Global Journal of Human-Social Science: E
Economics
Volume 16 Issue 3 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-460x & Print ISSN: 0975-587X

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GJHSS-E Classification: FOR Code: 149999

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I. Introduction

World population is increasing energetically from around 6.1 billion in 2000 to more than 7.2 billion in 2014, and expected to reach 9 billion by 2050 (FAOSTAT 2015). As a result of this rapid growth which is causing threat to food security, there is a need to understand agricultural growth and productivity for increasing agricultural outputs in order to meet the high demand for food. Agriculture remains fundamental in the 21st century for economic growth. According to World Bank (2014), agriculture accounts for one-third of gross domestic product (GDP) and three-quarters of employment in Sub-Saharan Africa. Agriculture, however, is more vulnerable to climate change than any other sector. A warming climate could cut crop yields by more than 25%. Agriculture and land use change are also responsible for 19-29% of global greenhouse gas emissions (World Bank 2014).

Agriculture is the traditional mainstay of the Cambodian economy. It remains as the dominant sector over the country's history. In 1985, agriculture accounted for 90% of GDP and employed approximately 80% of the work force (Nesbitt 1997). Although contribution of agricultural sector to national GDP have been decreased, growth in agricultural sector still played a crucial role in the development of Cambodia (Asian Development Bank 2014). This sector continues to make a rising contribution to the growth of the Cambodian economy. The sector grew 4.3% in 2012 and accounted for 4.75 million workers out of a labor force of 8 million in 2011 (OECD 2013). 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 (Central Intelligence Agency CIA 2014).

Rice cultivation 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 GDP). It is not only the most important food crop playing an unprecedented role in combating food insecurity for the nation, but also a key production economic crop. The production of rice is the most organized food production system in the country, occupies more than 80% of total cultivated land and is the most essential exported agricultural commodities (Yu and Diao 2011). Rice farming has an important role as a sector producing staple food for almost all of the population and provides a livelihood for millions of people in rural areas. Moreover, the value-chain of rice is one of the four major mainstays of Cambodian economy, along with textile, tourism and the construction industry. Unfortunately, the exportable surplus of Cambodian rice (3 to 4 million tons a year) are processed in Vietnam or Thailand today, which represents an important loss in terms of added-value for the sector (Agence Française de Développement AFD 2011).

Rice is the « White Gold » for Cambodian people. The Royal Government of Cambodia (hereafter, RGC) has declared that supporting the development of the national rice value-chain is one of its first priorities. With the strongly support of RGC, rice production has grown rapidly since 2003, which has firmly changed the country's position from rice deficit to surplus (Yu and Diao 2010). Nevertheless, 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 (World Bank 2014). Therefore, productivity and efficiency use of existing resources might be another source of rice development potential in Cambodia. Nevertheless, although significant

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productivity gains have been achieved in the country since the end of the conflict, the average rice yield still remains below those reached by neighboring countries.

In the recent years, although the studies of productivity and efficiency have been taken the attention of most economists and policy makers around the world (Sawaneh, Latif et al. 2013), agricultural productivity and efficiency studies (particularly rice production efficiency studies) in Cambodia still seem to be very rare. Only research works conducted by the related government agencies such as MAFF[1], CDRI[2], CARDI[3], etc. could be found these days, while the studies of the scholars still remain identical infrequently to see. Given the scarcity of literature on efficiency in Cambodia, the study consequently seeks to supplement literature and contribute in many ways to bridge the gap and supplement the shortage.

This study attempts to contribute to productivity literature of Cambodian agriculture by exploring the distribution of technical efficiency (hereafter, TE) among rice production households operating in the northwest region (specifically Battambang province) which is the high potential region of rice production. The aims of this study are to measure the TE of household's rice production and trying to determine its main influencing factors for explaining the possibilities of increasing productivity of rice, which might be the useful information for rice producers as well as policy makers of the government and related parties for improving Cambodian rice production for sustainable economic and social development at large.

The rest of this paper is organized as follow: Section 2 converses methodology and analytical frameworks of the study. Section 3 presents sources of data and descriptive statistics of input and output variables, while results are presented and discussed in Section 4. Finally, conclusion remarks are given in Section 5.

II. Research Methodology

Theoretically, *productivity* is the ratio of output(s) that produces to input(s) that uses (Coelli, Rao et al. 2005). *Efficiency*, alternatively, is defined as the level of operation that produces the greatest amount of output(s) with the lowest amounts of input(s). It is the main factor determining productivity. Efficiency score range between 0.00 and 1.00. The maximum score (1.00) represents the highest efficiency while the scores of 0.00-0.99 show a firm's inefficiency, indicating the relative displacement from the *frontier*[4] (Ueasin, Liao et al. 2015). Most references to the concept of efficiency are based directly or indirectly on Farrell (1957) which states that "the efficiency can be measured in relative terms as a deviation from best practices of producers compared with producer groups". The production process is technically efficient if and only if the maximum quantity of output(s) can be achieved for a given quantity of input(s) and technologies (Haryanto, Talib et al. 2015). More importantly, Farrell (1957) also suggested to measure TE by estimating frontier production function.

Technical efficienciy (TE) is measured as the ratio between the observed output(s) to the maximum output(s) under the assumption of fixed input(s) (called *output-oriented TE* "OO"), or as the ratio between the minimum input(s) to the observed input(s) under the assumption of fixed output(s), called *input-oriented TE* "IO" (Farrell 1957, Coelli, Rao et al. 2005). There are some basic differences between OO and IO models which further details in Hong and Yabe (2015) and Coelli, Rao et al. (2005). Furthermore, *TE in production* is defined as the ability of the producer (i.e. firm, factory, or farmer) to produce at the maximum output at the given quantities of inputs and production technology (Aigner, Lovell et al. 1977). *Production efficiency* is concerned with the relative performance of the process used in transforming input(s) into output(s). The greater the ratio of production output(s) to the factor input(s), the greater the magnitude of TE and vice versa (Balde, Kobayashi et al. 2014).

The present study implement the *stochastic frontier production function* (hereafter, *SFA model*) which is originally proposed by Aigner, Lovell et al. (1977), and Meeusen and Van den Broeck (1977) for measuring the *technical efficiency (TE)* of Cambodian rice farmers in the northwest region. The study applied *FRONTIER 4.1c* (Coelli 1996), the most commonly used package for estimation of *SFA model*, with the logarithmic form of *translog production function*. *FRONTIER 4.1c* was widely applied in different fields of research in the recent years, especially in agricultural studies like Battese and Coelli (1995), Balde, Kobayashi et al. (2014), Heriqbaldi, Purwono et al. (2014), Haryanto, Talib et al. (2015), Kabir, Musharraf et al. (2015), Nehal Hasnain (2015), Ueasin, Liao et al. (2015), Kea, Li et al. (2016), Shinta, Setiawan et al. (2016) .etc. for instance.

Technical efficiency of i^{th} household can be estimated by the ratio of observed output for i^{th} household relative to the potential output defined by *SFA model*, as follow:

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

[1] MAFF : Ministry of Agriculture, Forestry and Fishery

[2] CDRI : Cambodia Development Resource Institute

[3] CARDI : Cambodia Agricultural Research and Development Institute

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

Technical efficiency changes (hereafter, *TEC*) of i^{th} household between period t and $t+1$ are measured as the ratio of one household's efficiency scores in period $t+1$ to its efficiency scores in period t, which can be expressed as:

$$TEC_i^{t,t+1} = TE_i^{t+1}/TE_i^t \quad (2)$$

According to Aigner, Lovell et al. (1977) and Meeusen and Van den Broeck (1977), the general form of *SFA model*:

$$Ln\, y_{it} = Ln\, f(x_{it}, t\, ;\, \beta) + v_{it} - u_{it} \quad (3)$$

where y_{it} and x_{it} are output and input vector of rice production of i^{th} household within period t respectively; Ln indicates the natural logarithm function form; β represent the estimated coefficients; v_i is two-side random error term which represented statistical noise assumed to be normal distribution, $v_i \sim N(0, \sigma_v^2)$; u_i denotes technical inefficiency, is one-side error term that assumed to be independent to v_{it} with half-normal distribution, $u_{it} \geq 0$, $u_i \sim |N(0, \sigma_u^2)|$; v_i and u_i are independent; $i = 1,2, \ldots \ldots, N$; N is number of total samples, and t is time variable measured as year, $t = 1,2, \ldots, T$.

Translog production function of *SFA model* can be written as:

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

where x_{ji} is rice production input j^{th} of i^{th} household; J is number of inputs variables; β_0, β_j and β_t represent estimated coefficients; v_{it} and u_{it} are same as above notation.

The *technical inefficiency (TI) model* for rice production of i^{th} household can be expressed as:

$$u_{it} = \delta_0 + \sum_{k=1}^{n} \delta_k z_{kit} + \omega_{kit} \quad (5)$$

where u_{it} is the inefficiency effects that could be estimated by 2-stage estimation technique in *FRONTIER 4.1c* extemporaneously; ω_{kit} is the stochastic noises; z_{kit} denotes exogenous variables that are factors affecting the households' rice production TE scores; δ_0 represents the intercept term; δ_k is the parameter for k^{th} independent variables to be estimated; if δ_k is negative indicates positive relationship between affecting factor variables and efficiency scores, conversely, if δ_k is positive shows negative relationship between efficiency scores and affecting factors.

The parameters estimation of *SFA model* can be achieved by applying *Maximum-Likelihood (ML)* estimation method which estimates the likelihood function in terms of two variance parameters, see Coelli (1995):

$$\gamma = \sigma_u^2/\sigma_s^2\ ;\quad \sigma_s^2 = \sigma_v^2 + \sigma_u^2 \quad (6)$$

Gamma (γ) takes value between zero and one, reflects validity of the random disturbances (v_i, u_i) proportion. If γ is closer to zero, it indicates that gap between actual output and maximum possible output mainly comes from uncontrolled pure random factors, makes use of *SFA model* meaningless. In contrast, if γ is closer to one, it shows gap comes mainly from *technical inefficiency* due to effects of one or more exogenous variables, indicates using *SFA model* is more appropriate (Coelli and Battese 1996, Coelli, Rao et al. 2005).

III. Data and Descriptive Statistics

Primary data were collected from random sample of 301 rice production households in three selected districts of Battambang province (*the rice bowl of Cambodia*) using structured questionnaires. The district of Thmar Koul, Moung Russei, and Sangkhae were purposively selected as the study areas based on their total rice production area and total number of *rice farmers*[5] in 2014, which ranked from first to third among all 14 districts of Battambang. Field surveys were conducted in February and December of 2015 gathered 3-years data of households' rice production (2013, 2014 and 2015).

The *SFA model* was constructed by one output (i.e. *quantity* of rice) and five inputs included *land*, *labor*, *fertilizer*, *pesticide*, and *other capital*. Output was the total quantity of un-milled rice produced by households within the year (hereafter, *household rice output*), unit in kilograms (kg). *Land* input was the annual area of rice actually harvested in hectares (ha), expected to have positive effect on *household rice output* since *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 farmers harvested smaller *land*. Alternatively, *labor* input measured as total annual working days of adult family members (18-65 years old) on the rice field(s), unit in days/person/year. In developing countries like Cambodia, *labor* tends to have negative relationship with *rice output* as there were plenty of unskilled and low productivity labors existing since most of them were not well educated yet, unskilled labors often spend longer time than productive labors to produce the same level of output(s). Therefore, *labor* was expected to have negative effect on *household rice output*. Furthermore, *fertilizer* input was total amount of chemical and organic fertilizers' quantity using by households in rice production annually (in kg), while *pesticide* input measured as total amount of poisons for insects and grass's quantity (both chemical and organic) using by households, in kg. These two input

[5] Rice farmers : farmers with rice farming as primary occupation

variables were expected to be positively related to *household rice output* as followed by green revolution concept (Wikipedia 2016). Additionally, another input was determined as *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 rentals such as wage paid for labors or equipment rentals during various stages of rice production. Annual depreciation of machinery was calculated as the division of its bought price by expected usage life. Expected usage life of tractors, *koryons*, pumping machines, and pesticide prayers were assumed to be 15, 10, 5 and 5 years respectively according to observations in the study area. *Other capital* investment was also expected to have positive effect on *rice output*, as farmers with more capital were believed to be able to generate higher opportunities for improving their rice production rather than farmers with lower available capital. Table 1 provides summary statistics of the output and inputs of households' rice production of Battambang from 2013 to 2015.

Table 1: Output and input summary statistics for households' rice production in Battambang, 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
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

Output *quantity* of households' rice produc-tion was higher in 2014 than 2013 which increased 8.5% in average from 16.7 thousand kg to 18.1 thousand. Nevertheless, *household rice output* has been decreased by 6.5% between 2013-2015 as the results caused by disasters occurred in 2014 (flood) and 2015 (drought) which reduced *rice output* to 15.6 thousand kg/household (in 2015). Annual rice area harvested by farmer households ranged from 1 ha to 82 ha. During the study period, in average farmers harvested around 7 ha (included both wet and dry season) in 2013, and increased by 1.2% 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 was 108 days/person in 2013, and increased to 110.5 days in 2014, then reduced to 106.7 days in 2015. Conversely, *fertilizer* input increased by 2.5% between 2013-2015 from average of 772 kg (2013) to 791 kg (2015), while between the same period *pesticide* input also increased by 1.6% from 70.8 kg to 72 kg in average. In the study period, the level of households' *other capital* investment showed the impressively deduction by 4%, particularly during 2014/2015 (decreased 12.6%), indicated the farmers' response to effects of natural disasters that reduced availability of rice area to be harvested.

Figure 1 illustrates the percentage changes of output and input statistics of rice production of farmer households in Battambang for the periods 2013-2014, 2014-2015, and 2013-2015. The percentage changes within output and input variables 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 tended to decrease (particularly in *labor* and *other capital* input which decreased by 6.8% and 12.6% respectively) due to effects of natural disasters, caused *household rice output* to decrease greatly by almost 30% compared to the production of 2014.

In the *technical inefficiency (TI) model*, there were twelve influencing factors of household's rice production TE to be considered. z_{1it} is *age of household head* (years old). The age of household head might indicate the possibility of a farmers (younger or older) to adopt innovation such as new ideas and techniques in rice cultivating, and also 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 (Balde, Kobayashi et al. 2014). However, rice production in Cambodia still seems to be labor-intensive which most works often depends on man-power. Thus, older farmers often have lower body strength (man-power) than younger farmers. z_{2it} represents *household head's sex* is the gender dummy variable which value of zero if household head is male and one if female. z_{3it} is the *education of household head*, i.e. 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 (Abedullah and Mushtaq 2007). z_{4it} represents *family size*. z_{5it} denotes *female labor*, is the total female family member in the household age 18-65 years old (persons). z_{6it} is *other crops' cultivated area*, i.e. 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} is the *irrigated areas* measured as the percentage of rice production land located near water sources or benefited from irrigation systems to total annual rice cultivated land. z_{8it} symbolizes *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 (0-1 km), one if 1-2 km, two if 2-3 km, three if 3-4 km, four if 4-5 km, five if the production land is far (≥5 km). z_{9it} represents *distance to district* is the variable of distance from the village to the district center, in kilometers (km). z_{10it} is *number of plot area*, i.e. the total number of plot lands owned and cultivated rice crops by farmers. z_{11it} denotes *number of cultivation per year* is the number of annual cultivation times that farmers can cultivate their rice crops. *Disaster* is symbolized by z_{12it}, is the dummy variable with the value zero if 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.

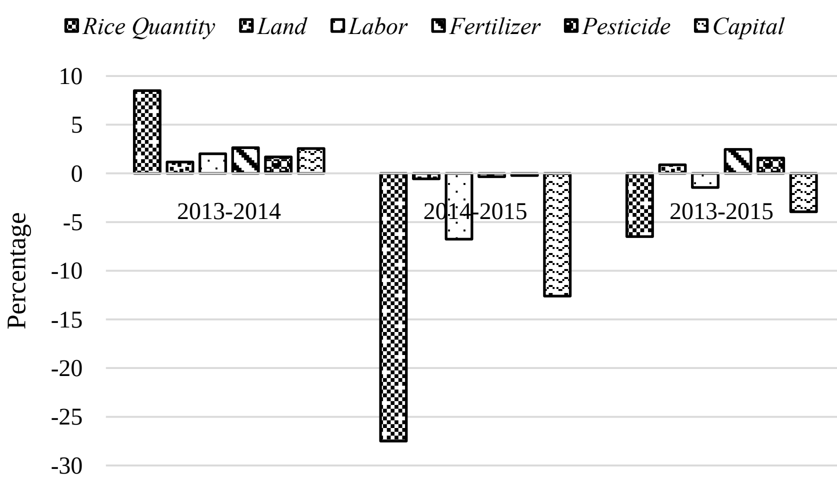

Figure 1: Percentage changes in output and input statistics for households' rice production in Battambang for the periods 2013-2014, 2014-2015, and 2013-2015

Descriptive statistics of *TI model*'s parameters between 2012 and 2015 are given in Table 2. Most of variables remain insignificant changed between this three years period. The overall statistics reveal that 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, 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 is about 5.17 persons/household (ranged from 2 to 12 persons/household), while existing *female labor* in average was about 1.63 persons/household.

The average *cultivated area under other crops* beside rice was about 485 m^2 in 2013. However, this amount had been decreased (by almost 50%) to 247 m^2 in 2014 and 2015. Furthermore, *irrigated areas* were 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 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. In average, rice production lands of rural farmers located around 2.91 km from the nearest water sources (or irrigation systems). This distance is quite far and often causes inability for farmers to use water from existing water sources or irrigation systems. Likewise, the results also show that only 39% of farmers' rice fields 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, is the proxy variable of farmers' accessibility to information sources related to rice production such as price information as

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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 (ranged from 1 km to 28 km).

Table 2: 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 (18-65 years old)	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

Rice farmers in Cambodia 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, and about 44% of farmers able to cultivate rice crops more than once per year. More importantly, between 2013 and 2014, only 6-7% of 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.

IV. Results and Discussions

a) *Estimation of SFA Model*

In *SFA model*, a test whether there is TE exist or not can be conducted by testing the null hypothesis $H_0: \gamma = 0$, versus alternate hypothesis $H_1: \gamma \neq 0$. Coelli (1995) argued that *Maximum-Likelihood (ML)* shall be estimated by the calculation of 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 x^2 distribution for a standard test of size 2α. Thus, one-sided *LR 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%, $x^2(2\alpha)$ has value of 100.62. In the present study, however, *LR test* 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 TE effect exists in the model.

Table 3 lists parameters estimation results by implementing the *ML* estimation in *FRONTIER 4.1c* econometrics software of Coelli (1996). The variance ratio parameter, gamma (γ), had a value of 1.00 significant at $\alpha = 1\%$, shows that the variation of composite error term was mainly from the TE (u_i) almost 100%, and the variation of random error (v_i) less than 1%, indicated that the efficiency of households' rice production between 2013 and 2015 mainly comes from TE of production. Almost all estimated coefficients have the expected signs. *Land* input had positive coefficient and significant at 1%, while *fertilizer* and *pesticide* input both had positive coefficients but significant at 5%, indicates positive contribution of these inputs to *household rice output*. These results designated enlarging harvested *land*, increasing quantity used of *fertilizer* and *pesticide* could cause the increasing of *household rice output*. Furthermore, with the estimated coefficient of 0.83, annual area of rice actually harvested was the main input factor driving extra output for household's rice production compared to *fertilizer* and *pesticide*, which means farmers who cultivate additional lands have the ability to maintain reasonable levels of the necessary inputs. Yu and Diao (2011), Smith and Hornbuckle (2013) and some researches of Asian Development Bank (ADB 2012, ADB 2014) also have similar results. Cultivated land can be increased by expanding irrigation that permits multiple season cropping. Rice is predominately grown in the wet season 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 (Eng 2004, Smith and Hornbuckle 2013). Production efficiency, nevertheless, is constrained by low rates of irrigation (ADB 2014). 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 season rice farming is significantly constraint and has occasionally caused conflict among farmers (CDRI 2012). Yu and Diao (2011) argued that 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.

Table 3: Parameters estimated for the SFA model

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 x Labor	0.0341	0.0433	0.7876
Land x Fertilizer	-0.0248	0.0210	-1.1796
Land x Pesticide	0.0089	0.0189	0.4701
Land x Capital	-0.0054	0.0269	-0.1992
Labor x Capital	-0.0034	0.0425	-0.0801
t.t	-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%*

Besides farmland 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 *System of Rice Intensification* (SRI[6]). Increase of *fertilizers* and *pesticides* application are the main characteristics of Green Revolution in rice agriculture, which spread throughout the Southeast and East Asia during the past 30 years, could increase productivity of rice (Eng 2004, ADB 2012, Smith and Hornbuckle 2013, ADB 2014). This is undoubtedly supported by the sturdy significant of *fertilizer* and *pesticide* inputs in *SFA model* of the current study. Nonetheless, *labor* input has negative coefficient but not significant at any α level, reveals that there was no significant relationship between *labor* and *household rice output* in Battambang during the study period. Furthermore, the present study also established no significant relationship between household *rice output* and level of household's *other capital* investment in household's rice production.

Table 4 illustrates the input elasticity of household's rice production in Battambang between 2013 and 2015. It is clearly demonstrated that all inputs (except *labor*) have had the increasing return to scale. *Land* input had the highest elasticity among entire inputs, following by *pesticide* and *fertilizer*. Elasticity of *land* had the value of 0.83 in average indicating that 1% increase of harvested *land* (of rice) could cause *household rice output* to increase by 83%. Similarly, with the average elasticity of 0.083 and 0.056 respectively, revealing 1% increase in *pesticide* and *fertilizer* could cause the increasing of *household rice output* by 8.3% and 5.6% (respectively). The elasticity of *other capital*, on the other hand, had value of 0.0086 in average showing 1% increasing in capital investment to rice production could also cause the increasing of household rice output (by 0.86%).

[6]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 CEDAC (2008). Report on the Progress of System of Rice Intensification in Cambodia 2007. Phnom Penh, Cambodia, Cambodian Center for Study and Development in Agriculture (Centre d'Etude et de Dévelopment Agricole Cambodgien)..

Table 4: Input elasticity of household's rice production in Battambang province, from 2013 to 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

The negative elasticity of *labor* not only explained the overused of labors in rice production but also viewing inefficiency performance of existing labors in rice fields. Although *labor* input were not significantly affecting *household rice output* in the present study, its negative coefficient in the *SFA model* 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.

b) Technical Efficiency Analysis

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 5. The findings revealed the overall mean TE of rice production is estimated at 0.34 (ranged from 0.097 to 0.913) indicated that households 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. 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 in 2015) and other influencing factors (will be discussed in the next section), TE of household's rice production in Battambang had been decreased gradually from 0.352 (in 2013) to 0.302 in 2015, 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 increase further by almost 70% at the current levels of inputs.

Sangkhae district had the highest TE score among three selected districts in all years of the study period. In 2013, rice farmers in Sangkhae district produced 38.2% of rice at best practice while farmers in Thmar Koul and Moung Russei district produced only 35.5% and 32.7% of rice 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. Between 2013 and 2014, TE 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 rice production in this district declined sharply to 0.24 (diminished by 27% between 2013-2015). However, during the study period farmers' rice production in Thmar Koul district had the decreasing trend of TE from 0.355 (2013) to 0.342 (2014), then continued to decrease to 0.297 in 2015 (decreased by 16.3% between 2013-2015). In contrast with the situation in Thmar Koul district, household's rice production of farmers in Sangkhae district had the increasing trend of TE from 0.383 in 2013 to 0.387 in 2014, and still continued to increase to 0.389 in 2015 (1.65% increased between 2013-2015).

At the commune-level, statistical results reveal that 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. 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).

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Table 5: Technical efficiency (TE) and technical efficiency change (TEC) of household's rice production in Battambang province, 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

Figure 2 illustrates the TE distribution of Cambodian household's rice production in Battambang 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 TE of 35.2% in 2013, while in 2014 household's TE ranged from 14.6% to 86.7% with a mean TE of 35.3% (increased 0.27%). TE of household's rice production in 2015, on the other hand, ranged from 9.7% to 91.3% with a mean TE of 30.2% (decreased 14.3% between 2013-2015). Thus, rice production of farmers in Battambang performed better during 2013 and 2014 than 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 TE score between 0.21-0.30 (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.

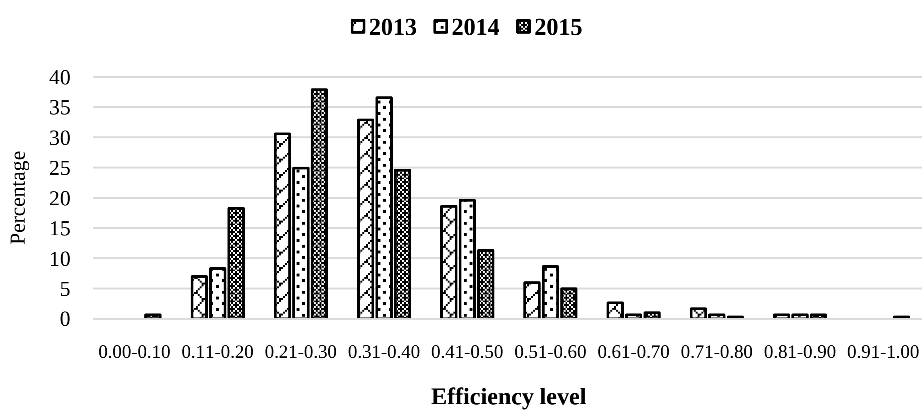

Figure 2: Technical efficiency distribution of household's rice production in Battambang, 2013-2015

c) Technical Inefficiency Model and Affecting Factors

The *Maximum-Likelihood (ML)* estimates coefficients of explanatory variables in the *TI model* of household's rice production in Battambang, and these estimated coefficients are of interest and have implication as shown in Table 6. A negative sign on a parameter explaining the positive effect of the variable on TE means the variable is improving TE, while for a positive sign the reverse is true. It is noticeable that *disaster* and *other crops' cultivated area* both had positive coefficient signs and 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. With the highest coefficient of 0.27, *disaster* was the core influencing factor leads to decreasing TE, while *education of household head* and *family size* are the second and third factors with estimated coefficient value of 0.03 and 0.01 respectively. These results indicate 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 of household's rice production, implying 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 is consistent with the finding of Balde, Kobayashi et al. (2014), who found that education level was significant and negatively affecting TE of Mangrove rice production in the Guinean coastal area. Kabir, Musharraf et al. (2015) 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, *family size* also has a negative and significant 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 indicates reducing rice's cultivated area for growing other crops beside rice might cause the TE to decrease. However, the value of this coefficient is quite tiny, reflecting the very little effect of other crops' cultivated area on TE.

The *irrigated area* had negative coefficient sign and significant at 1%, while *number of plot area* and *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. With the similar estimated coefficient value of 0.07, *number of plot area* and *sex of household head* are two core factors increasing TE, signposted 1% increase in these factors could cause TE to increase by 7%. The key messages from this finding are farmers who cultivated on additional plot lands might have extra opportunities to obtain further benefits from their rice production. The positively significant of *sex of household head*, on the other hand, is not only explain the imperative roles of female in rice production and 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, further extraordinary procedures might need to put in place to enhance the efficiency of labor utilization or allocation.

Table 6: Rice production technical inefficiency model parameters

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	0.0123 *	0.0070	1.7672
Female labor (18-65 years old)	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%.*

Strongly significant of *irrigated area*, showing the greater percentage of irrigated rice land could lead to increasing TE. This result highlights the important of irrigation systems in Cambodian rice production, particularly in high potential province like Battambang. Therefore, focusing on irrigation development and good water management are the key factors to increase rice productivity in the northwest region of Cambodia that might need to be concerned and developed gradually.

V. Conclusions

The aims of this study are to measure TE of household's rice production in the northwest region of Cambodia and to determine its main influencing factors using *SFA model*. The study utilized primary data collected from 301 rice farmers in three selected districts of Battambang province by structured questionnaires. The empirical results indicated that level of *rice output* varied according to differences in production techniques and efficiency of production processes. The mean TE is 0.34 (ranged from 0.097 to 0.913) which means famers in Battambang produce 34% of rice at best practice, indicates that *rice output* has potential of being increased further by 66% at the same level of inputs if farmers had been technically efficient. Furthermore, during the study periods the TE of household's rice production recorded a -14.3% decline rate due to highly affected of drought in 2015.

Three main conclusions emerged from the study's results. First, based on decomposing of *SFA* *model*, increasing harvested *land* (particularly in dry season through development of irrigation systems and good water management practices for gaining benefit from multi-cropping systems) is the major influencing factor of household's rice production in Battambang, while increased *fertilizers* and *pesticides* application are the second and third influencing factors respectively. Second, calculation of input elasticity reveals that all inputs, except *labor*, have had the increasing return to scale, while *land* input had the highest elasticity value among entire inputs following by *pesticide* and *fertilizer*. 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. Finally, the decomposing of *TI model* reveals that core influencing factors lead to decreasing TE of household's rice production are *disaster* (i.e. droughts, floods, and insects), *education of household head*, *family size* and *other crops' cultivated area*, while the main influencing factors lead to increasing TE are *irrigated area*, *number of plot area* and *sex of household head*.

VI. Acknowledgments

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 (project number: 71273211) and the Northwest A&F University of China.

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