7.05	0.52
Labor (days)	108.27	5.58	110.45	5.66	106.69	5.32
Fertilizer (kg)	771.73	55.02	792.09	55.98	790.72	55.87
Pesticide (kg)	70.84	6.64	72.03	6.75	71.95	6.70
Other capital (USD)	857.18	59.49	879.05	59.31	823.37	55.72

Source: Calculated by Ms. Office Excel 2016, S.E = Standard Error

Figure 2 illustrates the percentage changes of output and input statistics of rice production of farmer households in three selected districts of *Battambang* for the periods 2013-2014, 2014-2015, and 2013-2015. The percentage changes within output and input variables from year to year indicated that entire inputs had been increased for 1% to 2.6% between 2013 and 2014 which leaded rice output to increase by 8.5%. However, between 2014 and 2015 all inputs used by households tended to decrease (particularly in labor and capital input which decreased by 6.8% and 12.6% respectively) due to effects of natural disasters in the recent years, caused household rice output to decrease greatly by almost 30% compared to the production of 2014.

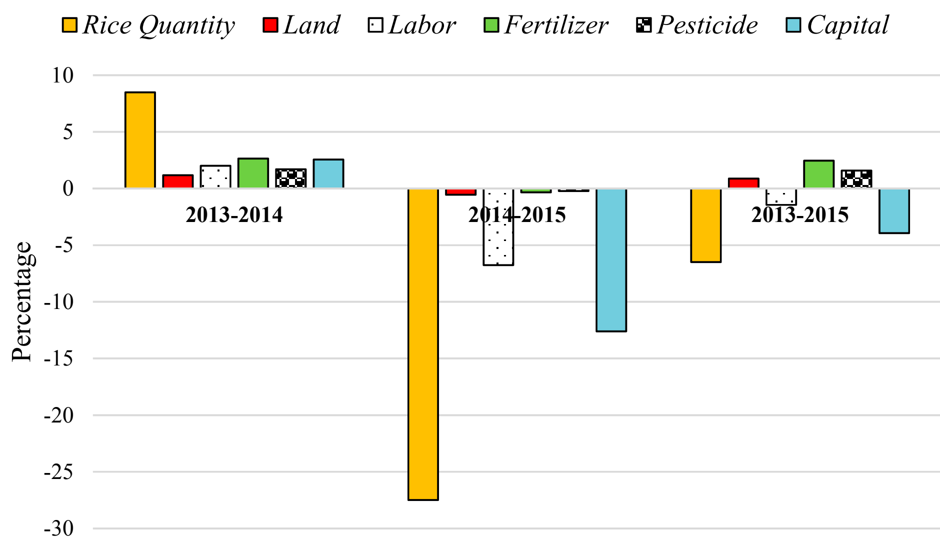

Figure 2. Percentage changes in output and input statistics for households rice production in Battambang for the periods 2013-2014, 2014-2015, and 2013-2015

The technical inefficiency (TI) model of household's rice production can be expressed as the following form:

$$\mathbf{u_{it} = \delta_0 + \sum_{k=1}^{n} \delta_k z_{kit} + \omega_{kit}} \quad (6)$$

where, u_{it} is the inefficiency effects that could be estimated by 2 stage estimation technique in FRONTIER 4.1c extemporaneously; δ_0 represents the intercept term; δ_k is the parameter for k^{th} independent variables to be estimated; z_{kit} is the parameter of influencing factors affecting the TE of household's rice production in period t; andω_{kit} represents the stochastic noises. In thisTI model, there were twelve influencing factors (z_{kit}) of household's rice production TE to be considered in the current case study. See Table A4 in Appendix for z_{kit} variables description.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

Table 4. Descriptive statistics of technical inefficiency model's parameters, 2012-2015

Variables	2013		2014		2015	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Household head's Age	47.39	0.69	48.39	0.69	49.39	0.69
Household head's Sex	0.17	0.02	0.17	0.02	0.17	0.02
Household head's Education	2.33	0.05	2.33	0.05	2.33	0.05
Family size	5.16	0.11	5.17	0.11	5.17	0.11
Female labor (18-65yr)	1.63	0.05	1.63	0.05	1.63	0.05
Other crops' cultivated area	485.02	241.36	247.14	106.52	247.14	106.52
Irrigated areas	16.82	1.22	17.35	1.23	17.30	1.24
Distance to water sources	2.91	0.14	2.91	0.14	2.91	0.14
Distance to district	15.89	0.43	15.89	0.43	15.89	0.43
Num. of plot area	1.48	0.04	1.52	0.04	1.52	0.04
Num. of cultivation per year	1.44	0.03	1.44	0.03	1.44	0.03
Disaster	0.06	0.01	0.07	0.01	0.74	0.03

Source: Estimated by Ms. Office Excel 2016. "S.E": Standard Error.

Descriptive statistics of rice production technical inefficiency model's parameters between 2012 and 2015 are given in Table 4. Most of variables remain insignificant changed between this 3-year period. The overall statistics reveal that the average age of household's head was 49.4 years old in 2015 ranged from 21 to 83 years old, in which 17% were female household head. Moreover, the average education level was 2.33, indicating that most of rice farmers' household head just only giant education at secondary school (i.e. grade 7-9) in Cambodian education system. The results also reveal that average family size of rice farmers in Battambang province is about 5.17 persons per household (ranged from 2 to 12 persons per household), presenting the general figure of rice farmers in the rural Cambodia nationwide. Additionally, female labor (age between 18 and 65 years old) existing in *Battambang*'s rice households during the study period in average was about 1.63 persons per household.

The total cultivated area under other crops beside rice such as corn, sugarcane, cassava, cucumber, pepper, wax melon, bitter melon, bean, eggplant, and other vegetables, was about 485 square meters (m^2) in average in 2013. However, this amount had been decreased (by almost 50%) to 247 m2 in 2014 and 2015. Furthermore, irrigated areas, which is the percentage of rice production land located near water sources or benefited from irrigation systems to total annual cultivated land of rice, was about 16.8% in 2013 average, and had been increased to 17.35% in 2014. Water shortage in 2015, nonetheless, had been leading this percentage to decrease a little bit to 17.3% (in average). These percentages disclose the lack of irrigation facilities and water management policies, since almost 85% of farmers' rice cultivated areas still not benefit from irrigation systems and remain as rain-fed agricultural lands that are very vulnerable to the global climate change. In average, rice production lands of rural farmers in Battambang located around 2.91 km from the water sources (or the nearest irrigation systems). This distance is quite far and often causes inability for farmers to use water from existing water sources and irrigation systems. Likewise, the results also show that only 39% of farmers' rice fields that located less than 1 km from water sources (or the nearest irrigation systems), thus, other more than 60% of rice fields still located far from the water sources. Distance to district, on the other hand, measured as the distance from the village to the district center in kilometers, is the proxy variable of farmers' accessibility to information sources (related to rice production such as price information, as well as adoption of new production techniques). Within the study areas, most villages located in average of 15.9 km from the center of district (range from 1 km to 28 km).

Rice farmers in Battambang in average cultivated on 1.48 plot lands (in 2013), and increased to 1.52 in 2014 and 2015. The statistics reveal that around 63% of farmers cultivated on only one plot land of rice (during the study period).Furthermore, there are only 44% of farmers who able to cultivate rice crops more than once per year. More importantly, between 2013 and 2014, only 6-7% of

 doi:10.20944/preprints201709.0161.v1

rice farmers reported the affecting by natural disasters (i.e. droughts, floods, and insects) on their rice fields. Nevertheless, in 2015, almost 75% of famers' rice fields had been reported affecting by natural disasters, particularly the drought during 2015's dry season.

4. Results and Discussion

4.1. SFA Model Estimation

Table 5 lists the parameters estimation results by implementing the maximum likelihood estimation method in *FRONTIER version 4.1c* econometrics software of Coelli [24]. At national-level, 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.

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.

Table 5. Parameter estimates of SFA model at National-level

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 × Labor	0.0420 **	0.0197	2.1339
Land × Fertilizer	-0.0771 *	0.0429	-1.7966
Land × Pesticide	0.1680 ***	0.0309	5.4381
Land × Machinery	-0.1210 ***	0.0241	-5.0263
Labor × 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%.

In addition to capital investment in agricultural machineries and fertilizer application, total actual harvested land was another 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 [35] and some studies of Asian Development Bank [2, 36]. Furthermore, total families using quantity of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

poison for insects and grass (included both chemical and organic poison) existing in the province, i.e. *pesticides* input, 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 incorrect 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 6 illustrates the input elasticity of rice production in Cambodia between 2012 and 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. Within 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). Input elasticity of *machinery*, on the other hands, was unexpectedly negative related to *rice output* during the study period of 2012-2015. As being shown in the previous table (Table 5), *machinery* input had the highest positive coefficient of 1.86 (compared to other inputs) and significant toward *rice output* at confidence level 99%, indicated the expansion of amount used of *machinery* in rice farming could increase *rice output* level. However, a closer look at the relationship between *machinery* and another inputs, such as *land* and *labor*, indicated that *machinery* has had negative (substitution) relationship with *labor* input, which was not surprising for most agricultural researches that unskilled-workers could be replaced by the utilization of machinery for gaining more output as well as saving more times. Likewise, *machinery* has also had negative relationship with *land* input and strongly significant at confidence level 99%, which was quite surprised. Conversely, the ratio of investment level on agricultural machineries to total rice cultivated land in most high-potential provinces in the production of rice, such as *Battambang*, *Banteay Meanchey*, *Kampong Thom*, *Kampong Cham*, *Prey Veng*, *Takeo*, *Svay Rieng*, etc., seemed to be relatively low compared to some other provinces with lower-potential in rice production like *Phnom Penh* suburb and *Pailin* for instance. This could be explained the insufficient investment of machinery in the territory of high-potential provinces in rice production. Moreover, negative relationship between land and machinery input (showed in Table 5) also indicated inefficiency performances of existing agricultural machineries for rice farming in high-potential provinces, which leaded input elasticity of machinery input to be negative within the study period of 2012-2015. Thus, in addition to enlargement of investment on *machineries*, for improving rice production in Cambodia (particularly in high-potential provinces) the techniques or solutions for increasing the performance efficiency of existing machineries as well as labor skills also needed to be considered (by related agencies).

Table 6. Input elasticity of national 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

In SFA model, a test whether there is technical inefficiency exists or not can be conducted by testing the null hypothesis $H_0: \gamma = 0$, versus alternate hypothesis $H_1: \gamma \neq 0$. Coelli [37] argued that *maximum likelihood* (ML) shall be estimated by the calculation of the critical value for *one-sided likelihood ratio* (LR) test. The critical value for a test of size α is equal to the critical value of the x^2

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

distribution for a standard test of size 2α. Thus, one-sided likelihood ratio test has suitable range, where H_0 is rejected when $LR \geq x^2(2\alpha)$ for a test of size α. At α=1% significant level, $x^2(2\alpha)$ has value of 100.62. In household-level frontier model, however, LR test of the one-sided error has value of 171.80, which is bigger than $x^2(2\alpha)$. Therefore, the null hypothesis, H_0: $\gamma = 0$, was rejected, indicates that technical efficiency effect exists in our model.

Table 7 lists parameters estimation results by implementing the *maximum likelihood* estimation method in *FRONTIER version 4.1c* econometrics software of Coelli [24]. The variance ratio parameter, gamma (γ), had a value of 1.00 significant at $\alpha = 1\%$, 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 that the efficiency of households' rice production in study area between 2013 and 2015 mainly comes from the *technical efficiency* of the production.

Table 7. Parameters estimated for the SFA model at Household-level

Variables	Coefficient	Standard Error	t-ratio
Constant	8.2818 ***	1.0064	8.2288
ln(land)	0.8276 ***	0.2232	3.7085
ln(labor)	-0.0485	0.2297	-0.2112
ln(fertilizer)	0.0945 **	0.0402	2.3490
ln(pesticide)	0.0694 **	0.0339	2.0494
ln(capital)	0.0323	0.1892	0.1708
t	0.1083	0.0971	1.1152
Land × *Labor*	0.0341	0.0433	0.7876
Land × *Fertilizer*	-0.0248	0.0210	-1.1796
Land × *Pesticide*	0.0089	0.0189	0.4701
Land × *Capital*	-0.0054	0.0269	-0.1992
Labor × *Capital*	-0.0034	0.0425	-0.0801
t^2	-0.0163	0.0248	-0.6570
γ	1.0000 ***	0.0994	10.0565
σ^2	0.0993 ***	0.0047	20.9696
log likelihood function			-235.2186
LR test of the one-sided error			171.8042

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

Almost all estimated coefficients have the expected signs. As being showed in Table 7, *land* input had positive coefficient and significant at $\alpha = 1\%$, while *fertilizer* and *pesticide* input both had positive coefficients but significant at $\alpha = 5\%$, indicates positive contribution of these three inputs to *household rice output*. These results designated that enlarging the area of harvested *land*, increasing quantity used of *fertilizer* and *pesticide* input, could cause the increasing of *household rice output*. Furthermore, with the estimated coefficient of 0.83, total area (both in wet season and dry season) of rice actually harvested within the year was the main input factor driving extra output for household's rice production in Battambang province compared to *fertilizer* and *pesticide* (input). This means farmers who cultivate additional lands have the ability to maintain reasonable levels of the necessary inputs; otherwise, additional area does not increase *rice production output* if the levels of inputs are not maintained. Area of cultivated land can be increased by expanding irrigation that permits multiple season cropping. Despite the importance of rice farming in the Cambodian landscape, it has traditionally been dependent on rainfall. Rice is predominately grown in the wet season which produces 80% of the total crop, and irrigation is mainly used for dry season rice and to complete wet season rice if necessary. Furthermore, it is also an essential component to ensure that farmers can crop during the dry season, and helps to better regulate water inputs which is essential for improved yields [35, 38]. Production efficiency, nevertheless, is constrained by low rates of irrigation [2]. Most Cambodian farmers are able to cultivate rice only once in a year because of inadequate irrigation system and good water management practices. Lack of water during dry

 doi:10.20944/preprints201709.0161.v1

season rice farming is significantly constraint and has occasionally caused conflict among farmers [39]. Cambodia has a huge potential to increase rice production since it is known for its abundant agricultural land and water resources. Such natural resource potential has been underutilized: less than 30% of potential arable land is under cultivation, and a much smaller portion of area suitable for irrigation is actually irrigated. Thus, expansion of farmland area and irrigation development can be a straightforward way to increase rice production (which is quite similar to the situation in other developing countries like India [40]).

In addition to farmland area expansion and *irrigation* development, rice yield can also substantially be increased through crop intensification techniques including both increased use of fertilizer and better farming practices such as those identified under the System of Rice Intensification (SRI)[1]. Increase use of fertilizers and pesticides are the main characteristics of the Green Revolution in rice agriculture, which spread throughout the Southeast and East Asia during the past 30 years, could increase productivity of rice [2, 35, 36, 38]. This is undoubtedly supported by the sturdy significant of fertilizer and pesticide input variables in the SFA model of the current case study.

Most developing countries have an unused labor surplus i.e. simple, low-cost, labor-extensive, and low-yielding agricultural production [38]. In general case, workers drop out of agriculture only if they are assured that they can purchase food at attractive prices. If food is not imported in greater amounts, workers remaining in agriculture will have to maintain or increase agricultural production, to produce the food surplus for the non-agricultural workers in exchange for non-agricultural goods and services. Labor input tends to have a positive effect on output yield for small farmers; which is in the contrast view to large-scale (commercial) farmers in the picture of improvement of mechanization. Nonetheless, labor input of the SFA model in the present case study has negative coefficient but not significant at any α level, reveals that there was no any significant relationship between labor input and household rice output in the three districts of Battambang province during the study period. Furthermore, the present case study also established no significant relationship between household rice output and level of household's capital investment in household's rice production.

Table 8. Input elasticity of household's rice production in Battambang, Cambodia 2013-2015

Year	*Ln (Land)*	*Ln (Labor)*	*Ln (Fertilizer)*	*Ln (Pesticide)*	*Ln(Capital)*
2013	0.8259	-0.0175	0.0562	0.0831	0.0087
2014	0.8256	-0.0171	0.0559	0.0833	0.0085
2015	0.8253	-0.0169	0.0559	0.0833	0.0086

Source: Calculated by Ms. Excel 2016.

Table 8 illustrates the input elasticity of household's rice production in Battambang province of Cambodia between 2013 and 2015. From this table, it is clearly demonstrated that all inputs, except *labor*, have had the increasing return to scale to *household rice output*. *Land* input had the highest elasticity value among entire input factors, following by *pesticide* and *fertilizer* input. Elasticity of actual harvested area of household rice production had the value of 0.83 in average during the study period, indicating that 1% increase of harvested *land* (of rice) could cause *household rice output* to increase by 83%. Similarly, with the elasticity value of 0.083 and 0.056 (in average) respectively of *pesticide* and *fertilizer* inputs, revealing that 1% increase in these two inputs could cause the increasing of *household rice output* by 8.3% and 5.6% respectively. The elasticity of *capital* input, on the other hand, had the value of 0.0086 in average, showing that 1% increasing in capital investment to agricultural machineries (such as walking tractors or *koryons*, tractors, pumping machine, etc.) as

[1]System of Rice Intensification (SRI) was introduced by Ministry of Agriculture, Forestry and Fisheries (MAFF) of Cambodia with the support of CEDAC (Cambodian Center for Study and Development in Agriculture: Centre d'Etude et de Dévelopment Agricole Cambodgien). Under SRI, 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 41. CEDAC, *Report on the Progress of System of Rice Intensification in Cambodia 2007*. 2008, Cambodian Center for Study and Development in Agriculture (Centre d'Etude et de Dévelopment Agricole Cambodgien): Phnom Penh, Cambodia..

 doi:10.20944/preprints201709.0161.v1

well as other rentals for rice production could also cause the increasing of *household rice output* (by 0.86%).

The negative input elasticity of *labor* are not only explained the overused of *labors* for household's rice production but also showing the inefficiency performance of existing labors in the rice fields. Although *labor* input were not significantly affecting the *household rice output* in the current study, its negative coefficient in the SFA model (presented previously in Table 7) also clearly revealed the over and inefficient used of *labor* forces. Therefore, additional special policies or regulations might be needed for snowballing efficiency of rice production's existing labor forces, in the purpose of improving Cambodian rice production for sustainability social development as large.

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.

Figure 3 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.

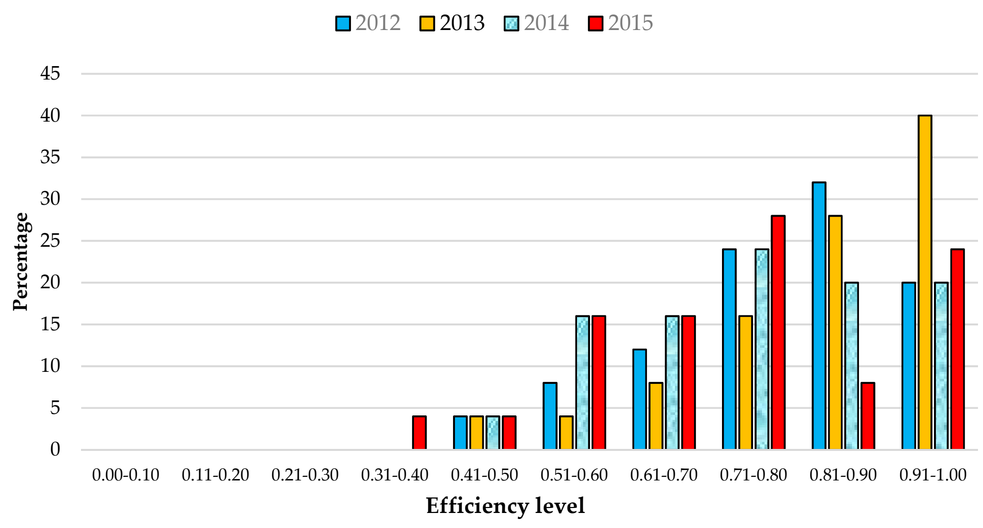

Figure 3. Technical efficiency distribution of rice production in Cambodia, 2012-2015

Table 9 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 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*

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

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.

Table 9. Regional technical efficiency of rice production in Cambodia, 2012-2015

Regions	2012		2013		2014		2015		TEChange (%)		
	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[1]	0.81	0.05	0.87	0.04	0.71	0.05	0.77	0.04	6.8	-12.4	-5.4
Mekong plain[2]	0.86	0.07	0.89	0.10	0.88	0.07	0.88	0.07	3.2	2.6	2.2
Mekong plateau[3]	0.79	0.04	0.79	0.04	0.74	0.06	0.70	0.06	0.0	-6.7	-11.3
Mountain[4]	0.66	0.09	0.76	0.08	0.63	0.09	0.53	0.09	14.6	-5.7	-19.7
Coastal[5]	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. [1]*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 country's total area). [2]*Mekong plain* included the province of *Kampong Speu*, *Kandal*, *Prey Veng*, *Svay Rieng*, and *Takéo*. Total area: 21,997 km² (12.35%). [3]*Mekong plateau* included the province of *Kampong Cham*, *Kratié*, *Stung Treng*, and *Tbong Kmom*. Total area: 31,663 km² (17.78%). [4]*Mountain* region included the province of *Mondulkiri*, *Ratanakiri*, *Preah Vihear*, and *Otdar Meanchey*. Total area: 45,016 km² (25.28%). [5]*Coastal* region included the province of *Kampot*, *Koh Kong*, *Kep*, and *Preah Sihanouk*. Total area: 17,237 km² (9.68%).

The *technical efficiency* (TE) and *technical efficiency change* (TEC) between 2013-2014 and 2013-2015 of household's rice production is being showed in Table 10, categorized by districts and communes. The findings revealed that the overall mean technical efficiency of rice production is estimated at 0.34 (ranged from 0.097 to 0.913) which indicated that households in the study areas produce 34% of rice at best practice at the current level of production inputs and technology. In other words, *household rice output* could have been increased further by 66% at same levels of inputs if farmers had been technically efficient. As being showed in Table 10, all rice production households in Battambang produce 35.2% of rice at best practice in 2013. In 2015, however, due to affecting of the natural disasters (particularly drought during the dry season of 2015 that affected rice production of Cambodia nationwide) and other influencing factors (will be discussed in further details in the next section), the TE of household's rice production in selected districts of Battambang had been decreased gradually from 0.352 (2013) to 0.302 in 2015 (decreased by 14.3% between this 3-years), indicating that in 2015 rice farmers produced only 30.2% of rice at best practice at their existing inputs level and technology. Thus, there is still a huge gap for improving rice productivity in the high potential province of rice production like *Battambang*, since *household rice output* of rice farmers in this province still have been able to increased further by almost 70% at the current levels of inputs (in case the farmers had been technically efficient).

Sangkhae district had the highest TE score among three selected districts in all years of the study period (2013, 2014 and 2015). In 2013, rice farmers in *Sangkhae* district produced 38.2% of rice at best practice (at the current level of production inputs and technology), while farmers in *Thmar Koul* and *Moung Russei* district produced only 35.5% and 32.7% of rice (at best practice) respectively. In 2015, rice farmers in *Sangkhae* district continued to be able to utilize their resources in rice production more efficiently than farmers in the other two districts, by produced almost 40% of rice at best practice, while the rice production of farmers in *Thmar Koul* and *Moung Russei* district became worse, in which respectively produced only 29.7% and 24% of rice.

 doi:10.20944/preprints201709.0161.v1

Between 2013 and 2014, TE score of farmers' rice production in *Moung Russei* district increased by 2.98% from 0.327 to 0.336, claimed as the highest increasing percentage among three districts (between this two-years). Nonetheless, in 2015, the TE of household's rice production in this district declined sharply to 0.24 (diminished by 27% between 2013 and 2015, and also the highest declining percentage among three districts). However, during the study period, farmers' rice production in *Thmar Koul* district had the decreasing trend of TE score from 0.355 in 2013 to 0.342 in 2014, and then continued to decrease to 0.297 in 2015 (decreased by 16.3% between 2013 and 2015). In contrast with the situation in *Thmar Koul* district, household's rice production of farmers in *Sangkhae* district had the increasing trend of TE score from 0.383 in 2013 to 0.387 in 2014, and still continued to increase to 0.389 in 2015 (1.65% increased between 2013 and 2015).

At the commune-level, the statistical results reveal that the production of rice of farmers' household in *Reang Kesei* commune had the highest TE score among all communes in *Sangkhae* district during the study period by producing around 50% of rice at the best practice of its current inputs level and technology. Farmers' rice production in *Thmar Koul* district, on the other hand, the commune that have had the highest TE score in all years between 2013 and 2015 was *Boeng Pring* commune, which produced around 26-36% at the best practice. Likewise, the production of rice in *Prey Svay* commune of *Moung Russei* district was also the commune production with the highest TE score in the district, by producing 26-35% at best practice (at the existing level of inputs and technology).

Table 10. Technical efficiency (TE) and technical efficiency change (TEC) of household's rice production in Battambang province of Cambodia, from 2013 to 2015

District	2013		2014		2015		TEC (%)	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	2013-14	2013-15
Moung Russei	**0.3267**	**0.01**	**0.3364**	**0.01**	**0.2396**	**0.01**	**2.98**	**-26.66**
Moung	0.3056	0.02	0.3086	0.02	0.2054	0.01	0.98	-32.79
Prey Svay	0.3503	0.01	0.3614	0.01	0.2673	0.01	3.17	-23.70
Ruessei Krang	0.3287	0.02	0.3238	0.02	0.2502	0.02	-1.49	-23.89
Kakaoh	0.3220	0.01	0.3517	0.01	0.2354	0.01	9.21	-26.89
ThmarKoul	**0.3550**	**0.01**	**0.3415**	**0.01**	**0.2971**	**0.01**	**-3.80**	**-16.31**
Anlong Run	0.3273	0.02	0.3296	0.02	0.2808	0.02	0.72	-14.20
Ta Meun	0.3528	0.02	0.3291	0.02	0.2857	0.02	-6.70	-19.01
Boeng Pring	0.3840	0.02	0.3651	0.02	0.3239	0.02	-4.94	-15.66
Sangkhae	**0.3827**	**0.02**	**0.3865**	**0.02**	**0.3890**	**0.02**	**1.00**	**1.65**
Ta Pon	0.3370	0.03	0.3407	0.02	0.3338	0.02	1.10	-0.94
Kampong Preah	0.3067	0.02	0.3205	0.02	0.3359	0.02	4.51	9.53
Reang Kesei	0.5044	0.03	0.4983	0.03	0.4973	0.03	-1.21	-1.41
All households	**0.3520**	**0.01**	**0.3529**	**0.01**	**0.3016**	**0.01**	**0.27**	**-14.30**

Source: Estimated by FRONTIER 4.1. "S.E." = Standard Error; "TEC" = Technical Efficiency Change

Figure 4 illustrates the distribution of technical efficiency of Cambodian household's rice production in Battambang province from 2013 to 2015. The study indicates that individual household's TE ranged from a low of 12.6%to a high of 82.5% with a mean technical efficiency of 35.2% in 2013, while in 2014, household's TE ranged from a low of 14.6%to a high of 86.7% with a mean technical efficiency of 35.3% (increased by 0.27%). TE of household's rice production in 2015, on the other hand, ranged from a low of 9.7%to a high of 91.3% with a mean technical efficiency of 30.2% (decreased by 14.3% in average between 2013 and 2015).Thus, rice production of farmers in Battambang performed better during 2013 and 2014 than in 2015, for which around 33-37% of households had TE score between 0.31-0.40 compared to 2015 that had only 25% (due to affecting of drought). However, in 2015, most households had the TE score between 0.21-030 (accounted for almost 38%). These percentages indicated a huge gap (between 62-75%) of rice farmers in Battambang to increase their production using the current levels of inputs and technologies.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

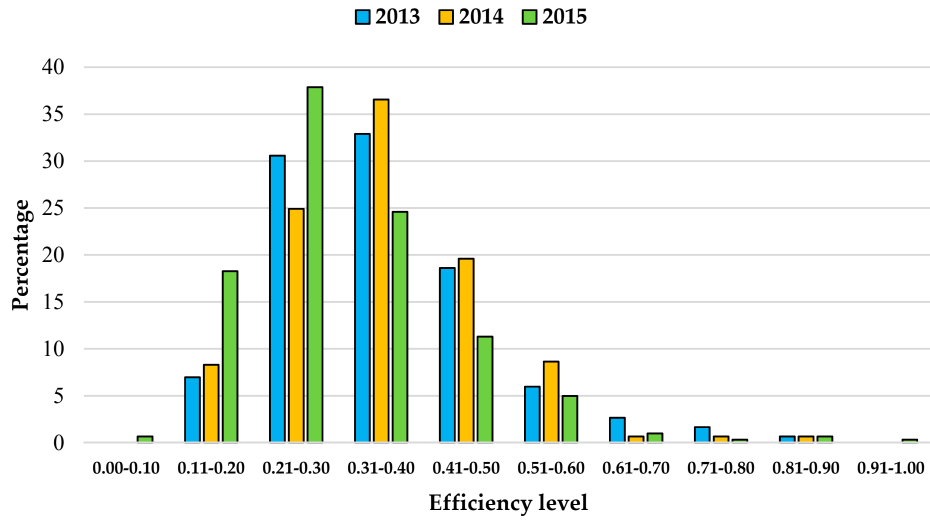

Figure 4. TE distribution of household's rice production in Battambang, Cambodia, 2013-2015

4.3. Technical Inefficiency Model and Affecting Factors

Table 11 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 11. 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%.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

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 [35] 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 thousands of 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 average rice yield and rice price still continued to increase between 2014 and 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.

The *maximum likelihood* (ML) estimates coefficients of the explanatory variables in the model for the *technical inefficiency* (TI) of household's rice production in Battambang province, and these TI estimated coefficients are of interest and have implication as shown in Table 12. A negative sign on a parameter explaining the positive effect of the variable on TE (negative impact on the technical inefficiency TI) means that the variable is improving TE, while for a positive sign, the reverse is true. The results indicated that the *sex of household's head*, the *education level of household's head*, *family size*, the *cultivated area of other crops* (beside rice), *percentage of rice cultivated area benefited from irrigation systems*, *number of plot area*, and *disasters* (droughts, floods, insects) are significant determinants of the technical efficiency in the Cambodian rice production.

As being showed in Table 12, it is noticeable that the variable of *disaster* and *other crops' cultivated area* both had positive coefficient signs and were significant at 1%, while *education of household head* and *family size* also had positive coefficient signs but significant at 10%, indicating negative relationships of these factors to TE of *household's rice production* (positive impact on the TI), means that these factors are decreasing TE. With the highest coefficient of 0.27, *disaster* was the core influencing factor leads to decreasing *TE of household's rice production*, while the *education of household head* and *family size* are the second and the third factors with the estimated coefficient value of 0.03 and 0.01 respectively. These results indicate that 1% increasing in *disaster*, *education of household head* and *family size* will cause the decreasing of TE by 27%, 3% and 1% respectively. The impact of *education level of household's head* is negatively significant on the efficiency (TE) of *household's rice production*, implying that less educated rice farmers are more efficient than better educated farmers. It means being an educated rice farmer was not enough to significantly attain greater levels of efficiency. This result, thus, is consistent with the finding of Balde, Kobayashi [26], who found that education level was significant and negatively affecting the TE of Mangrove rice production in the Guinean coastal area. Kabir, Musharraf [29] who estimate the impact of bio-slurry to Boro rice production in Bangladesh, also found the same negative sign of coefficient of education relation to production inefficiency of rice. Besides, the variable of *family size* also has a negative and significant

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

impact (on TE). This result implies that farmers with fewer family members seem to perform better than those with more members. Additionally, the negatively significant of other crops' cultivated area variable, indicating that reducing rice's cultivated area for growing other crops beside rice like corn, sugarcane, cassava, cucumber, pepper, wax melon, bitter melon, bean, eggplant, and other vegetables, etc. might cause the TE of household's rice production to decrease. However, the value of this variable's coefficient is quite tiny, reflecting the very little effect of other crops' cultivated area on TE.

Table 12. Rice production technical inefficiency model parameters at household-level

Variables	Coefficient	Standard Error	t-ratio
Constant	1.3048 ***	0.2213	5.8954
Household head's Age (years old)	0.0007	0.0010	0.6266
Household head's Sex (0:male/1:female)	-0.0657 **	0.0327	-2.0097
Household head's Education	0.0295 *	0.0159	1.8614
Family size (total family members)	0.0123 *	0.0070	1.7672
Female labor (total females 18-65yr)	0.0161	0.0139	1.1639
Other crops' cultivated area	0.0000 ***	0.0000	3.4658
Irrigated area	-0.0087 ***	0.0017	-5.2380
Distance to water sources	-0.0264	0.0210	-1.2547
Distance to district	0.0004	0.0017	0.2602
Number of plot area	-0.0678 **	0.0273	-2.4867
Number of cultivation per year	-0.0581	0.1091	-0.5322
Disaster	0.2664 ***	0.0344	7.7360

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

The variable of *irrigated* area had negative coefficient sign and significant at 1%, while *number of plot area* and the *sex of household head* also had negative coefficient signs but significant at 5%, indicating the positive impact of these factors on *TE of household's rice production* (negative impact on the TI), means that these factors are increasing TE. With the similar estimated coefficient value of 0.07, *number of plot area* and the *sex of household head* are the two core factors increasing TE of rice production at household-level, signposted that 1% increase in these factors could cause the TE to increase by 7%. The key messages from this finding are that farmers who cultivated on additional plot lands might have extra opportunities to obtain further benefits from their rice production. This could be explained in some ways. For example, farmers who cultivated 2 or more plot lands, sometimes one of his plot lands affected by natural disasters (droughts, floods, or insects) while the other (of his plot lands) not. Thus, he still could be able to gain output of rice production from the plot(s) that did not affected by disasters. Likewise, the similar reason might be able to apply to the plot land that benefiting from irrigation systems as well. For the farmers cultivated more than one plot land, sometimes one of his plot lands does not benefit or located near irrigation systems or water sources such as rivers, lakes, or ponds (that cannot be cultivated during dry season) while his other plot land located near water sources (or benefiting from irrigation systems) which allow him to expand his production by expanding the annual cultivated area through dry season cultivation on plot land that benefiting from irrigation systems. These could be the benefits of cultivating on more plot lands compared to farmers who cultivated on only one plot land. The positively significant of sex of household head on TE of household's rice production, on the other hand, is not only explain the imperative roles of female in rice production as well as family management, but also reveals the limited abilities of existing male household's head and inefficiency used of male labors in their household's rice production. Thus, some further extraordinary strategies or procedures might need to be put in place to enhance the efficiency of labor utilization or allocation.

Strongly significant of *irrigated* area variable, which is the percentage of rice production land located near water sources or benefited from irrigation systems (i.e. irrigated rice land) to total annual cultivated land of rice, showing that the greater percentage of irrigated rice land could lead to increasing in TE of household's rice production. This result highlights the important of irrigation systems in Cambodian rice production, particularly in the high potential province for rice production like Battambang. Therefore, focusing on irrigation development and improvement as well as good water management systems are the key factors to increase rice productivity in the northwest region of Cambodia (especially in Battambang province) that might need to be concerned and developed gradually.

5. Conclusions

There are 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 national rice production of Cambodia, while the expansion of total rice *land* actual harvested area, and technically improvement of *fertilizer* application rank as the second and third main input factors respectively for rice production development in Cambodia at both national and household-level. Furthermore, *pesticide* is another important input factor for improving household's rice production. These are the straightforward techniques for increasing rice productivity in most developing countries in the world. Moreover, these results also confirmed the existing problems in Cambodian rice production sector which were previously addressed by relevant studies like [2, 5, 35, 36, 39].

Second, the calculation of input elasticity reveal that *harvested area* had the highest elasticity among all input factors of rice production in Cambodia (at both national and household-level), which 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. Currently, the RGC had been trying to increase rice production by enlarging the total area of rice fields annually, this enlargement, however, still remains far behind its enormous potential to increase productivity of rice, due to limitation of land resources. Moreover, *irrigation* facilities, irrigation systems and good water management practices (which is the key factor for enlarging rice cultivated area through multi-cropping systems) in Cambodia still remain low and inefficiency. Therefore, significant commitments and supported actions are required to address the problem.

Third, *production techniques* for rural farmers, technical skills and amount of *agricultural supporting staffs* are being as the most important influencing factors of national rice production in Cambodia. However, production of rice in Cambodia is very vulnerable to natural *disasters* like floods, droughts, and insects, due to lack and inefficient performance of *irrigation* system (which is also playing the crucial role as the disasters prevention device in most cases). Thus, development of *irrigation* systems and good water management practices is a relevant magnitude to be powerfully considered by policy-makers for strategically developing policies geared towards enhancing rice production at both national and household-level.

Therefore, the main factors affecting the output level of rice production in Cambodia appear to be capital investment in agricultural *machineries* as well as efficiency of machineries performances, *actual harvested area*, *fertilizers* and *pesticides* utilization while *irrigation* and good water management, *production techniques*, and technical *supporting staffs* serving as main factors affecting TE of national rice production in Cambodia, and the core influencing factors lead to decreasing TE of household's rice production are *disaster* (i.e. droughts, floods, and insects), education *level of household's head*, number of people in the family (i.e. *family size*) and *cultivated area of other crops* such as corn, sugarcane, cassava, cucumber, pepper, wax melon, bitter melon, bean, eggplant, and other vegetables. However, the main influencing factors that lead to increasing TE are *irrigated* area, *number of plot area* and the *sex of household's head*.

Acknowledgements: This study was a part of the project "*The study on the production factors allocation efficiency and its growth road of south area's household agricultural production under the situation of the new return of collective forestry reform*" funded by the China's National Science Foundation and the Northwest A&F University of China.

Author Contributions: Author contribution to the present study as follow: "Sokvibol Kea and Hua Li conceived and designed the study and survey; Sokvibol Kea performed the survey and gathered the data; Sokvibol Kea and Linvolak Pich analyzed the data; Sokvibol Kea, Hua Li, and Linvolak Pich contributed reagents/materials/analysis tools; finally, Sokvibol Kea wrote the paper."

Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. Variables description of SFA model at National-level

Variable	Description
Rice Output	Total provincial un-milled rice production quantity, measured in tons.
Land input	The total area of rice actually harvested within the year (included both wet season and dry season), 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 [42]. 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 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 [34]. Harvested area (i.e. land input), hence, was expected to have positive effect on provincial as well as total rice output.
Labor input	Total farmers with rice farming as primary occupation (i.e. rice farmers), unit in persons. According to dataset of the Royal Government of Cambodia [33, 34], 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.
Fertilizer input	Total amount of chemical and organic fertilizers' quantity using by total families cultivating rice (i.e. rice families) in the province (unit in tons).
Pesticide input	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 [43], both fertilizer and pesticide variables were expected to be positively related to rice output.
Machinery input	is 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.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 September 2017 doi:10.20944/preprints201709.0161.v1

Table A2. Variables description of technical inefficiency (TI) model at National-level

Variable	Description
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	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 cultivated land within the year. Irrigation systems could cause the availability of rice cultivated land expansion by improving multi-cropping[2], hence, irrigation was stalwartly expected to have positive relationship with rice production TE.
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[3], 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 [41]. 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.
Distant to information sources	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	Agricultural staffs 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, 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.
Dry-season rice production	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.

[2] Multi-cropping: cropping/cultivating several times of crop on the same plot land
[3] CEDAC: Cambodian Center for Study and Development in Agriculture (Centre d' Etude et de Dévelopment Agricole Cambodgien)

 doi:10.20944/preprints201709.0161.v1

Small-land farmers	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.

Table A3. Variables description of SFA model at Household-level

Variable	Description
Rice Output	Total quantity of un-milled rice produced by individual households within the year or the sum of rice output produced in bothwet and dry season by households(i.e. *household rice output*), unit in kilograms (kg).
Land input	Total area of rice actually harvested within the year, measured in hectares (ha). In agriculture, land always plays as an important input in production of (agricultural) crops, particularly rice. Farmers harvested larger land of rice tend to be able to produce higher amount of rice output than the farmers harvested on smaller land. Harvested area (i.e. land input), hence, was expected to have positive effect on total household rice output.
Labor input	Total annual working days of adult family members (18-65 years old) on the rice field(s) included both male(s) and female(s), unit in days per person per year. In many developing countries, *labor input* tended to have negative relationship with household rice output since there were plenty of unskilled and low productivity labors existing, unskilled labors always spend higher (longer) time than more productive labors to produce the same level of output. Farmers in Cambodia, however, still seemed to be the lower productive farmers, since most them were not well educated yet. Thus, in the present study farmers were expected to spend over need of times in rice production. Therefore, labor input was expected to have negative effect on household rice output.
Fertilizer input	Measured as total amount of chemical and organic fertilizers' quantity using by households in their rice production annually (unit in kg),
Pesticide input	Measured as total amount of poisons for insects and grass's quantity (for both chemical and organic poisons) using by households, unit in kg.
	Both Fertilizer and Pesticide input variables were expected to be positively related to household rice output as followed by the concept of green revolution [43].
Other input	was determined as the variable of other capital investment on rice production, included investments on agricultural machineries, seeds, and other rental expenses within the year, measured as sum of depreciation of agricultural machineries (i.e. tractors, walking tractors or *koryons*, pumping machines, pesticide prayers) owned by households, altogether with total expenses on seeds purchasing and other rental such as wage paid for labors or equipment rentals during various stages of rice production (like plowing, seeding, transplanting, irrigating, harvesting, threshing, as well as transporting). Annual depreciation of a machinery was calculated as the division of its bought price by expected life usage. Expected life usage of tractors, walking tractors (or *koryons*), pumping machines, and pesticide prayers, were assumed to be 15 years, 10 years, 5 years and 5 years respectively in the present study according to the observations from farmers in the study area. The variable of capital investment was also expected to have positive effect on household rice output also, as farmers with more capital investment were believed to be able to generate higher opportunities for improving their rice production rather than farmers with lower available capital (for investment in family's rice production).

 doi:10.20944/preprints201709.0161.v1

747 **Table A4.** Variables description of technical inefficiency (TI) model at Household-level

Variable	Description
z_{1it} *Age of household head (years old)*	The age of household head might indicate the possibility of a given rice farmers (younger or older) to adopt innovation (such as new ideas and techniques) in rice cultivating. This variable is also a proxy for experience which represents human capital, revealing that farmers with more years of experience in farming will have more technical skills in management and thus higher efficiency than younger farmers [26]. However, rice production in Cambodia still seems to be labor-intensive, which most works in rice cultivation often depends on man-power rather than machineries. Thus, farmers with older age tended to have lower body strength (man-power) than younger farmers.
z_{2it} *Household head's sex*	Household head's sex is the gender dummy variable of household head which value of zero if household head is male and one if female.
z_{3it} *Education level of household head*	The education level of household head, i.e. the education dummy variable with value of one if household head is illiterate, two if has primary school education, three if has secondary school education, four if has high school education, five if has bachelor education, six if has graduated education (Master or Ph.D.), seven for other type of education, such as vocational training or informal education system. Both education and age (which proxy for farming experience) are important variables that help to improve the managerial ability of the farmer [44].
z_{4it} *Family size*	Family size, is the variable of the total number of family members in the household (persons).
z_{5it} *Female labor*	Female labor, is the total number of female family member in the household age between 18-65 years old (persons).
z_{6it} *Other crops' cultivated area*	The other crops' cultivated area, is the total production area of other crops beside rice such as corn, sugarcane, cassava, cucumber, pepper, wax melon, bitter melon, bean, eggplant, and other vegetables, measured in square meters (m^2).
z_{7it} *Irrigated areas*	The irrigated areas measured as the percentage of rice production land located near water sources or benefited from irrigation systems to total annual cultivated land of rice.
z_{8it} *Distance to water sources*	The distance to water sources, is the distance of rice production land from water source dummy variable with value of zero if production land is near (0-1km), one if 1-2km, two if 2-3km, three if 3-4km, four if 4-5km, five if the production land is far (≥5km).
z_{9it} *Distance to district*	The distance to district is the variable of distance from the village to the district center, in kilometers (km).
z_{10it} *Num. of plot area*	The number of plot area, i.e. the total number of plot lands owned and cultivated rice crops by farmers.
z_{11it} *Num. of cultivation per year*	The number of cultivation per year is the number of annual cultivation times that farmers can cultivate their rice crops (times).
z_{12it} *Disaster*	Disaster, is the dummy variable with the value zero if the farmers' rice fields did not affect by floods, droughts, or insects during the study period, and one if farmers' rice fields affected by floods, droughts, or insects.

748

 doi:10.20944/preprints201709.0161.v1

References

1. Nesbitt, H.J., *Rice Production in Cambodia*. 1997: Cambodia-IRRI-Australia Project.
2. ADB, *Improving rice production and commercialization in Cambodia*. 2014, Asian Development Bank (ADB): Printed in the Philippines.
3. OECD, *Structural Policy Country Notes Cambodia*, in *The Economic Outlook for Southeast Asia, China and India 2014: Beyond the Middle-Income Trap*. 2013.
4. CIA. *The World Factbook*. 2014 June 23, 2014 [cited 2015 January 10]; Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/cb.html.
5. Yu, B. and X. Diao, *Cambodia's Agricultural Strategy: Future Development Options for the Rice Sector*. 2011, A policy discussion paper of Cambodia Development Resource Institute (CDRI): Phnom Penh, Cambodia.
6. Yu, B. and X. Diao, *Cambodia's Agricultural Strategy: Future Development Options for the Rice Sector*. 2010, International Food Policy Research Institute: Washington, D.C.
7. World.Bank, *Cambodia economic update: Clear skies (English)*. 2014, World Bank Group.
8. Coelli, T.J., *Recent Developments in Frontier Modeling and Efficiency Measurement.* Australian Journal of Agricultural Economics, 1995. **39**(3): p. 219-245.
9. Yang, W., et al., *An Empirical Analysis on Regional Technical Efficiency of Chinese Steel Sector based on Network DEA Method.* Procedia Computer Science, 2014. **31**: p. 615-624.
10. Svitalkova, Z., *Comparison and Evaluation of Bank Efficiency in Selected Countries in EU.* Procedia Economics and Finance, 2014. **12**: p. 644-653.
11. Detotto, C., M. Pulina, and J.G. Brida, *Assessing the productivity of the Italian hospitality sector: a post-WDEA pooled-truncated and spatial analysis.* Journal of Productivity Analysis, 2013. **42**(2): p. 103-121.
12. Fu, P., Z. Zhan, and C. Wu, *Efficiency Analysis of Chinese Road Systems with DEA and Order Relation Analysis Method: Externality Concerned.* Procedia - Social and Behavioral Sciences, 2013. **96**: p. 1227-1238.
13. Cullmann, A. and C. von Hirschhausen, *Efficiency analysis of East European electricity distribution in transition: legacy of the past?* Journal of Productivity Analysis, 2007. **29**(2): p. 155-167.
14. Mayston, D.J., *Analysing the effectiveness of public service producers with endogenous resourcing.* Journal of Productivity Analysis, 2015. **44**(1): p. 115-126.
15. Lin, B. and H. Long, *A stochastic frontier analysis of energy efficiency of China's chemical industry.* Journal of Cleaner Production, 2015. **87**: p. 235-244.
16. Manlagñit, M.C.V., *Basel regulations and banks' efficiency: The case of the Philippines.* Journal of Asian Economics, 2015. **39**: p. 72-85.
17. Manlagñit, M.C.V., *Cost efficiency, determinants, and risk preferences in banking: A case of stochastic frontier analysis in the Philippines.* Journal of Asian Economics, 2011. **22**(1): p. 23-35.
18. Kea, S., H. Li, and L. Pich, *Technical Efficiency and Its Determinants of Rice Production in Cambodia.* Economies, 2016. **4**(4): p. 22.
19. Kea, S., L. Hua, and L. Pich, *Technical Efficiency Analysis of Cambodian Household's Rice Production.* Global Journal of Human Social Science-Economics, 2016. **16**(3): p. 33-44.
20. Chambers, R.G., *Applied Production Analysis: A Dual Approach*. 1988, New York: Cambridge University Press.
21. Coelli, T.J., et al., *An Introduction to Efficiency and Productivity Analysis (Second Edition)*. 2005, New York, the USA: Springer Science + Business Media, Inc.
22. Aigner, D.J., C.A.K. Lovell, and P. Schmidt, *Formulation and Estimation of Stochastic Frontier Production Function Models.* Journal of Econometrics, 1977. **6**(1): p. 21-37.

 doi:10.20944/preprints201709.0161.v1

23. Meeusen, W. and J. Van den Broeck, *Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error.* International Economic Review, 1977. **18**(2): p. 435-444.
24. Coelli, T.J., *A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation*, ed. N. 7/96. 1996, Armidale, NSW 2351, Australia: University of New England.
25. Battese, G.E. and T.J. Coelli, *A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data.* Empirical Economics, 1995. **20**: p. 325-332.
26. Balde, B.S., et al., *An Analysis of Technical Efficiency of Mangrove Rice Production in the Guinean Coastal Area.* Journal of Agricultural Science, 2014. **6**(8): p. 179-196.
27. Heriqbaldi, U., et al., *An Analysis of Technical Efficiency of Rice Production in Indonesia.* Asian Social Science, 2014. **11**(3).
28. Haryanto, T., B.A. Talib, and N.H.M. Salleh, *An Analysis of Technical Efficiency Variation in Indonesian Rice Farming.* Journal of Agricultural Science, 2015. **7**(9).
29. Kabir, H., et al., *Technical efficiency of Boro rice production in Bangladesh: A case of bio-slurry application.* J. Bangladesh Agril. Univ., 2015. **13**(1): p. 101–108.
30. Nehal Hasnain, M., *Technical Efficiency of Boro Rice Production in Meherpur District of Bangladesh: A Stochastic Frontier Approach.* American Journal of Agriculture and Forestry, 2015. **3**(2): p. 31.
31. Ueasin, N., S.-Y. Liao, and A. Wongchai, *The Technical Efficiency of Rice Husk Power Generation in Thailand: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis.* Energy Procedia, 2015. **75**: p. 2757-2763.
32. Shinta, A., et al., *Measurement of Technical Efficiency That Involving Farmers Preferences Towards Risk of Rice Farming in Malang (Indonesia).* Russian Journal of Agricultural and Socio-Economic Sciences, 2016. **51**(3): p. 3-13.
33. RGC, *Profile on Economics and Social in Year 2015, Based on Commune Databaes (CDB), December Year 2014 (Khmer language)*, in *Provincial Profile on Economics and Social*. 2015, The Royal Government of Cambodia (RGC), Ministry of Planning (MoP), Provincial Department of Planning (PDP): Cambodia.
34. RGC, *Profile on Economics and Social in Year 2016, Based on Commune Databaes (CDB), December Year 2015 (Khmer language)*, in *Provincial Profile on Economics and Social*. 2016, The Royal Government of Cambodia (RGC), Ministry of Planning (MoP), Provincial Department of Planning (PDP): Cambodia.
35. Smith, D. and J. Hornbuckle, *A Review of rice productivity in Cambodia and water measurement using direct and indirect methods on a dry season rice crop*. 2013, Technical Report to ACIAR, Canberra, CSIRO Sustainable Agriculture Flagship, Australia.
36. ADB, *The Rice Situation in Cambodia*. 2012, Technical Assistance Consultant's Report of Asian Development Bank (ADB).
37. Coelli, T., *Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis.* The Journal of Productivity Analysis, 1995. **6**(3): p. 247-268.
38. Eng, P.v.d., *Productivity and Comparative Advantage in Rice Agriculture in South-East Asia Since 1870.* Asian Economic Journal, 2004. **18**(4): p. 345-370.
39. CDRI, *Annual Development Review 2011-12*. 2012, Cambodia Development Resource Institute (CDRI): Phnom Penh, Cambodia.
40. Battese, G.E. and T.J. Coelli, *Frontier production functions, technical efficiency and panel data, With application to paddy farmers in India.* The Journal of Productivity Analysis, 1992. **3**: p. 153-169.

 doi:10.20944/preprints201709.0161.v1

41. CEDAC, *Report on the Progress of System of Rice Intensification in Cambodia 2007*. 2008, Cambodian Center for Study and Development in Agriculture (Centre d'Etude et de Dévelopment Agricole Cambodgien): Phnom Penh, Cambodia.
42. Baldwin, K., et al., *Southeast Asia's Rice Surplus*. 2012, United States Department of Agriculture (USDA), Economic Research Service.
43. Wikipedia. *Green Revolution*. 2016 September 06, 2016 [cited 2016 September 08]; Available from: https://en.wikipedia.org/wiki/Green_Revolution.
44. Abedullah, K., S. and K. Mushtaq, *Analysis of technical efficiency of rice production in punjab (Pakistan): Implications for future investment strategies.* Pakistan Economic and Social Review, 2007. **45**(2): p. 231-244.