Sustainable Farming Techniques and Farm Size for Rice Smallholders in the Vietnamese Mekong Delta: A Slack-Based Technical Efficiency Approach

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Abstract

Small farm size and fragmented land are considered constraining agricultural development. This study uses the Vietnam Household Living Standard Survey 2016 (VHLSS 2016) dataset to measure the technical efficiency of rice smallholders and its determinants, including farm size, in the Mekong Delta. Data envelopment analysis was employed to examine efficiency scores in the first stage based on data of 506 paddy farms. The overall efficiency calculated through slack-based measure was low at 0.59 and the input slacks are quite large. This indicated that local farmers have not been using their resources efficiently in producing paddy. Further, farms smaller than 2 hectares in transition faced low overall efficiency at 54% and higher slacks in terms of all input types. The second-stage Tobit result showed that all types of efficiency could be improved if farmers expanded their farm size and reduced the over-use of inputs. Thus, enabling small farms to achieve economies of scale through collective farming in the Large Field Model (LFM) will be critical for upgrading production efficiency and reducing slacks as labor costs rise and natural resources are constrained. It is recommended that farmers should follow strictly to eco-friendly farming packages in order to reduce their current excessive usage of seed cost by 28 USD/ha, pesticides by 61 USD/ha, and fertilizers by 155kg/ha to reach efficient production frontier. The government needs to take measures to replicate and closely monitor climate smart agriculture programs in large-scale production to improve the overall efficiency of paddy sector, in addition to the important goal of protecting the environment and natural resources of the region.

Keywords: farm size, efficiency, data envelopment analysis, slack-based measure, sustainable rice farming, Mekong Delta

1. Introduction

Asian countries, including Vietnam, remain characterized by the duality of modern and traditional systems because of the sustained dominance of a large number of smallholders who may not meet the conditions required to enter the modern value chains (Yamauchi et al., 2021, Otsuka 2013). Several existing literature has provided some evidence about the relationship of paddy farm size and the efficiency. By increasing the operation scales of paddy farms, it is possible to increase the allocative and scale efficiencies (Watkins et al., 2014). In the context of Chinese agriculture, the consolidation of fragmented lands could improve production efficiency by lowering transaction costs in mechanization (Wang et al., 2020). In Japan, it is suggested that increasing the scale of farming is an effective way to improve technical efficiency (Li et al., 2018) and enhance the energy efficiency of highly mechanized rice production (Masuda, 2018). Similarity, Tu et al. (2021) drawn a conclusion that land accumulation from tiny plots is positively associated with both technical and environmental efficiencies of rice production in the Vietnamese Mekong region.

The Mekong Delta (MKD) is well known as a key rice producing area that plays a particularly important role in ensuring Vietnam's national food security and exports. Every year, the Mekong region contributes to more than 50% of the rice production and 90% of the total national rice exports. By the end of 2018, the paddy cultivated area of the MKD reached 4.11 million hectares (ha), representing a proportion of 58% over the total figure of the country. Productivity was estimated at 5.97 tons/ha which is higher than national average yield at 5.82 tons/ha; total output reached 24.5 million tons and accounted for 55.8% of the paddy volume of whole country (GSO, 2020). However, rice production in Vietnam appears to be highly fragmented and small farms are often rendered less efficient by consisting of tiny plots. In the Red River Delta, 97% of holdings in 2011 were under 0.5 ha. In MKD region, about 83% of farmers' land size is less than 2 ha. Nationally, the average size of a paddy holding is only 0.44 ha, meanwhile this figure is 1.2 ha in the MKD (World Bank, 2016). Small farm size and fragmented land are believed to be the disadvantages to agricultural development and input uses in Vietnam and the MKD. It is more difficult to improve productivity through mechanization, consistent investment in new technology and efficient water management (Smith, 2013). Certainly, the rapid increase in tractor use in Vietnam would be associated with an increase in the relative advantage of large farms (Liu et al., 2020). Also, tractors or combine harvesters are mostly concentrated in the large landholding groups, especially those exceeding 3 ha. Moreover, larger-scale farmers in the MKD had more opportunities to access formal credit access for their production investment purpose from agricultural or commercial banks, whereas smaller-scale farmers had to rely more on informal credit sources in their local areas (Quang, 2017).

Understanding production efficiency and farm size in developing countries has become a major interest of many scientists. Some previous studies have analyzed the technical efficiency (TE) of paddy smallholders, using the parametric stochastic frontier approach (SFA) (Ho, 2019; Khai and Yabe, 2011; Ebers et al., 2017; Nguyen et al., 2003), non-parametric data envelopment analysis (DEA) (Watkins, 2014; Linh, 2015; Le, 2017; Krasachat, 2004; Khosroo, 2013; Islam, 2011; Dhungana, 2004; Li et al., 2018; Brázdik, 2006), or a hybrid (Huy, 2009). Overall, studies on production efficiency in the MKD are limited in number, and most of them draw out conclusions about efficiency scores without the connection with farm size and sustainable agricultural programs in local areas.

Regarding radial DEA approach, Charnes, Cooper, and Rhodes (CCR) and the Banker, Charnes, and Cooper (BCC) models reflect the common proportional maximum reduction of all types of input. However, in the reality, especially in the rice sector, not all of the inputs will be reduced in the proportional way (like labor, material, capital, etc.). If we want to consider the efficiency scores as the only indexes to evaluate the performance of households as decision making units, the radial approaches may mislead the decision since they neglect these important slacks in reporting the efficiency scores. A slack-based measure (SBM) (Tone, 2001)—which is a non-radial DEA approach—is first introduced in our study to calculate the overall and mix efficiencies of rice smallholders in the MKD. This scalar measure deals directly with input excesses or output shortfalls in production steps and only be determined by consulting the reference set of decision making unit (DMU) which is not affected by statistics of the whole dataset. Overall efficiency calculated through SBM is considered to be an important indicator for regional agricultural development since it is the product of the three efficiencies, i.e., global technical, scale and mix efficiencies. Furthermore, based on the slack analysis from SBM, some recommendations will be presented to bridge efficiency improvement strategies including farm size and natural environment protection by reducing chemical inputs in the delta.

Therefore, this study will: i) estimate the production efficiencies of paddy households with respect to technical, scale, mix and overall efficiencies and input slacks, ii) examine how farms' socio-economic indicators, including farm size, are influencing production efficiency, and iii) provide the implication to sustainable rice farming in MKD. Because of the high usage of agrochemicals (Berg and Tam, 2021; Huan et al., 2008) and the characteristically small scale of rice farms, our research will apply input-oriented DEA to estimate the technical efficiency of rice production.

The structure of this paper is as follows. Section 2 presents an overview of the rice production in the Vietnamese MKD. Section 3 explains the methodology and data used here. Section 4 presents results and discussions. The last section concludes, with policy recommendations for sustainable rice farming in MKD.

2. Overview of rice production in the Vietnamese Mekong Delta

The Mekong Delta is an important economic and ecological region of Vietnam and is located in the lower part of the Mekong River and bordered by the East Sea (with a coastline of about 700 km) along the West, the Southwest, and the South. The MKD includes 1 city—Can Tho—and 12 provinces: Long An, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Dong Thap, An Giang, Kien Giang, Bac Lieu, and Ca Mau. According to the General Statistics Office (GSO) of Vietnam in 2018, the MKD had an area of 40,816.4 km^2 and a total population of 17,273,630 people (Figure 1). With the rich natural supply of freshwater and alluvial soils, it is an advantageous environment for a fruitful rice production in the MKD (GRiSP, 2013). The water resources management in this region is characterized by a complex rivers and canal systems that have been extensively developed during the past 20 years (MARD, 2016).

The MKD has always played a very important role in the paddy industry as well as in national food security. It accounted for more than 50% of the total Vietnamese rice farming area and rice production during the 20-year period from 1996 to 2016. During this period, Vietnam's rice production was driven by a focus on meeting production targets with high yielding varieties for export rather than raising rice quality. Agriculture in the MKD is still largely based on small scale production by a large number of smallholders. According to the World Bank Rural Development Strategy (World Bank, 2003), smallholders are those farmers "with a low asset base and operating in less than 2 ha of cropland". In Asia, examples of the average sizes of smallholder farms are 0.24 and 0.32 ha in Bangladesh and Vietnam, respectively (FAO, 2015). The total number of smallholder households involved in the MKD's rice industry in 2016 was 1,138,995, most of whom owned small and fragmented land holdings. Figure 2, based on agricultural census data, shows the average farm size and share of rice households in Vietnam and Mekong Delta in 2016. There, about 53.7% of Vietnamese farm households have less than

0.2 ha, 35% have between 0.2 and 0.5 ha, 12.3% between 0.5 and 2 ha, and 2.6% more than 2 ha. The proportions of farms smaller and larger than 2 ha in the MKD were 83.4% and 16.6%, respectively[1] (GSO, 2018). This figure of smallholders represents the main barrier to the development of sustainable farming systems and advanced technology application for intensive rice production. To enhance the capacity of the small-scale rice sector, the Vietnamese government officially introduced the Large Field Model (LFM) in late 2011 through Resolution 21/2011/QH13. This model is embodied as a production organization that establishes a link between farmers and enterprises; it gathers small-scale farmers of the same agricultural products into larger groups, to create favorable conditions for the application of new technologies and for output price stability. In the LFMs, a reduction in rice production costs is achieved by taking advantage of economies of scale through application of modern agricultural machinery and thus reduced labor costs (Thang et al., 2017). The LFM is also the foundation for the application of advanced cultivation methods and the pursuit of CSA techniques. Paddy LFMs in the MKD occupied an area of 426,528 ha with the participation of 139,556 households, which accounted for only 10.05% of the total paddy area of the MKD (4.24 million ha) in 2016 (GSO, 2018).

Paddy sector required approximately 65% of the country's total fertilizer demand (GSO, 2014). In the MKD, the closed dyke system that allows for intensive rice cultivation has caused soil degradation, especially a lack of alluvium; this has been aggravated by the excessive use of chemical fertilizers by farmers in this region. It was reported that seed density and the use of nitrogenous fertilizer doubled over the period 1990–2004 from 95 to 144 kg/ha and 70 to 140 kg/ha, respectively; these amounts of input use far exceeded the quantity recommended by the government (Huan et al., 2008). The agricultural sector in the MKD has been facing a big concern in the form of pesticide pollution of the environment and of drinking water resources. Berg and Tam's study (2012) reported that the application

[1] Descriptive data from Rural, Agricultural and Fishery Census in Vietnam, 2016.

frequency of both herbicides and fungicides has more than halved since 1999 for all rice and rice-fish interviewed households in MKD, while insecticide applications has doubled for Integrated Pest Management (IPM) farmers (i.e., those who had already undergone IPM training). Due to the suboptimal pesticide management in MKD, there has been a wide range of pesticide residues present in water, soil, and sediments over a long period (Toan et al., 2013). Health risks to farmers and communities using water sources with pesticide residues are becoming ever more evident. Clean water sources appear to be absent, and water-related health risk is becoming a serious issue in MKD due to pesticide pollution (Chau et al., 2015).

Fertilizer and pesticide expenses are also the primary reason for the extremely high cost of rice production. In the 2014 crop year, farmers in the MKD spent about 255 USD on fertilizers and 245 USD on pesticides per hectare, accounting for approximately 50% of the total rice production costs (1,097 USD/ha). These figures are much higher than those of Thailand, with 243 USD/ha for fertilizers and 102 USD/ha for pesticides of a total production cost of 1,366 USD/ha (MOST, 2016). To address the concern about an unsustainable rice sector, some climate smart agriculture (CSA)[2] techniques have been implemented in Vietnam and the MKD to improve the quality of rice products and protect the environment. One of the best-known CSA techniques in Vietnam, One Must Do Five Reductions is a technology package that was developed during Phase IV of the Irrigated Rice Research Consortium of International Rice Research Institute (IRRI) and promoted by the Agricultural Competitiveness Project of the World Bank. In 2013, data collected from just eight provinces in the MKD indicated that 34,500 farmers participated in training, and that about 240,000 farmers were implementing “One Must Do, Five Reductions” over 300,000 ha. Farmers are urged to use certified seeds—the “One Must,” or the one

[2] Climate smart agriculture (CSA) is defined by the FAO (2010) as a form of agriculture that sustainably helps farmers to increase productivity, enhance resilience, reduce greenhouse gas emissions, and achieve national food security.

thing they must do—while the “Five Reductions” refer to reductions in sown seed density, nitrogen application, pesticide use, water use, and post-harvest losses (IRRI, 2012).

3. Methodology and data

3.1. Measuring efficiency of rice production using data envelopment analysis (DEA)

DEA is a nonparametric linear programming (LP) approach for measuring the relative efficiency among a set of decision making units (DMUs), which represent rice households in this study. This tool originated from Farrell (1957), but the term “data envelopment analysis” became more popular following the works of Charnes et al (1978) and Banker et al. (1984). A DEA model can be input-oriented (minimizing inputs while maintaining the same level of outputs) or output-oriented (increasing outputs with the same level of inputs). Due to the specificity of the Vietnamese rice sector, which mainly relies on limited resources, an input-oriented DEA model is more appropriate to measure efficiency scores than an output-oriented model. There are two types of DEA approaches, namely, radial and non-radial. For radial DEA, CCR and BCC models are very well known in DEA literature, while an SBM (Tone, 2001) is a non-radial method that deals directly with input slacks in each rice field. The details of each model are described briefly as follows:

The Charnes, Cooper, and Rhodes (CCR) model

The CCR model (Figure 4) is built on the assumption of CRS (constant returns to scale) of the DMU’s activities. The input-oriented CCR model evaluates the efficiency θ^* of a DMU by solving the following LP:

$$\text{[CCR-I]} \quad \theta^*_{CCR} = \min_{\theta,\lambda} \theta \qquad \text{subject to} \quad \begin{aligned} & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0 \quad , \\ & \lambda \geq 0 \end{aligned} \qquad (1)$$

where θ is the scalar, λ is a *Nx1* vector of constants (assumes that there are data on *N* farms). The value of θ^*_{CCR} obtained is the efficiency of the i^{th} rice farm and it ranges from 0 to 1. If the θ^*_{CCR} of a farm is equal to 1, that household is fully technically efficient; otherwise, it is not efficient (Coelli et al., 2005).

The Banker, Charnes, Cooper (BCC) model

The CRS assumption is appropriate when all DMUs are operating at an optimal scale. However, in reality, imperfect conditions in production may cause a farm not to be operating at optimal scale. Banker, Charnes, and Cooper (1984) proposed the BCC model under VRS situations by adding the convexity constraint *N*1'λ = 1 to equation (1) to provide:

$$\text{[BCC-I]}\ \theta^*_{BCC} = \min_{\theta,\lambda} \theta \qquad \text{subject to} \quad \begin{array}{l} -y_i + Y\lambda \geq 0, \\ \theta x_i - X\lambda \geq 0 \\ N1'\lambda = 1 \\ \lambda \geq 0 \end{array}, \qquad (2)$$

where θ is the scalar, *N1* is an *Nx1* vector of 1, and λ is an *Nx1* vector of constants (Coelli, 2005). The BCC score ranges from 0 to 1. The production frontier of the BCC model will contain more efficient DMUs than the CCR frontier (as shown in Figure 4). A DMU is called efficient when θ^* = 1; otherwise, it is inefficient.

Scale efficiency

If a DMU is fully efficient in both the CCR and BCC scores, it is operating at the most productive scale (Cooper et al., 2007). If a DMU has the full BCC efficiency but a low CCR score, then it is operating locally efficiently but not globally efficiently, due to the scale of the DMU. Therefore, the scale efficiency (SE) of a DMU is defined by the ratio of the two CCR and BCC scores. The TE that is calculated by the CCR model can be decomposed into pure technical efficiency (PTE), by using the BCC model under VRS assumption, and SE. This is to define whether the inefficiency of DMUs results from inherent causes or from disadvantages in the conditions under which the DMUs are operating (Cooper et al., 2007).

SE is defined as follows:

$$\mathrm{SE} = \frac{\theta^*_{CCR}}{\theta^*_{BCC}}, \tag{3}$$

where $\theta^*{}_{CCR}$ and $\theta^*{}_{BCC}$ are the CCR and BCC scores of a DMU, respectively. The SE of a DMU will be not greater than 1. With SE = 1, rice fields achieve SE or constant return to scale, while SE < 1 indicates scale inefficiency of that field. As seen in Figure 3, rice fields between B and C are fully efficient (100%) in both the CCR and BCC scores, and are hence operating at the most productive scale (SE = 1). The BCC-efficient but CCR-inefficient rice field A is operating locally efficiently $\left(\frac{LA}{LA}=1\right)$ but not globally efficiently $\left(\frac{LM}{LA}<1\right)$ due to the inefficient scale $\left[\left(\frac{LM/LA}{LA/LA}\right)<1\right]$.

The SBM model

CCR-type models evaluate radial (proportional) efficiency, but do not take into account the input slacks. Therefore, an SBM overall efficiency was introduced to reflect the nonzero slack in inputs of DMUs. The input-oriented SBM model under the constant returns-to-scale assumption (Tone, 2001) evaluates the efficiency ρ^* of a DMU (x_o, y_o) by solving the following linear program:

$$\text{SBM-I} \quad \rho^* = \min_{z^-,\lambda} 1 - \frac{1}{m}\sum_{i=1}^{m}\frac{z_i^-}{x_{io}} \qquad \text{subject to} \quad \begin{aligned} & x_0 = X\lambda + z^-, \\ & y_0 \le Y\lambda, \\ & \lambda \ge 0, z^- \ge 0 \end{aligned} \tag{4}$$

where λ is the intensity vector, and z^{-} represents non-radial input slacks vector. The SBM ρ^* was strongly related to the CCR θ^* model, and a particular DMU is SBM-I efficient if and only if it is CCR-I efficient.

Mix efficiency

Mix efficiency was first introduced by Tone (2001), and later explained by Cooper et al. (2007). The mix efficiency is also based on orientation, which is the input and output mix of efficiency. For the purpose of this paper, we continue with the input orientation of mix efficiency, consistent with both the CCR-I and the SBM-I model in the paragraphs above. Cooper et al. (2007) defined input mix efficiency as follows:

$$\text{MIX} = \frac{\rho^*}{\theta^*_{CCR}}, \tag{5}$$

where ρ^* and θ^*_{CCR} are the SBM and CCR score of a DMU. Mix efficiency score is not greater than 1, when ρ^* is equal to θ^*, mix efficiency is 1. From Equation (3) and (5) above, the non-radial efficiency SBM score can be decomposed into radial and mix efficiency measures, as follows:

SBM-I [non-radial efficiency] = TE_{CRS} [radial efficiency] x ME [mix efficiency]

or SBM = CCR x ME = BCC x SE x ME. (6)

3.2. Determinants of efficiency of rice production in MKD

The Tobit regression model (Tobin, 1958) is applied in the second stage to estimate the association of production efficiency and household characteristics. Since all the efficiency scores of rice households range from 0 to 1, the Tobit model is more appropriate than OLS regression. Some previous studies also employed the Tobit model as a second-stage regression technique in efficiency studies (Watkins et al., 2014; Li et al., 2018; Khosroo et al., 2013; Linh et al., 2015).

$$y_i^* = \beta_0 + \sum_{m=1}^{M} \beta_m x_{im} + \varepsilon_i , \varepsilon_i \sim \ IN(0, \sigma^2) , \qquad (7)$$

where β_m are unknown parameters, y^*_i is a latent variable representing the efficiency score for field *i*, x_{im} represents explanatory field characteristic variables associated with field *i*, and ε_i is an error term that is independently and normally distributed with a mean of zero and constant variance σ^2. The latent variable y_i* is expressed in terms of the observed variable y_i (the efficiency scores calculated using DEA analysis in the first stage), as follows:

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}$$

3.3. Data

The study uses the Vietnam Households Living Standard Survey (VHLSS) dataset of 2016. Since the year 2002, the VHLSS has been conducted every 2 years by the GSO to monitor the living standards of the Vietnamese population. The VHLSS includes content that reflects the living standards of residents in the 63 Vietnamese provinces and cities, such as: demographic characteristics of household members, farm size, household incomes and expenditures, education and working status, housing assets and facilities, participation in credit and poverty reduction programs, and some other information. The 2016 VHLSS was conducted nationwide with a sample size of 46,995 households in 3,133 communes/wards, which were representative at the national, regional, urban, rural, and provincial levels. Among the 46,995 households surveyed in 2016, 37,596 households were interviewed about income and other topics, 9,399 households were investigated about income, expenditure, and topics such as education, health care, housing, electricity, water, sanitation facilities, and participation in poverty reduction programs. First, 1,905 observations from the MKD were extracted based on their codes by province, district, commune, locality, and household levels. In the next step, households that had produced plain rice utilizing either family or hired labor in the last 12 months were identified, to analyze production efficiency using data from sheet 4B11 of Section 4 – Income.[3] The final sample consisted of 506 observations of rice farms from the MKD.

A DEA model with one output and six inputs was used to calculate the efficiency scores among rice smallholders. The output is defined by the total plain rice yield (tons/ha) for a crop year. The six inputs comprises four inputs with monetary units. They are the total seed, pesticides, hired labor and machinery expenditures per hectare for a crop year. The remaining inputs are the total quantity of chemical fertilizers used (including N, P_2O_5 and K_2O in kilograms per ha) and the working hours of family members for rice farming activities in one crop year.

Table 1 shows the descriptive statistics of one output and six inputs that were included in the efficiency estimation for the year 2016. It can be seen that, to produce the average rice yield of 5.78 tons/ha/year, households have to pay 73.64 USD for rice seeds, 115 USD for pesticides, 54 USD for hired labor, and 152.66 USD for renting the machines. Households use more than 460 kg of total synthesis fertilizers on their farms. Family members contribute to the production with 187 working hours on average.

The explanatory variables used in the Tobit regression analysis are listed in Table 2, including gender, age, education level of household heads, family members, formal credit status of households,

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[3] The other sections in VHLSS 2016 are: 1 – Household information; 2 – Education; 3 – Health; 5 – Expenditures; 6 – Assets and durable goods; 7 – Housing; and 8 – Participation in supported programs. Section 4 consists of 30 pages; other pages present information about rice production costs and costs of other households whose focus is crop and fruit production, livestock, fishery, or forestry.

the farmer's association membership, rice farm size and the quadratic of farm size. In all, 83% of household heads are male, and the average age of household heads is 51.4 years old. The education level of household heads is quite low, with the mean at nearly 6 years. There is also big variability of farm size among rice farms in the MKD with the size ranging from 0.1 ha to 31.88 ha with an average of 3.05 ha per household.

4. Results and discussion

4.1. Technical efficiency of rice production in Vietnamese Mekong Delta

The input-oriented efficiency scores including BCC, CCR, SE, SBM, and ME are indicated in Table 3. The summary statistics for TE are presented under both CRS and VRS. The mean CCR, TE score under CRS, is 0.71 and ranges from 0.15 to 1, whereas the mean BCC, TE score under VRS, is 0.81 and ranges from 0.20 to 1. The mean BCC score indicated that 195 households were fully efficient with a score of 1, and the remaining 311 households were inefficient, with TE scores less than 0.81. The results of the CCR model show that only 62 households have a global TE of 1, while the remaining 444 households are considered technically inefficient. Compared to some recent studies using DEA to estimate the rice production efficiency of MKD, including Huy (2009) and Le et al. (2017), the mean CCR and BCC calculated in this study were lower.

The mean SE score among paddy farms was 0.88, which implies that most households operate at near the optimal farm size. This result is lower compared to an SE score of 0.96 of MKD rice farms from the study of Huy (2009), Indonesian farms at 0.90 (Brázdik, 2006), and Nepalese farms at 0.93 (Dhungana et al., 2004) and equal to Bangladesh farms (Islam et al., 2011). Farmers in the MKD could improve their rice yield by about 12% if they could reach an optimal scale of operation. The overall efficiency SBM-I score is 0.59, which is the lowest figure among all types of efficiency, as is expected due to input slacks. Further, the non-radial efficiency by SBM score can be decomposed into radial efficiency CCR and ME scores. The average ME score that reflects the balance of inputs used by rice households in MKD is about 83%.

Regarding the cultivated farming area classification, paddy fields with farm size greater than 2 ha achieve significantly higher efficiency for all score types. Particularly, larger farms obtain pure TE (BCC), global TE (CCR), SE, SBM and ME at 82%, 75%, 91%, 65% and 85%, respectively. Those figures of small farms are listed sequentially at 79%, 66%, 84%, 54%, and 80%. Due to better SE and mixture of inputs, larger farms have a significantly higher overall efficiency (SBM) compared to smaller farms. This result is consistent to recent literature of Foster and Rosenzweig (2010), Liu et al. (2013) and Otsuka (2016), which implies that the advantage of small farms relying on family labor is declining and large farms' advantages are enhanced by the use of farm machinery as the general wage rate increases in Asian countries. Household heads in the MKD are mainly male; paddy fields managed by male household heads have a significantly higher production efficiency in terms of technical, farmland scale, and overall efficiency, although the difference in pure TE (BCC) was marginal. It is also indicated that the participation in credit program do not positively contribute to efficiency improvement of paddy fields in MKD.

Among 506 rice-farming households observed in SBM analysis, only 22% operated at CRS, wherein their output increased proportionately with the increase in inputs. From the results of previous studies about the returns to scale characteristics in developing countries, rice farms in MKD have a larger proportion of units that achieved CRS than farms in Bangladesh, with 8% (Coelli et al., 2002); Indonesia, with 5% (Brázdik, 2006); and Nepal, with 11% (Dhungana et al., 2004), but less than that in Thailand, with 32% (Krasachat, 2004). From the estimation of authors, about 65% of households operate at increasing returns to scale (IRS), reflecting the need to expand the production operation scale in coming years to achieve an ideal TE, while 13% of the farms are exhibiting DRS and operating at a larger scale than the optimal size.

Concerning to the strategy to minimize input cost, the result of the SBM model in Table 4 presents the slacks, the level and the proportion of inputs that needs to be reduced on average and by farm size. The presence of these slacks points to suggestions for inefficient households to achieve the efficiency frontier, and especially the inputs cost reduction. Specifically, farmers in the MKD can possibly cut down approximately 27.81USD/ha of seeds cost, 60.80USD/ha of pesticides cost, 77.88 USD/ha of machinery cost and 155.61kg/ha of the amount of fertilizers that they are using to reach the efficiency frontier. Similarly, the expenses of hired labor and the working hours of family labor, and machinery should also be reduced by more than 36USD/ha, 119 hour/ha, and 77.88USD/ha respectively. The heterogeneity of input slacks and percentage of reduction based on farmland area is also described in this table. Paddy fields greater than 2 ha reflect not only higher efficiency scores but also lower slack of inputs, in which statistical significance of seeds cost, machinery cost, fertilizer quantity and family labor working hour per ha. Moreover, the required reduced percentage figures of land plots smaller than 2 ha are also significant at the level of 1% with pesticides cost and the four input items mentioned above. It can be concluded that small farms relying on family labor in our study lose their advantage, while large farms' advantages and efficiency are enhanced by the use of farm machinery. This statement was also pointed out in previous studies of Foster and Rosenzweig (2010), Liu et al. (2013) and Otsuka et al. (2016). The graphical presentation of slacks based on land size is also illustrated in Figure 4.

Based on the SBM results, if one rice household could possibly reduce 50% of slacks for fertilizer—about 78 kg/ha—there would be a reduction of more than 333 million kg of fertilizer for the entire MKD region in a crop year.[4] This eradication of excessive input usage could only be potentially

[4] The planted area of paddy land in the MKD in 2016 was 4,241.1 thousand ha (GSO, 2017)

implemented when more households in the MKD participate in the smart agriculture farming systems recommended by the Vietnamese government like “One Must Do, Five Reductions” (Tho et al., 2021). Specific technical indicators in the eco-friendly farming package are: seed sowing density should be from 80 to 100 kg/ha, nitrogen fertilizer should not exceed 130 kg/ha, spraying pesticides frequency should be not more than 4 times. When seed quantity is reduced to the amount of 80–100 kg/ha, pests and diseases will decrease compared to a thick seeding situation. Therefore, farmers can reduce the amount of pesticide and nitrogenous fertilizer use and save much water for irrigation. In addition, applying the Alternative Wetting and Drying could solve the problem of high irrigation cost. This is a water-saving technology developed by IRRI that lowland rice farmers should apply to reduce their water use in irrigated fields. Traditional irrigation technique usually keeps a layer of water continuously on the field surface in 70%–80% of the life cycle of rice plants. In contrast, in the Alternative Wetting and Drying technique, the field surface is only flooded for about 5 cm of the total life cycle time of rice plants. Adopters of this water-saving practice can reduce the total water usage for rice production by 15%–40% and does not require N-fertilizer management differently compared to the traditional continuous flooding procedure, with no major negative impact on rice yield (Yamaguchi et al., 2016; Humphreys et al., 2010; Cabangon et al., 2004). The results for SBM score and input slacks are also in line with indicators of the LFM (Thang et al., 2017) and CSA programs launched by Vietnamese government in recent years.

4.2. Factors influencing the efficiency of rice production in the Vietnamese Mekong Delta

The result of Tobit regression of farm characteristics and production efficiency is displayed in Table 5. Three variables are found to impact the efficiency of rice farms in the MKD, including educational level of household heads, family members, farm size, farm size squared, credit status and gender of household head. First, the education of the household head is believed to have a positive impact on the SE of rice farms. This means that farmers who are well educated are expected to have better skills and knowledge to manage larger-scale farms. In previous studies, it was also implied that the more educated farmers are more energy efficient (Khosroo et al., 2013) and technical efficient ((Khai and Yabe, 2011; Le et al., 2017) in comparison with their less educated counterparts. However, household heads in this study have very low education level and old age (see Table 2). Those households which prefer traditional cultivation could find it difficult for practicing CSA models and follow up contract farming with enterprises in the MKD. For that reason, financial support from enterprises for innovations and young start-ups in agriculture could help to develop the rice sector in the near future.

The variable family members, or household size has a significantly negative impact on the overall and mix efficiencies of paddy farms at the significance level of 5%. This indicates the ineffective use of family labor in small rice farms in the MKD, as referred to the very high slack of home labor working hour in Table 4. Indeed, there is a rapidly growing machine rental market in Vietnam in recent decades (Liu et al. 2020; and Zhang et al. 2011) which represent a change from labor-intensive to capital-intensive systems. Hence, the advantage of small farms relying on family labor is declining, while large farms' advantages are enhanced by farm machinery (Otsuka et al., 2016).

The cultivated land size has an important role in determining rice production efficiency, with significantly positive impacts on SE, SBM and ME scores. Smaller farms could be less efficient due to difficulties in water pumping, transportation, and on-time inputs contribution from local suppliers. It is also harder for farmers who own small and fragmented land to apply mechanization and technical advances in production steps. This result is also consistent with the above statistic that most rice farms in the MKD are operating at IRS as mentioned in section 4.1. Therefore, an increase in farm size or land accumulation into larger farms could enable households in the MKD to achieve higher technical (Ho and Shimada, 2019; Nguyen et al., 2003) and environmental efficiencies (Tu et al., 2021). In Japan, this statement was also analyzed and concluded in the study by Li et al. (2018) and Otsuka (2013), when the real wage rate continues to increase in high-performing countries in Asia. Moreover, we have found a negative effect of farm size squared on scale efficiency, i.e., inverted-U relationship. From this regression result, taking the first order partial derivative of scale efficiency with respect to farm size, it is possible to find the threshold optimal scale for rice production in the. This means that when paddy farms increase larger in size, the effect on scale efficiency scores is increased. However, if the field size exceeds the threshold optimal scale, which is around 21.81 ha, the scale efficiency could decrease due to i) farmers have to hire more workers and it is difficult to control their working attitudes, ii) limited capital coupling with underdeveloped input market made it difficult to ensure the quality of input suppliers, and iii) the low management capacity of farmers due to low educational level (Duyen and Khiem, 2018). There were some local studies that mentioned about the maximum scale threshold corresponding to paddy production, which is about 5.2 ha (Dung and Ninh, 2015) and ranging from 6.94 ha to 7.18 ha (Duyen and Khiem, 2018), depending on cropping season. We have not found this statistically significant inverted U-shaped nonlinear relationship between farm size and overall efficiency or mix efficiency. In order to deal with the deficiency of fragmented rice land, the Vietnamese government implemented the LFM in 2013 (Decision 62/2013/QD-TTg, MARD). The LFMs also provide farmers with advantages for the application of advanced cultivation methods and to follow strictly modern techniques. Also, the LFMs must be within the agricultural development plan of the region and have the production scale of about 300 - 500 ha (Thang et al., 2017). However, the application rate of the LFM and CSA is still very low (about 10%) due to poor condition of infrastructure and irrigation systems. Thus, promoting the participation of rice companies into the LFM is important since those corporations can rent land from farmers to form their raw material areas, provide inputs and implement farming contracts with every household in the model.

The next variable, credit status, has negative and significant coefficients, implying that obtaining a loan could result in scale and overall inefficiencies of rice farms. This can be explained by the granting of agricultural loans for unsuitable purposes to borrowers, or by the stress of interest payment that could lead to the inefficient management of inputs. Especially, paddy smallholders in the MKD usually buy inputs from closely local suppliers and highly rely on the short-term store credit in the beginning of each season and mainly live off the quantity of rice at harvest time (The Anh et al., 2020). This result indicates that the credit program was not effective for improving the TE of small-scale farms in the MKD, as similarly concluded by Le et al. (2017) and Nguyen et al. (2003). There were arguments of Binam et al. (2004); Bozoḡlu and Ceyhan (2007) that credit program helped farmers improve their technical efficiency. Therefore, special credit programs from banks granting to groups of household/cooperatives that engage in CSA models or produce aromatic/high-quality rice should be promoted extensively. With the strict standards on the level of chemicals use in rice products providing to both domestic and international markets, those households that produce rice in CSA models or use aromatic/high-quality varieties would be very important factors in the sustainable farming theme in the region.

The last dummy variable that has a positive effect on scale efficiency is gender. In this case, man household heads appear to be more efficient in managing large farms than their female counterparts. In Vietnam, male-headed households have obtained a larger share of cropland versus female-headed households. Also, Vietnamese culture considers male receive family property inheritance, male possibly get larger landholdings (Thang et al., 2016). Thus, the argument that women farmers are less efficient than male farmers (FAO 1985) is acceptable in our study.

5. Conclusion

This study is the first to evaluate rice production efficiency in the Vietnamese MKD using both radial and non-radial DEA approaches. Non-radial DEA, including SBM and ME scores, helps eliminate restrictive and problematic radial DEA when quantifying overuse of inputs such as seeds, fertilizer, or pesticides. Almost 65% of households in the MKD exhibited IRS, while only 22% showed CRS. Rice farms in the main region of national production and export scored 0.71, 0.81, and 0.88 for global TE, PTE, and SE, respectively. The SBM overall efficiency and mix efficiency scores, applied to rice production data in Vietnam, resulted in 0.59 and 0.83 respectively, which are quite low due to the presence of input slacks revealed in the SBM analysis. The slack-based SBM reveals that when inefficient farms could improve not only the production efficiency but also the quality of the surrounding soil and water sources for the subsequent seasons by reducing fertilizer and pesticides.

Paddy farms with greater farm size obtain higher efficiency, since they obviously have greater advantages in water pumping, transportation, and mechanization. Land accumulation from small holders into larger fields/paddy cooperatives, officially called the LFM, should be encouraged and monitored more actively in every province of the MKD. Farmers who engage in the LFMs could take advantage of economy of scale to apply modern agricultural machinery (such as tractors) and thus reduce the labor costs. Also, the LFMs created a basis to apply advanced cultivation methods and to follow strictly CSA techniques such as: One Must Do, Five Reductions, Alternate Wetting and Drying and System of Rice Intensification. More specifically, rice farms in the MKD should prioritize participating in CSA farming models to enhance the quality of products and protect the natural resource environment. Promoting the participation of rice enterprises into the LFM and CSA programs could be such an urgent action of the government.

The main shortcoming of this study is the absence of information on farming patterns, physical data of seed sown density and advanced technology application for rice production. Analyzing the impact of the LFMs or climate smart farming systems on production efficiency or environmental benefits of rice farms in the MKD would be a good future research topic. The results of this in-depth research could provide policy makers with the right orientation toward sustainable farming for smallholders in Vietnam in the future.

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Availability of data and materials

The VHLSS 2016 questionnaire section and dataset analyzed in this study are available from the corresponding author on reasonable request.

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Figures

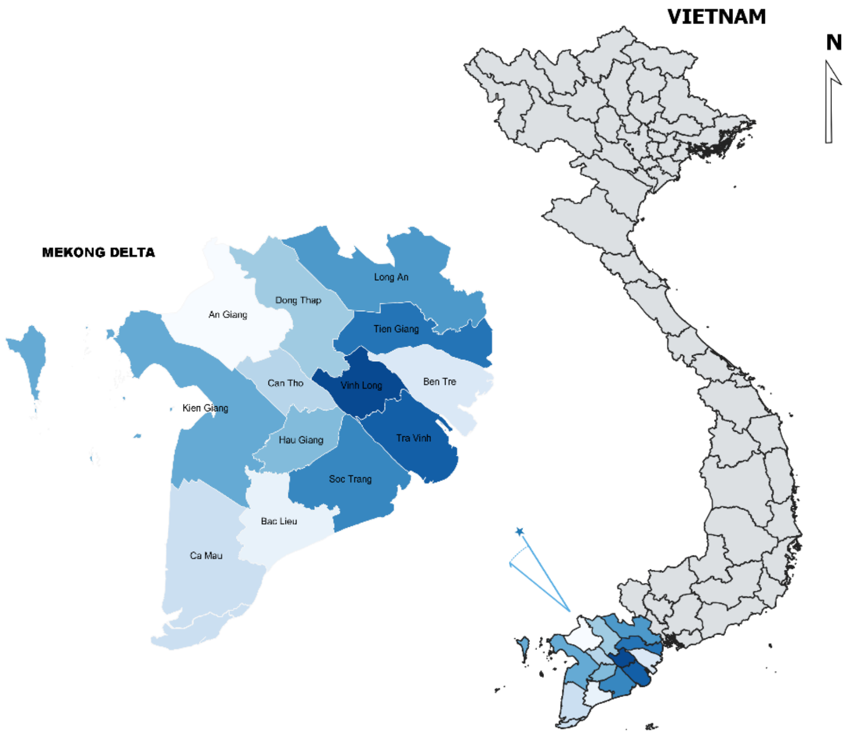

Figure 1. Map of Vietnam and the Mekong Delta

Source: Author's compilation, using GIS mapping

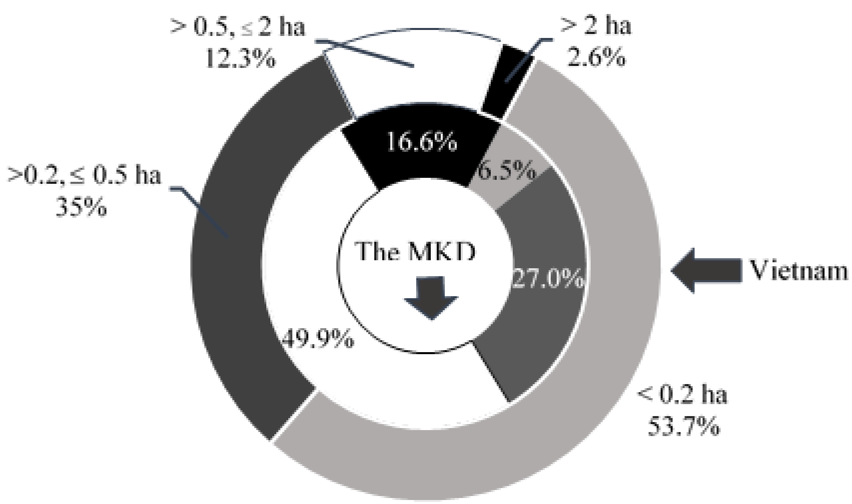

Figure 2. Average farm size and share of rice households in Vietnam and the Mekong Delta

Source: Rural, Agricultural and Fishery Census in Vietnam, 2016

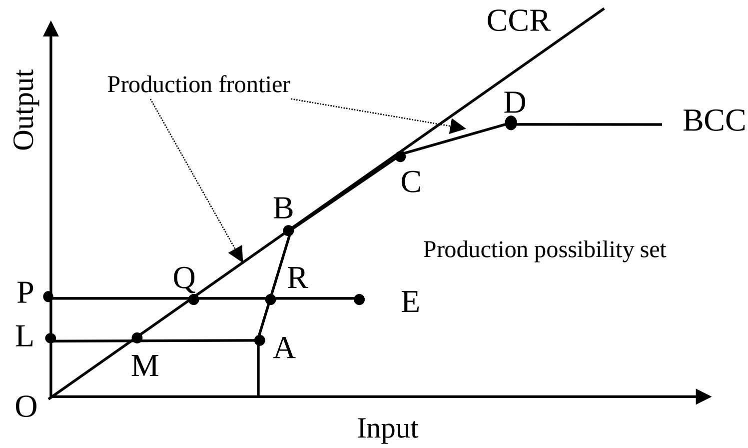

Figure 3. Production frontier of the CCR, BCC models and scale efficiency (Cooper et al., 2007)

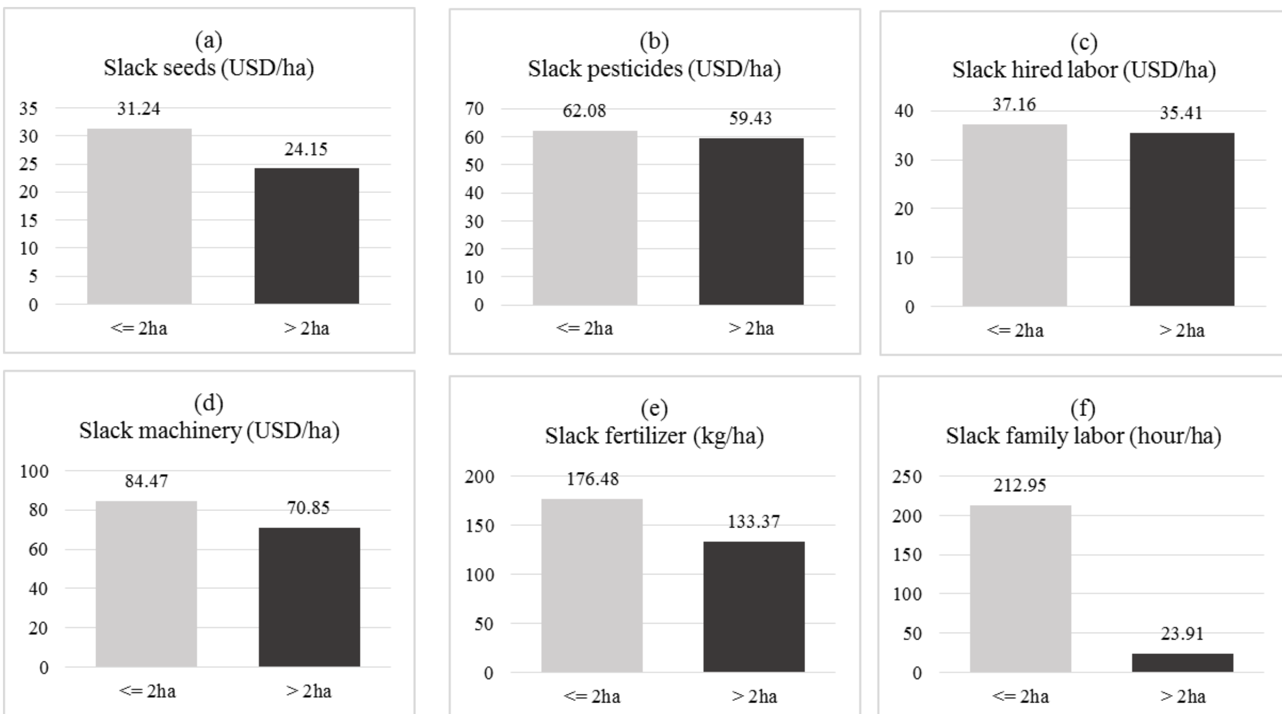

Figure 4. Input slacks by land size category of households in MKD

Source: authors' compilation

Tables

Table 1. Information on output and inputs of rice farms used in DEA

Variables	Unit	Mean	Std. Dev.	Min	Max
Output – Rice production	tons/ha	5.78	1.35	0.85	10.17
Inputs					
Seed cost	USD/ha	73.64	48.43	10.15	879.31
Pesticide cost	USD/ha	115.95	85.08	0	937.94
Hired labor cost	USD/ha	53.77	64.59	0	612.80
Machinery cost	USD/ha	152.66	61.67	0.00	485.19
Fertilizer quantity	kg/ha	460.67	173.89	0	1763.8
Family labor	hour/ha	187.41	287.81	0	2110

Source: Author's calculation from VHLSS 2016 survey data (N = 506)

Table 2. Summary statistics of variables used in Tobit regression analysis

Variables	Unit	Mean	Std. Dev.	Min	Max
Age	years	51.42	12.55	26	89
Education	years of schooling	5.87	3.45	0	12
Family members	persons	4.09	1.43	1	9
Farm size	hectare	3.05	3.61	0.10	31.88
Gender (dummy)	% male	0.83	0.37	0	1
Credit status (dummy)	% yes	0.46	0.49	0	1
Farmer Association (dummy)	% yes	0.15	0.36	0	1

Source: Author's calculation from VHLSS 2016 survey data (N = 506)

Table 3. Input-oriented efficiency scores of rice households in MKD

	N = 506	BCC_I	CCR_I	SE_I	SBM_I	ME_I
Summary efficiency						
Mean		0.81	0.71	0.88	0.59	0.83
Std. Dev.		0.20	0.20	0.13	0.22	0.11
Min		0.21	0.15	0.36	0.11	0.51
Max		1	1	1	1	1
Farm size						
<= 2ha	261	0.79 (0.21)	0.66 (0.20)	0.84 (0.15)	0.54 (0.22)	0.80 (0.12)
> 2ha	245	0.82 (0.17)	0.75 (0.18)	0.91 (0.09)	0.65 (0.19)	0.85 (0.08)
t-stat		-1.84^{*}	-5.09^{***}	-5.78^{***}	-5.59^{***}	-5.16^{***}
Gender						
Male	424	0.81 (0.19)	0.72 (0.19)	0.89 (0.13)	0.60 (0.21)	0.83 (0.11)
Female	82	0.78 (0.20)	0.65 (0.20)	0.84 (0.16)	0.55 (0.22)	0.83 (0.12)
t-stat		– 1.19	-2.86^{***}	-3.05^{***}	-2.17^{**}	– 0.02
Credit status						
Yes	235	0.80 (0.20)	0.69 (0.19)	0.86 (0.14)	0.57 (0.20)	0.82 (0.10)
No	271	0.81 (0.19)	0.72 (0.20)	0.89 (0.12)	0.61 (0.23)	0.83 (0.11)
t-stat		0.57	2.11^{**}	2.70^{***}	2.36^{**}	1.29
Frequency distribution (%)						
≤50%		7.71	17.00	1.58	37.35	0
> 50% ≤ 60%		11.86	15.42	3.56	18.58	2.17
> 60% ≤ 70%		13.04	14.43	6.72	15.22	11.07
> 70% ≤ 80%		14.03	18.77	11.26	10.67	23.91
> 80% ≤ 90%		9.29	13.44	16.01	5.53	35.97
> 90% ≤ 100%		44.07	20.95	60.87	12.65	26.88
Number of efficient DMUs		195	62			
Number of inefficient DMUs		311	444			
	Total	506	506			

*Notes: Standard deviation in parentheses; *, ** and *** indicate 10%, 5% and 1% significance levels, respectively.*
Source: author's calculation

Table 4. Input slacks and the required percentage decrease of each input on average and farm size

	N = 506	Seeds (USD/ha)	Pesticides (USD/ha)	Fertilizers (kg/ha)	Hired labor (USD/ha)	Family labor (hour/ha)	Machinery (USD/ha)
Input slacks		27.81	60.80	155.61	36.32	119.61	77.88
<= 2ha	245	31.24	62.08	176.48	37.16	212.95	84.47
> 2ha	261	24.15	59.43	133.37	35.41	23.91	70.85
t-stat		1.70^{*}	0.40	2.94^{***}	0.36	9.29^{***}	2.45^{**}
Required % decrease		(– 30.32)	(– 46.75)	(– 30.33)	(– 45.74)	(– 42.02)	(– 47.90)
<= 2ha	245	(– 33.72)	(– 54.20)	(– 33.85)	(– 44.00)	(– 53.41)	(– 53.13)
> 2ha	261	(– 26.69)	(– 38.80)	(– 16.25)	(– 47.54)	(– 29.89)	(– 42.32)
t-stat		-3.12^{***}	-5.38^{***}	-4.63^{***}	1.06	-9.02^{***}	-3.96^{***}
Projection		46.16	55.50	304.89	18.69	67.81	74.78

*, ** and *** indicate 10%, 5% and 1% significance levels, respectively.
Source: author's calculation

Table 5. Tobit regression analysis of factors affecting overall efficiency of rice households in MKD

Variables	SE		SBM		ME	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
age	–0.00003	0.00055	–0.00090	0.00092	–0.00029	0.00047
education	0.00341	0.00204 *	–0.00211	0.00337	–0.00131	0.00171
family members	0.00090	0.00457	–0.01387	0.00758 **	–0.00925	0.00384 **
farm size	0.01658	0.00402 ***	0.02038	0.00675 ***	0.01113	0.00342 ***
(farm size)^2	–0.00038	0.00021 *	–0.00009	0.00036	–0.00010	0.00018
credit status (dummy)	–0.03980	0.01277 ***	–0.05469	0.02111 ***	–0.01715	0.01071
gender (dummy)	0.03207	0.01799 *	0.04233	0.02978	–0.00540	0.01512
farmer assoc. (dummy)	–0.00010	0.01783	0.00390	0.02951	–0.00204	0.01497
Constant	0.81670	0.04132	0.65310	0.06846	0.87716	0.03474
Observations	506		506		506	
Log likelihood	185.23786		– 59.53239		244.24168	

SE: scale efficiency; SBM: slack-based technical efficiency (overall efficiency); ME: mix efficiency.
Note: *, ** and *** indicate 10%, 5% and 1% significance levels, respectively.