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Improving the Technical Efficiency of Sengcu Rice Producers through Better Financial Management and Sustainable Farming Practices in Mountainous Areas of Vietnam

Thi Lam Bui [1,2,*], Huu Cuong Tran [2], Hossein Azadi [3,4] and Philippe Lebailly [1]

1 Economics & Rural Development, Gembloux Agro-Bio Tech, University of Liège, 5030 Gembloux, Belgium; philippe.lebailly@uliege.be
2 Faculty of Accounting and Business Management, Vietnam National University of Agriculture, Hanoi 100000, Vietnam; trancuong@vnua.edu.vn
3 Department of Geography, Ghent University, 9000 Ghent, Belgium; hossein.azadi@ugent.be
4 Faculty of Applied Economics, Department of Engineering Management, University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium
* Correspondence: btlam@vnua.edu.vn

Received: 28 April 2018; Accepted: 26 June 2018; Published: 2 July 2018

Abstract: This paper analyzes the impacts of financial management and farming practices on the technical efficiency of Sengcu rice growers in Laocai, a mountainous province of Vietnam. The stratified random sampling method was employed to select 170 households representing two typical ecologies, lowland and upland. The structured questionnaire was applied to collect primary data through face-to-face interviews regarding current farming practices in the 2016–2017 growing seasons and farm-specific characteristics. The importantly, the study makes recommendations for policy-makers regarding how to manage provision extension, irrigation, and credit services more effectively and for producers regarding how to better manage cash-flows and receive more benefits from public support in order to improve the effectiveness of rice production and make a livelihood while working towards sustainability.

Keywords: technical efficiency; mountain rice; agricultural credit; financial management; sustainable intensification; Laocai; Vietnam

1. Introduction

The Northern Midlands and Mountains (NMMs) is the largest ecological region of Vietnam, constituting 29% of the national land area and 34% of upland rice cropping [1,2]. It is characterized by a hilly mountainous topography and a high diversity of ethnic groups, and is the poorest region of Vietnam. Local farmers are still mostly subsistence households and live a life of deprivation and misery. Helping poor farmers develop agricultural production and improve their living standard is always high on the list of government priorities. However, top-down policies and their implementation have created ineffective results [2]. Ranaweera (1993) and Laquihon (1992) also drew a sad picture of the Asian uplands, of which the key symbols were poverty, hunger, hopelessness, discontent, greediness, and exploitation. They explain that this is due to "the lack of system perspective in the development and use of upland technologies" [3,4]. This is true in Vietnam. There is a huge income gap between different regions, ethnicities, and citizens that has deepened over the last decade. For instance, the NMMs contain more 50% of total poor households and nine out of 10 of the poorest provinces of the country. Moreover, on average, ethnic minorities' income was 40% of Kinh's in 2015 [5,6]. As

observed in the case study in Laocai, the lowest income quintile families were surviving on a tiny monthly income of 116 and 722 (thousand VND), compared to 901 and 5888 (thousand VND) in the highest income group in 2005 and 2016, respectively [7]. (The corresponding figures are $5.11; $31.82; $39.71; $259.50 with the Exchange: 1 USD = 22,690 VND on 26 March 2018). The consequence of rising economic disparity is unexpected social–economic–political instability, especially in a border province like Laocai.

The survey carried out by the General Statistics Office of Vietnam (GSO) in 2014 revealed that more than 90 percent of households living in the NMMs rural area engage in agriculture, with rice production a crucial activity that has a dual function as an income-generating crop and as food security. One of the major challenges is low productivity. Figure 1 compares the paddy productivity of the three selected provinces belonging to the Northern Mountain region (another name for NMMs) with the whole country and the region between 1995 and 2016 [8]. Although paddy output in mountainous areas increased remarkably, it was still low. Even though it has the same mountainous topography, Hagiang always obtained the highest yield and was the only province to exhibit the average value of the whole country as well as the highest in the region. Meanwhile, other provinces made much lower gains (e.g., Dienbien, Laichau, Caobang, etc.). During the same period, the quantity of paddy rice per hectare of Laocai was equal to that of the whole region, so it is considered the ideal research site representing the mountainous areas of Vietnam.

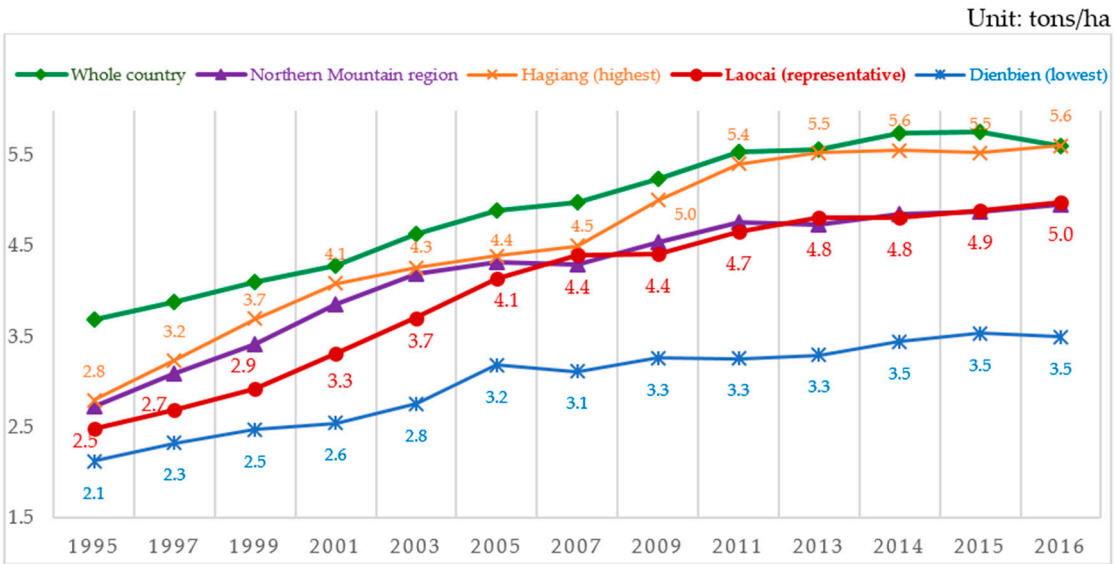


Figure 1. Paddy productivity of selected regions and provinces in Vietnam. Source: Vietnam General Statistic Office, 1995–2016 [8].

In Laocai, under the context of the scarcity of arable land (0.035 hectare per person, 46% and 18% compared to Vietnam and the world, respectively), increasing the effectiveness of agricultural production is essential for local farmers and the provincial economy [9]. Fortunately, the province has various favorable natural conditions such as temperature, fertile alluvial soil, and water sources for cultivating Sengcu rice (hereafter: SC rice). This high-quality rice has the highest price in the domestic market (38,000 VND/kg ($1.67, the Exchange: 1 USD = 22,690 VND)) because it meets the demand of high-end customers, so it brings great economic value to rice growers. Although this special rice occupied around 25% of total harvested rice land, local authorities have been paying attention to develop these spearhead agricultural products. The findings of our household survey disclosed a few main reasons for the low productivity and technical efficiency (hereafter, TE), leading to SC rice growing not being attractive to producers. They are: (i) improper farming practices causing high production costs and concurrently damaging the field ecosystem; (ii) financial trouble leading to lower

investment and/or untimely input application; (iii) household characteristics such as minority, low literacy, gender, and the information sources used in decision-making, etc., which also prevent growers from accessing extension services and applying advanced techniques. To improve this reality, various earlier studies suggested that farmers have to manage their finances and production technology well through access to several corresponding key services like credit, extension, education, and so on [10–15].

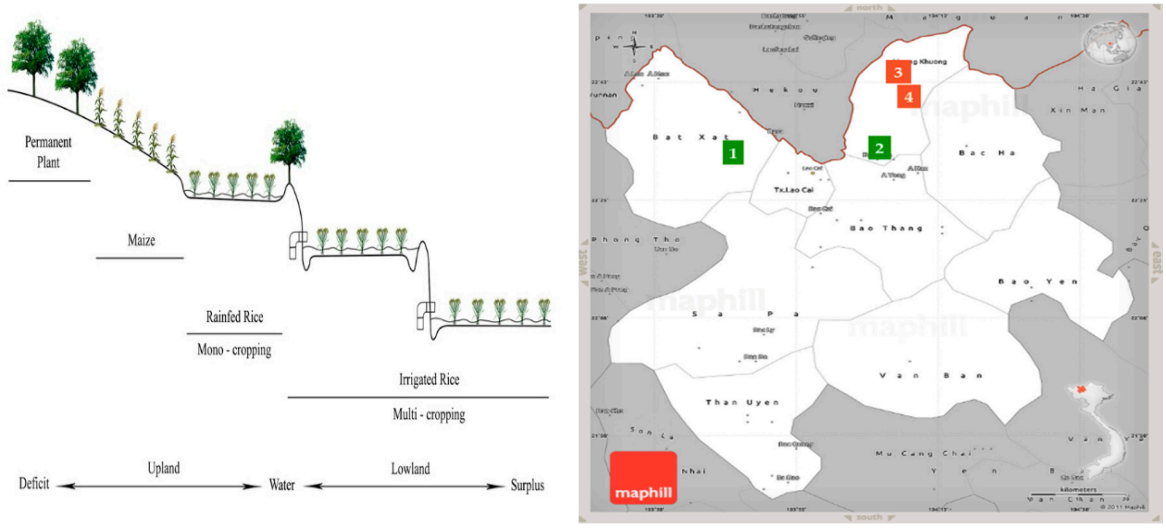
Thus, the paper aims to measure the TE levels of SC rice producers in two rice-growing areas (i.e., upland and lowland) of Laocai. The study also identifies the impacting factors and their directional impacts on TE score, hence suggesting how producers might achieve maximum paddy output through better farming practices and financial management. Furthermore, growers not only enhance the productivity, but may also increase the harvested area devoted to this special rice to gradually improve livelihoods and sustainability. Additionally, the study makes comprehensive recommendations for policy-makers as to how to provide better agricultural support services. This research is necessary because there is still little empirical evidence concerning solutions to agricultural development and sustainable livelihood for vulnerable groups (i.e., ethnic minorities, the poor, and smallholder farmers) in mountainous areas of Vietnam.

2. Methodology

2.1. Selection of the Study Sites

Laocai was chosen for researching rice production in NMM areas of Vietnam because it is the only province with the same average rice productivity as the whole region (see Figure 1). The province also contains typical features of mountains such as a high poverty rate (34.3%) and diversity of 25 ethnic minority groups living together [7,16]. Moreover, the province is endowed with various natural advantages for rice cultivation such as a high difference between daytime and night-time temperature with an average temperature at 20.45 °C; low latitude at 21°30′ N and 22°51′ N; moderate sunshine duration at around 1500 h per year; and total annual rainfall of more than 2050 mm [7]. According to Maclean and Hardy [17], if rice is planted in low-latitude areas that have high solar radiation and cool nights, higher productivity will result. Therefore, rice cultivators must be able to exploit geographic features to obtain high quality and high yield in order to improve their economic situation. Last but not least, the province is a frontier region of Vietnam, so it deserves attention because of its importance from a political, social, and economic perspective.

The agricultural sector is a major livelihood of local households (15.69%), whereas 79.77% of the total provincial workforce was engaged in farming activities in 2016. Regarding cereals, rice plays a vital role, so most arable land is devoted it. Maize is planted on steep hills and places where it is not possible to harvest rice because of water shortages. In 2016, there were 31,609 hectares cultivating rice, generating 158,198 paddy tons, which is 53.29 percent of total cereal yield [7]. There are two main typical agro-ecologic zones in Laocai, upland and lowland. In upland, rice is planted in small terraced plots on hillsides. Because of water limitations, the majority of rice in highlands is cropped just one time (i.e., mono-cropping) during the wet season from May to October. On the contrary, rice in the lower zone is grown in much larger, flat fields and harvested twice per year. Not only is this convenient in terms of water storage, but lowland farmers also receive more attention from provincial authorities through a well-constructed irrigation system (Figure 2a). In 2016, there were 1735 mono-cropping rice hectares, accounting for 23.98% of total harvested rice area [18].



(**a**) (**b**)

Figure 2. (**a**,**b**) Description of the research sites for the study. Note: The white area is Laocai [19]. The numbers 1 and 2 is Muongvi and Banxen commune, representing for lowland areas with its height below 300 m. Numbers 3 and 4 are Lungkhaunhin and Namlu communes, standing for upland areas at a height of more than 800 m.

To analyze in more detail, we studied two districts planting SC rice, namely Batxat and Muongkhuong. In 2016, there was around 1200 SC rice ha in these districts, accounting for nearly 70% of the total planted area devoted to SC rice in Laocai [18]. The four largest SC rice-production communes were selected (see Figure 2b) [19,20]. Besides standing for agroecosystems in the undulated terrains, these research sites also illustrate the significant differences in demographic characteristics like ethnicity, livelihood, economic state, level of education, etc.

2.2. Data Source and Sampling

The study collected both secondary and primary data as follows.

Firstly, the desk research gathered all previous documents, reports and relevant official statistics about the given regions and national emerging concerns. The result of this step is to identify the studied issue as well as the proper research site and agricultural products for the study. Moreover, these data also support the primary data collected from the fieldwork in the next steps.

Secondly, key informant interviews (KIs) were conducted to get an overview of the agricultural sector as well as SC rice production in the studied district and representative communes. These key persons involved officials working at Laocai DARD (one person) and two people in sub-departments in the two selected districts. Regarding supporting services in remote areas, the research emphasizes the agricultural extension and financing policies issued by the central government for ethnic minorities, the poor, and rice growers. Thus, there were eight extension personnel, and eight banking staff members working at Agri-bank and Bank for Social Policy at provincial, district, community, and village levels were invited to individual interviews.

Thirdly, group discussions at the farm level including 8 to 10 participants were carried out in four studied communes to identify the current local rice farming practices, the main difficulties, and the reasons why farmers were not able to (and/or did not want to) apply advanced practices. Base on the second and third step, the agrarian histories of rice production and the provision of basic agricultural services in the study areas were relatively clear. With regard to SC rice, it provides high economic value for growers; it also plays an important role in culture, especially in uplands. Additionally, it is the main raw material for making several traditional dishes for special family events.

The final and the most important stage is the household survey through face-to-face individual interviews with the stratified random sampling method. This method is considered the most suitable in the case of a heterogeneous population [21]. The structured questionnaire was used to interview householders face to face to collect primary data on (i) the specific characteristics of the household; (ii) SC rice farming practices and input management; (iii) costs and income generated from SC rice production as well as other activities (e.g., breeding livestock, wages, salary, and business); and (iv) the farmers' feedback on two important services, agricultural credit and extension.

In order to meet the representative demand, the sample size including 170 households was divided equally into two rice ecologies, which were investigated repeatedly in the 2016 and 2017 rice growing seasons. If the farmer cultivated other rice types (not SC rice), this observation was excluded from the sample. This number was calculated by the following formula used in the work of Cochran [22]:

$$\mathbf{n} = \frac{\mathbf{Z^2} \times \boldsymbol{p} \times (1 - \boldsymbol{p})}{\mathbf{e^2}}, \quad (1)$$

where **n** is the sample size; **Z** is the statistical value containing the area under the normal curve (e.g., **Z** = 1.96 for 95% level of confidence); ***p*** is the estimated proportion of a feature that is present in the population (in general, the *p* value is equal to 0.5); and **e** is the desired level of precision (7.5%). With the values given above, the sample survey of 170 SC rice cultivators was identified. This sample size is used to calculate and describe households' characteristics. However, the authors removed 10 non-representative outliers and divided the 160 remaining observations into two SFA models containing 80 rice-growing households. Moreover, lowland households had larger cultivated areas than uplanders (0.65 and 0.37 ha/household, respectively). Additionally, lowlanders allocated about 92.56% of their total rice-cultivated land to SC rice production, whereas highlanders devoted only 48.19% to SC rice. The main purpose of cultivation was to provide an explanation for the differences between these two groups. The main goal of lowlanders was to maximize income. On the contrary, uplanders aimed to improve food security along with cultivating high-yielding hybrid rice.

2.3. Data Analysis

The assessment of productive efficiency is increasingly applied because of its importance in economic theory and practice for grass-root level and policymakers. It was first introduced by Farrell in 1957 [23] and widely developed by various authors [24–27]. There have hitherto been two methods to measure the efficiency of production, data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Coelli [28] and Fatulescu [29] are the authors of ideal papers describing its development from the 1950s to the present and its application in different fields such as industry, agriculture, service, health, education, environment, etc. The authors analyzed the contribution of Charnes and Cooper [30], Aigner and Lovell [31], and Meeusen and van Den Broeck [32] to the validation of mathematical equations (DEA and SFA, respectively) to evaluate the effects of input factors on technical efficiency (i.e., output). In essence, DEA modeling frequently applies a non-parametric approach by using linear programming, whereas SFA exploits the econometric method and applies parametric equations. Although DEA has the advantage of evaluating multiple inputs and outputs simultaneously, it is not necessary for this study because it does not take into account the random events and/or factors in the model. Therefore, in this case, the SPF model is recommended because agricultural production frequently suffers from potential risks from natural conditions such as climate, disease, and the like [28,33,34].

In general, the empirical model specification of the stochastic frontier function is written as in the following equation:

$$Y_i = f(\beta; X_i) + V_i - U_i, \; i = 1, 2, ..., n, \quad (2)$$

where Y_i and X_i represent for the output and input (in quantity) of the ith household, respectively; n is the sample size; β is the estimated coefficients of the parameters (X_i); V_i is the symmetric randomness (i.e., two-side error) caused by measurement error and other random factors, as mentioned above, like weather, diseases, etc., assumed to be independently and identically normally distributed $N(0,\delta_v^2)$; U_i

is non-negative randomness (i.e., a one-sided residual) causing technical inefficiency in the production of ith household with the half-normal distributed assumption as $N(0,\delta_u^2)$. Therefore, if $U_i = 0$, the household's technical inefficiency is nonexistent (i.e., the farm obtained the maximum output with the set of given inputs) and vice versa [35]. In addition, two noise components of V_i and U_i, are also assumed to be independent of each other and the variation parameters are specified as in the following equation:

$$\delta^2 = \delta_v^2 + \delta_u^2 \text{ and } \gamma = \frac{\delta_u^2}{\delta_v^2 + \delta_u^2} \quad (3)$$

The parameter gamma (γ) can range between 0 and 1, explaining the impact of inefficiency factors on the independent variable. In more detail, if Gamma (γ) is closer to 0, the variation of the observed output is due to random effects. Meanwhile, a value of Gamma (γ) closer to 1 implies that the fluctuation of the producer's output is explained by inefficiency [36,37].

To choose an empirical function in order to estimate all parameters in the frontier model, there are a variety of alternative functional forms but the Cobb–Douglas is the most commonly used [28]. It is simple and convenient compared to others, namely the Translog used by Greene [38] and the Zellner–Revankar applied by Kumbhakar and Ghosh [39]. In the models, all the variables were converted into a natural logarithm (Ln) in order to minimize heteroscedasticity. The estimated results therefore reflect the elasticity of an input factor causing the change in independent variable. More precisely, it tells us by what percentage the paddy productivity changed if there is a 1% change in a given variable input, *ceteris paribus*. For this study, the Cobb–Douglas production function using six independent variables, seed rate, quantity of manure, NPK, nitrogen fertilizer, pesticide cost and labor for optional work, was chosen and expressed as in Equation (4).

The study is also based on the theory of Edwards (1954), which states that the decision-making process of each person tends to be influenced by individuality, socioeconomic circumstances, and other psychological factors [40]. Concerning the multicollinearity (VIF), R^2 (i.e., R squared) (the proportion of the variance of the dependent variable is estimable by the independent variables in the model) and statistical significance, the study used stepwise regression for removing and retaining the independent variables. Finally, there are 11 independent variables put into the models to evaluate the effects leading to technical (in) efficiency in rice production as in Equation (5). It is noted that if an explanatory variable has a significantly negative sign, it has a positive effect on output, and vice versa. All parameters in the models above are automatically calculated by the one-stage estimation under the Frontier 4.1 Program written by Coelli [41].

$$\mathrm{Ln}(Y_i) = \beta_0 + \beta_i \,\mathrm{Ln}(X_i) + V_i - U_i,\ i = 1, 2, ..., n \quad (4)$$

$$|U_i| = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \ldots + \delta_{11} Z_{11}, \quad (5)$$

where β_0 is the intercept of the efficiency model (4); β_i is the regression coefficient of the explanatory variable to be estimated; and X_i represents the six independent variables, seed rate (X_1: kg/ha); quantity of manure used (X_2: kg/ha); NPK applied per season (X_3: kg/ha); nitrogen fertilizer (X_4: kg/ha); amount of pesticide (X_5: 000 VND ha^{-1}); and labor for optional works (X_6: man-day/ha).

δ_0 is the intercept of the inefficiency model (5); δ_i denotes the estimated parameter of the corresponding variable; Z_i is the factors contributing directly to technical ineffectiveness, which include ethnicity (Z_1); gender (Z_2); education (Z_3); farm size (Z_4); experience in cultivating SC rice (Z_5); financial availability (Z_6); farmland ratio (Z_7); share of non-farm income (Z_8); extension (Z_9); IPM adaptation (Z_{10}); and extension*ethnicity (Z_{11}).

3. Findings and Discussion

In Vietnam, there are a lot of advanced rice farming programs deployed nationwide such as System of Rice Intensification (SRI); Integrated Pests Management (IPM); One Must and Five Reductions (farmers must use certified seeds from an official source and reduce the amount of seed, fertilizer, pesticide, water used, and post-harvesting losses) (1M5R); 3 Gain and 3 Reductions (if a farmer reduces

the quantity of seed, fertilizer, and pesticides, they will increase rice productivity, quality, and efficiency (3G3R), Good Agricultural Practice (GAP), the straight-row planting method, etc. These are part of the concept of Sustainable Intensification (promoted by the Royal Society and developed in more detail by a Foresight report in 2011) (SI) in rice growing and agricultural production, in broader terms. SI is defined as a farming method in which yield is increased in the same planting land unit without adverse environmental impact and/or environmental improvements [42]. Other synonyms are used in previous studies, like Low-Input Sustainable Agriculture (LISA) [43], Good Agricultural Practice (GAP) [44], Sustainable Crop Production Intensification (SCPI), and so on [45,46]. In essence, all the farming methods mentioned above have the same goal: optimal exploitation of natural and human resources without causing a negative impact on the ecosystem in order to maximize technical efficiency and improve the economic state of households. Our study will describe current farming practices precisely, at the same time making a comparison with the advanced methods popularized by extension personnel in the province [47]. Our research focuses on four kinds of external input that farmers use to control technical efficiency as well as production costs. These are seed, fertilizer (manure, NPK, urea) pesticides, and labor. In the next section, we will illustrate the impacts of farm and non-farm factors on technical (in)efficiency using the SFA model.

3.1. Descriptive Statistics

Table 1 presents descriptive statistics of output–input in rice production at the study site. Lowlanders obtained an average grain yield at 5.3 tons ha^{-1}, higher than that of highlanders by 21.47% (nearly 4.4 ton/ha). This gap is explained by the differences in farming practices (i.e., input management) and socioeconomic features of rice growers. Regarding input management, there were significant differences between the five kinds of external input, except for nitrogen fertilizer.

Table 1. Descriptive statistics of continuous variables used in the SFA function.

Items	Unit	Upland (n = 80)	Lowland (n = 80)	All (n = 160)	*T*-Test Ratio
Y: Productivity	kg/ha	4378	5318	4848	0.00
X_1: Seed rate	kg/ha	55.72	48.00	51.86	0.00
X_2: Manure	kg/ha	4324	3833	4078	0.06
X_3: NPK	kg/ha	768.2	1019	893.6	0.00
X_4: Urea	kg/ha	134.7	138.6	136.6	0.32
X_5: Pesticide	000 VND/ha	1209	4082	2686	0.00
X_6: Labor	Man-day for OWs/ha	37.71	31.51	34.61	0.05
Z_3: Education	Years of attendance	5.106	7.013	6.060	0.00
Z_4: Experience	Years of SC rice production	5.131	9.163	7.147	0.00
Z_5: Household size	Number of HH's members	4.763	4.088	4.225	0.01
Z_7: Farmland ratio	sao */person	1.573	2.161	1.867	0.00
Z_8: Non-farm income	Percent	0.149	0.203	0.176	0.01

Note: * 1 Sao = 360 m^2. Source: Household survey, 2016.

According to the household survey, there are four important transplanting techniques in the early crop management step leading to the significant difference in seed rate and grain yield. In terms of the recommendations issued by the provincial extension office, the survey indicates that lowlanders were more compliant than uplanders, reflected in the younger seedling age, wider spacing dimension, lower number of hills per meter squared, and proper number of seedlings per hill. Consequently, on average, upland and lowland farmers overused seeds by 39.3% and 20.0%, respectively, compared to the suggested amount of 40 kg per hectare. This improper application of seed causes not only an increase in production costs but also a reduction in paddy output. This is proven through previous experimental evidence [48–50].

The household survey shows that most respondents applied both organic manure and inorganic fertilizer, but there were remarkable differences in terms between the two studied rice-producing regions in terms of the actual fertilization used. In the rural areas of Vietnam, organic fertilizer (i.e., manure) is created from both animal waste (e.g., pigs, horses, cattle, chicken) and planting materials (e.g., straw, husk, leaves, grass, etc.) [51,52]. Even though the surveyed households have enormous

potential to create organic fertilizer from animal waste and green manure, all farmers used much less manure than the extension's recommendation (about 8000 kg/ha). Upland producers used a larger amount of green manure by 12.8% (4324 kg/ha) compared to the lowlanders' volume. By contrast, lowlanders prefer NPK composite usage because of its convenience of purchasing and applying. They therefore used much more than highlanders (32.7%) and the recommended dose at around 850 kg/ha [47]. In fact, farmers have been accustomed to applying nitrogen fertilizer at around 135 kg as a customary practice even though local extension staff did not recommend its use because NPK fertilization ensures balanced nutrients for the whole cropping season.

According to our calculation and comparison with the recommendations, (1) lowlanders have been abusing chemical fertilizers (overuse of nitrogen by 83.5% and of phosphorus by 19.2%; (2) uplanders applied too much N at 50.9% but a smaller amount of Kali at 31.4%; (3) farmers in both research areas should increase the amount of organic fertilizer and better control the quantity of mineral inputs. The state of unbalanced nutritional imbalance (i.e., redundant nitrogen fertilizer) causes negative effects on the diversity of the ecosystem, the water-holding capacity of soil, and degradation [53–55]. Consequently, not only has the inevitable scenario of low grain yield been occurring but also natural disasters such as landslides, soil erosion, flood, etc. at a higher frequency.

It is noted that the majority of rice-growing farmers in the highlands use toxic chemicals to protect crops for three main reasons: (i) the advantage of a lower temperature leads to fewer insects and pathogens; (ii) highlanders also have experience in the exploitation of beneficial insects and natural agronomic practices (i.e., organic farming, sustainable agricultural practice)—for example, they know that most insect species (e.g., the stem borer and leaf roller) are the prey of some kinds of bird, frogs, ants, etc. (e.g., brown plant-hoppers, dangerous pathogens for rice, are attacked by spiders); (iii) the agricultural input market is unavailable. Because of the unavailability, farmers must be proactive in protecting their crops and controlling the field ecosystem via sustainable practices. However, they also struggle with diseases and crop failures due to late treatment. For instance, rice blast in the first season and yellow dwarf in the second season of 2017 caused lower productivity by nearly 30%. In contrast, lowland cultivators have been overexploiting pesticides and other toxic chemicals to protect plants. As can be seen from Table 1, lowlanders spent more than 4 million VND/ha/crop on harmful chemicals—four times as much as uplanders did. This figure is extremely high compared to previous estimates carried out by Hien and Kawaguchi [10] and Dogot and Lebailly [56] in the Mekong Delta. Lowlanders tend to join temporary workforces in cities and towns, so they do not spend a lot of time on rice field operations. According to local farmers, a large number of growers sprayed without regard to whether harmful insects and diseases appeared or not; in some cases the treatment was untimely and ineffective. Moreover, the availability of the agricultural input market and the lax management of local competent authorities facilitated the phenomenon.

To describe labor use in field operations, the authors divided it into two kinds of work, mandatory and optional. Mandatory work (MWs) consists of several practices regarding establishment, harvest and post-harvest (e.g., land preparation, transplanting, harvesting, threshing, transporting, and drying). Meanwhile, optional work (OWs) involves time devoted to advanced technical applications and plant protection. In this paper, we are interested in the second kind of work because of our hypothesis that the more time a farmer spends on controlling problematic events, the higher the paddy yield achieved. The household survey reveals that upland rice growers devoted more time (20%) to this type of rice-field operation than lowlanders.

To understand the low TE scores of rice farmers in Laocai, the authors used five continuous variables (i.e., Z_3, Z_4, Z_5, Z_7, Z_8) and five dummy ones (Z_1, Z_2, Z_6, Z_9, Z_{10}), given in Tables 1 and 2, respectively. Using dummy variables to measure the technical efficiency has great importance, so it is applied widely in SFA models. This argument is clearly demonstrated in Djokoto's work, which examined the variations in the technical efficiency scores of 109 organic agricultural products in 42 empirical studies published from 2002 to 2014 [57]. The farm-specific characteristics illustrate the various socioeconomic advantages of lowlanders compared to ethnic-minority highlanders. They

have higher education, longer SC rice-growing experience, much larger farm size, a higher proportion of people accessed the extension service; there was more labor and fewer independent people; and there was more diversity of income and better financial accumulation. It is clear that farm-specific factors are significant, except for two explanatory variables: the proportion of farmers who applied IPM and the gender of the person making decisions on rice-farming practices. Based on the challenges of the minority farmers mentioned above, it is necessary to propose synchronized and comprehensive solutions at a grassroots level. Therefore, it leads to obtain better farming practices and improving the economic status.

Table 2. Descriptive statistics of dummy variables used in the SFA function.

Characteristic	Explanation	Upland (n = 80)		Lowland (n = 80)		Combined Sample (n = 160)	
		Value 0	Value 1	Value 0	Value 1	Value 0	Value 1
Z_1: Ethnic	1: Kinh; 0: Other	11	69	56	24	67	93
Z_2: Gender	1: Male; 0: Female	51	29	58	22	109	51
Z_6: Finance	1: Available; 0: No	41	39	52	28	93	67
Z_9: Extension	1: Access; 0: No	35	45	46	34	81	79
Z_{10}: IPM adaptation	1: Adapted; 0: Not	34	46	33	47	67	93

Source: Household survey, 2016.

3.2. Results of the SFA Model Estimation and Discussion

The central contribution is to determine the factors affecting the TE level in two rice ecologies and adjust them appropriately to use resources efficiently. According to Aigner, Lovell [31], Kolawole [58], and Dang [11], in the case of $\gamma = 0$, there were no technical inefficiency factors, and all deviations in the model were caused by noise. In that case, OLS estimation is chosen for explaining the effects of efficiency parameters and vice versa. In this study, the estimated value of Gamma (γ) was high, with the statistical significance at the 0.001 level, implying that there were inefficiency variables in rice production in the mountainous areas of Vietnam. It can be seen from Table 3 that the gamma score in the combined model, at 0.89, is lower than other models (0.99). The larger the sample size the smoother the distribution of observations, hence, there is a reduced magnitude between the actual TE score and the highest case. For example, the highest TE level in the whole sample is lower than the others and the lowest value in this model is higher than the others (Appendix A).

The results of the maximum likelihood estimation (MLE) including six rice-growing-input parameters and 11 farm-specific variables are displayed in Table 3. The findings reveal that there is a strong consistency in the directional impact of seed rate, quantity of urea, organic fertilizer, and labor for optional work (i.e., time to eliminate competing weeds and control harmful insects) on productivity for the selected ecologies and overall sampling. Its sign is negative and statistically significant at 1 percent, implying that if farmers reduce the amount of seed used in order to increase paddy output and vice versa. This parameter has the largest magnitude among all inputs investigated. Our findings conform to the research carried out by Hien and Kawaguchi [10], Nhựt [59], and Huynh-Truong [12] in the South of Vietnam, Chandio and Jiang [13] in Sindh, Pakistan, and Abdallah [60] in Ghana for maize farmers. However, our results are contrary to the findings of Bäckman and Islam [37] in Bangladesh and Khai and Yabe [61], who found a positive effect of seed (quantity and/or cost) on rice output.

It is clear that smallholder farmers should spend more time on optional work because the attractive scent of this rice specialty will encourage insects, bacteria, pests, and other pathogens. The gained results of the current study is in consistent with various relevant studies [10,14,37,61].

Table 3. The Maximum Likelihood Estimate results of the SFA function.

Variables	Upland (n = 80)		Lowland (n = 80)		Combined (n = 160)	
	Coefficients	SE	Coefficients	SE	Coefficients	SE
Efficiency factors						
Constant	8.50 ***	0.45	8.51 ***	0.24	8.24 ***	0.31
X_1: Seed rate	−0.17 ***	0.05	−0.16 ***	0.01	−0.21 ***	0.05
X_2: Org. fertilizer	0.05 **	0.02	0.01 ***	0.00	0.02 **	0.01
X_3: NPK composite	0.13 ***	0.03	−0.02	0.05	0.10 ***	0.02
X_4: Urea fertilizer	−0.08 ***	0.03	−0.03 **	0.01	−0.02	0.02
X_5: Pesticide	−0.03	0.02	−0.02 **	0.01	0.04 ***	0.01
X_6: Labor	0.02	0.02	0.06 **	0.02	0.04 **	0.02
Inefficiency factors						
Constant	0.65 ***	0.17	0.50 ***	0.12	0.76 ***	0.13
Z_1: Ethnic	−0.31	0.43	0.04	0.06	0.08	0.10
Z_2: Gender	0.20 ***	0.08	0.01	0.05	0.14 ***	0.05
Z_3: Education	−0.02	0.01	−0.01 *	0.01	−0.01	0.01
Z_4: Household size	−0.04	0.03	−0.01	0.02	−0.04 **	0.02
Z_5: Experience	−0.05 **	0.02	−0.01	0.01	−0.04 ***	0.01
Z_6: Financial situation	−0.20 **	0.08	−0.07	0.05	−0.18 ***	0.07
Z_7: Farmland ratio	−0.04	0.06	−0.01	0.02	−0.08 **	0.04
Z_8: Nonfarm income (%)	−0.89 **	0.34	0.02	0.18	−0.53 **	0.23
Z_9: Extension	−0.01	0.07	−0.13 *	0.08	−0.04	0.06
Z_{10}: IPM adaptation	−0.04	0.06	−0.12 **	0.06	−0.14 **	0.06
Z_{11}: Extension*Ethnic	0.36	0.45	−0.03	0.11	−0.28 *	0.15
Variance parameters						
Sigma—squared (σ^2)	0.03 ***	0.01	0.01 ***	0.00	0.02 ***	0.00
Gamma (γ)	0.99 ***	0.01	0.99 ***	0.00	0.89 ***	0.00
Log-likelihood function		86.46	113.58		169.64	
LR test of the one-side error		104.6	77.84		185.22	
Mean technical efficiency		0.855	0.883		0.869	

Note: ***, **, and * indicates the statistically significance at 1%, 5% and 10%, respectively.

Regarding the quantity of fertilizer, all the surveyed producers were able to completely eliminate nitrogenous fertilizer because it is contained in the NPK composite with the formula N:P:K in the ratio 5:10:3. If farmers still use both kinds of fertilizers, a nutritional imbalance occurs and the consequence is that the rate of partially filled grains increases. This advice is similar to previous studies such as Hien et al. and Chen et al. [10,62], but contrary to other authors [12,13,34,63]. Another suggestion to improve the soil fertility and optimize crop yield related to organic manure is that all farmers should apply about 2 to 3 times the current amount. This is in line with the findings of Rahman and Mia [64]. The regression coefficient of NPK fertilizer in the upland models is positive and significant at 1 percent, implying that when upland farmers increase the use of NPK by 0.13%, their yield increases by 1%. However, the reverse influence of NPK fertilizer used in the lowland model is not strong enough to explain because its sign is insignificant. The results again confirm the fact that highland growers made a lower investment in commercial inputs because of a financial shortage during the planting season. Whereas lowlanders have been practicing extensive farming to pursue the goal of maximum yield, they have been abusing chemical inputs and neglecting environmental impacts.

The estimated results explaining the influence of pesticides on TE score are noteworthy. It seems that *pesticides* have a positive impact on paddy yield in the combined sample, but a negative relationship between the two variables was revealed by the internal regional observations. First, the positive sign for pesticides could indicate that there is a proportional relationship between the paddy output and the pesticides used. For example, lowlanders used a higher amount of pesticide and gained higher paddy output than uplanders. Secondly, in the lowland, many better-off households with non-farm economic activities did not bother checking for pests in the field. Consequently, they made decisions regarding the usage of this toxic input by consulting their neighbors and/or other local

SC rice growers. Although rice diseases are correctly identified, the later treatments probably cause insufficient efficacy. To compensate for the later treatment, they often used a higher dosage, leading to an increase in pesticide costs. Finally, in the upland there are few pests and pathogens because of the cooler temperature. So, using pesticides is not as necessary, especially because it can cause damage to the ecological zone by killing beneficial insects/animals (ants, birds, frogs, etc.) that are enemies of harmful insects. Based on these analyses, we therefore suggested that the surveyed farmers should cut down on pesticides, concurrently increasing the time devoted to managing pests and the field ecosystem (i.e., sustainable farming practices). It is noted that there were a wide range of toxic and illegal pesticides available on the local market because of the limited capacity management the Vietnamese government, therefore some kinds of pesticide did not work well as expected [65–67]. As a result, lowland farmers have various difficulties coping with pests and invasive species and tend to poison them with toxic chemicals, regardless of the negative effects on the ecosystem. The suggestion of a reduction in pesticide use is considered consistent with sustainable socioeconomic–environmental development and most previous empirical evidence has been from the same viewpoint, except for the findings of Rahman et al. [64].

The models also show that on average rice producers at the research site obtained a technical efficiency score of 86.9%, with lowland growers having a higher score than uplanders at 88.3% and 85.5%, respectively. This empirical evidence suggests an increase of nearly 12–15% in rice output through applying better farming practices at the farm level. Based on the local prices of agricultural inputs, our estimation calculated that smallholder households could save 1.23 million Dong per hectare, with uplanders saving 621,290 VND/ha and lowlanders saving 609.720 VND/ha; the saving on seed wastage accounted for the dominant proportion in all three models (around 70%). In the best scenario, each surveyed farmer was able to increase paddy yield by 196 kg (2.94 Mil. VND) in uplands and 405 kg (5.66 Mil. VND) in lowlands. It is therefore extremely significant for poor farmers who depend on SC rice production as the most important source of income and livelihood.

As seen in Table 3, the estimated coefficient of gender is positive at a significance of 1% in the first and third models. This means that if women play the key role in decision-making about rice farming activities, these households will have higher productivity than others. This contradicts the findings of Simelton, who stated that men and women participated equally in almost all upland farming activities, and Oladeebo, who showed that male-headed households had a mean TE higher than poor female-headed households, and Yang et al., who found a negative relationship between rice output and female ratio [14,68,69].

The estimated results also indicate positive relationships between education level, household size, and farmland ratio and the change of paddy output. The majority of these findings are consistent with the facts indicated by previous studies in other developing countries as well as in other regions of Vietnam [10–12,14,33,61,62,70]. However, the positive sign of the variable regarding experience growing this rice specialty is different to the studies mentioned above, except for Bäckman et al. [37]. The reason may be that in these studies the more experience farmers have of rice growing, the more difficulty they face in adopting new technologies or a new rice variety. In our study, the situation is totally the opposite because the new variety required farmers to take up new practices that are very different from the traditional method.

In particular, the estimated coefficient of a highlander's non-farm income factor is negative and significant at the 5% significance level with the highest magnitude at 0.89. The result is that a one-percent rise in off-farm revenue will generate an increase in rice productivity of 0.89%. As a matter of fact, upland farmers often have other non-agricultural income that not only increases their financial capacity but also improves their farming skills and knowledge gained from other households and/or other information resources. However, the impact of this predictor variable in the lowlands is negative but insignificant. It could be explained as in the previous discussion: a trade-off occurred between agricultural activities and others.

With respect to the financing availability variable, its MLE coefficient is negative in all three models, and the magnitude is the highest in the first model. This reflects the common experience in rural areas of Vietnam: farmers lack money to purchase timely rice-producing inputs, therefore causing ineffective investment. Farmers have to improve their financial management, especially highlanders. For example, they have an abundance of money after harvesting and spend extra money on unnecessary activities, but the rest of the time they live in poverty. Figure 3 illustrates the impact finances have on rice output. The majority of farmers who have good financial sources in place obtained the highest technical efficiency (≥90%). Moreover, all of the farmers who achieved the lowest TE score (<70%) did not have good financial management. This once again supports the empirical findings of Hien and Kawaguchi [10], Binam and Tonye [70], Chaovanapoonphol and Battese [71], Bäckman and Islam [37], and Chandio and Jiang [13,15,70].

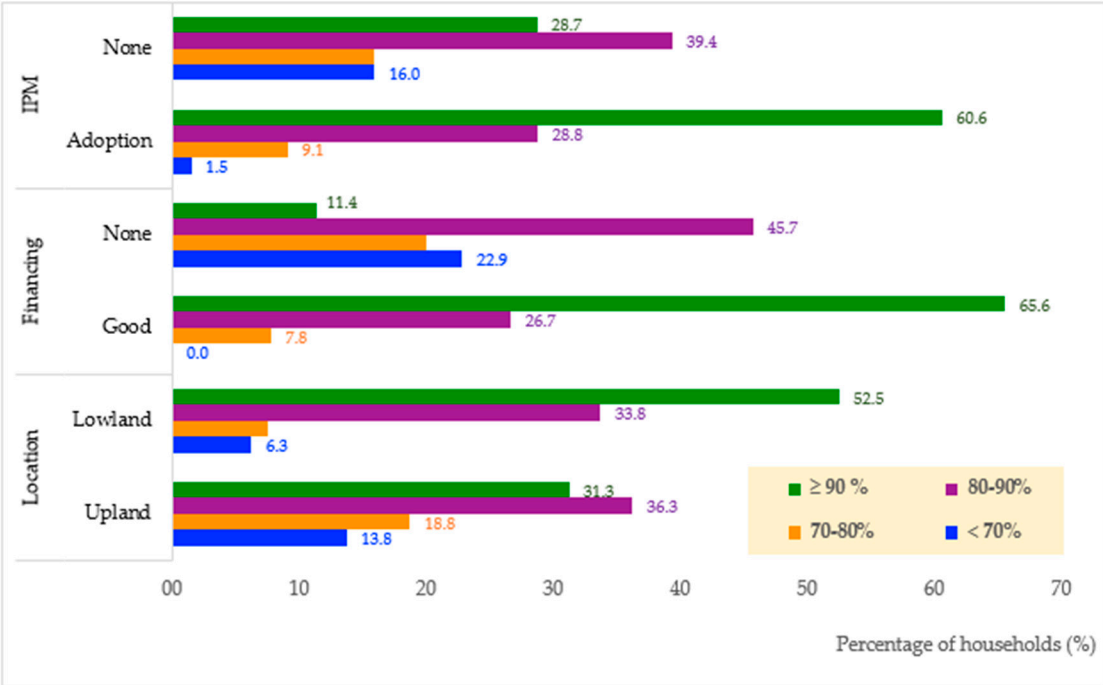


Figure 3. Frequency distribution of technical efficiency level divided by location, financial situation, and IPM adoption.

On the other hand, our research thoroughly analyzes agricultural extension, a service that has been playing a vital role in new technological applications in specialty rice cultivation. The results show that the access to extension has a negative sign in the three models; only the coefficient of the lowlander's model is statistically significant and the rest are not significant. This implies that farmers in the lowlands who received appropriate technologies from extension services had a higher TE score than those who did not. In general, this discovery is similar to the conclusions of previous research. Moreover, the estimated parameter of the variable named "extension*ethnicity" is negative and statistically significant at the 5% level. This may indicate that only lowlanders and Kinh people are taking full advantage of the extension service; meanwhile, the benefits to ethnic minorities in the uplands are still unstable. This finding is in line with the premise of Cuong and Tung [72], who found a positive effect of some supporting policies in the poverty reduction program on rice productivity but did not achieve their target of reducing the widening gap between ethnic minorities and the Kinh group. Given the encouraging impact of extension on productivity, our estimation supports the findings of most prior research.

Regarding IPM application, the statistically negative sign denotes the positive effect of advanced technology on rice yield. From Figure 3, we can see that a large proportion of the households (60.6%) applying the new techniques achieved the highest TE score (>90%), and vice versa. Also, a high proportion of non-compliant IPM households achieved the lowest TE score (<70%). This finding is similar to the results of Hien and Kawaguchi [10] but opposite to those of Huynh-Truong [12]. Accordingly, there was no significance of its mark in the first model. Therefore, it implies that the influence of IPM adoption is undefined and unclear in upland areas. It could be that the lower temperature in the uplands restricts insects, pests, and bacteria.

4. Recommendations

Based on our observations and the results of SFA estimation, we suggest three main recommendations related to three key agricultural services in mountainous areas of Vietnam. These are agriculture extension, credit, and irrigation. Furthermore, suggestions at both the farm level and the provincial level are issued in each corresponding section.

4.1. Agricultural Extension

In Vietnam, empirical agricultural experiments are often carried out in favorable regions (irrigated lowlands, wetlands, deltas) and the technical results are also applied to upland areas even though the environmental conditions are hugely different [3,73]. This is true in the national context as well as for Sengcu rice in Laocai. To be more precise, there is only one set of technical guidelines issued by Laocai DARD and these are applied to all rice-growing ecologies regardless of the differences in soil type, sub-climate, and water source [47]. Moreover, the participants surveyed in the training course organized biennially by extension office reported that trainers often talked about old rice diseases and/or "strange" technologies (i.e., sowing in line; too young a seedling age in the cold temperature ranging 10 to 12 °C in February, etc.), so the content is not relevant to growers in the uplands. As a result, 56% of upland and 77% of lowland respondents participated but only 23% and 19% of participants applied the guidelines from the previous training courses. To achieve the goal of SC rice cultivators applying good agricultural practices and extension services, a number of related solutions are suggested below.

First, the province should examine and issue two technical guidance documents associated with the two kinds of topography, or one for each district. In fact, there is a unique document relevant to lowland areas but it is also disseminated in the uplands. The provincial extension center should identify (and/or update) the requirements of local people in order to provide more valuable technologies and help farmers use their limited resources more efficiently. Second, we suggest that agricultural authorities provide a more suitable extension method, namely a farm field school, especially for highlanders with a low level of education. This is an alternative method replacing the current, traditional top-down approach. It focuses on group learning by practical discovery and observation in the field, so it is easier to remember, more effective, and enhances the production capacity for each member. Moreover, the same interest group also contributes to maintaining the good quality of the SC rice production zone because of purebred rice. Finally, the extension staff at the village level should be a well-connected farmer (but not be the head of the village), who is hardworking and able to manage the rice field ecosystem. As a matter of fact, the majority of farmers reported that they seldom meet the village extension staff person when he visits the fields and thus they doubt his ability.

4.2. Agricultural Credit and Financing Management

In Vietnam, even though the central government has been paying attention to financial support for the poor/ethnic minorities, disadvantaged people have not received valuable opportunities. For example, highlanders could not access agricultural credit from banks for the individual irrigation system mentioned below because this loan is not disbursed in accordance with the current regulations. Another example regards credit for agricultural machines: lowland farmers can access this preferential loan but upland rice growers cannot use machines in terraced plots on hillsides (there are many supporting policies from the Vietnamese government related to the use of agricultural machinery and reduction of losses in agriculture through preferential loans (e.g., Decision No. 68/2013/QD-TTg dated 14 November 2013; Decree No. 210/2013/ND-CP on 19 December 2013; Decision No. 497/QD-TTg dated 17 April 2009; etc.)). Therefore, the senior authorities should localize the demand for beneficiaries. On the other hand, provincial and district banks should disburse loans during the rice crop season to ensure the proper utilization of credit.

At the farm level, growers should enhance financial management through the bookkeeping method to record the frequent in–out cash flow generated from all household activities (both farm and non-farm). It may help recorders (i) calculate the ready money for purchasing agricultural inputs (fertilizer, pesticides, seed, animal feed, etc.) during seasonal cropping; (ii) choose the right time for buying commercial inputs and selling agricultural products; (iii) evaluate the profitable ratio of each economic operation, hence, decide the cropping pattern providing the highest income (e.g., increase the rate of land for SC rice planting because of its high economic value); and (iv) maintain balanced finances. Better financial management helps farmers not only to keep money available for timely investment but also significantly contributes to sustainable farming practices and livelihoods.

4.3. Irrigation Service

Because rice is a semi-aquatic plant, water is the most important factor influencing grain yield. Because of the unpredictability rainfall, rain-fed rice growers are frequently vulnerable to drought in the first season and flood in the second. For example, an extremely severe drought occurred in 2011, causing a reduction in rice productivity of 1280 ha. In 2017 alone, 451.75 ha of planted rice was destroyed by natural disasters, and racial minorities in uplands are affected more severely [18]. It is noted that there is a big difference in irrigation investment between regions, provinces, and kinds of topography. In better-off areas, farmers gain many more benefits from public investment including irrigation systems; meanwhile, the central government pays little attention to investment in uplands. For instance, the average number of water pumps per community for rice irrigation in the Red River Delta was 3.96, whereas the figure in the NMMs was 0.84 [74]. The calculation from our household survey indicated that uplanders were only able to practice mono-cropping on 76.36% of total cultivated land because of water shortage. Moreover, they have to invest an average of about 7.5 Mil. VND ($330) in the plumbing system to transport water from mountain springs to their plots. This individual irrigation can last 5–7 years without causing significant destruction. Based on all the evidence, we suggest that the central government and provincial authorities should pay more attention to improving basic agricultural production conditions, especially in the uplands, through small-value infrastructure such as small reservoirs, self-draining dams, pump stations, etc.

5. Conclusions

The main purpose of this study was to evaluate the TE score and its determinants of SC rice cultivators in two of the largest districts of Laocai province by using Cobb–Douglas stochastic frontier analysis (SFA) and FRONTIRE 4.1 software (CEPA, Brisbane, Australia). A set of structured questionnaires was used to collect primary data about the farming practices and socioeconomic characteristics of 170 rice farmers. The mean TE score of the special rice production in uplands, lowlands, and all surveyed households was 85.5%, 88.3%, and 86.9%, respectively, implying that there is still a great opportunity to enhance paddy yield. The results of the MLE estimation suggest that farmers should reduce several important external inputs including seed rate, nitrogenous fertilizer, and pesticides, concurrently increasing organic manure and time for applying advanced techniques in order to increase paddy productivity. Additionally, based on the fact that lowlanders are abusing inorganic fertilizers and other agro-chemicals to maximize output and highlanders invest less due to financial shortages, the study gives reasonable advice to these farmers in order to achieve higher paddy productivity as well as protect the environment. According to our calculations, on average each upland and lowland household will save 621,290 and 609,720 VND/ha ($27.40; $26.87) in commercial input costs, respectively. In addition, they increase their paddy yield by 196 kg ($138) and 405 kg ($268), respectively. This is significant for poor farmers who depend on SC rice specialty production as their most important source of income and livelihood. Nonetheless, eco-friendly agriculture will open up many opportunities for high-quality Vietnamese rice in high-end market segments. Furthermore, the study exhibits the effects of farm-specific factors on the TE level. Women participating in decision-making process, household size, growing experience, larger scale of farmland, finances, the adoption of advanced techniques, and access to extension services are all significantly positive influences on output.

In terms of policy, all households receive the same support from the central government regardless of the difference in topography. However, highlanders could not take full advantage of financial support packages, extension services, and irrigation. Based on our findings, we suggest three main recommendations related to these key agricultural services in mountainous areas of Vietnam. In general, both the central government and provincial authorities must identify the specific needs of beneficiaries in each farming typology and topography in order to tailor the service effectively. Banks should disburse loans in a timely manner during the rice-growing period to help farmers avoid money shortages when purchasing agricultural materials. At the farm level, they should frequently record cash flows through bookkeeping to better manage finances and make the maximum agricultural income.

The main limitation of the current study was the limited access to updated data. In fact, in Vietnam, the national and provincial data for 2017 will not be published until the second half of 2018. The information on SC rice production was insufficient. Therefore, in this study, the data relevant to the SC rice in 2016 were the latest available. However, semi-annual interviews were conducted (from 2016 to 2018) with leading staff who are working in the (Sub) Department of Agriculture and Rural Development. These interviews aimed to capture the reality of SC rice production as well as overcome the limitations of the data.

Author Contributions: P.L. is the promoter of this PhD research. He provided instructions for the research design and approach, and revised the paper. H.C.T. is the co-promoter of this PhD research in Vietnam. He contributed to the research design and commented on the revisions of the paper. H.A. is a senior researcher who commented on how to improve and revise the paper. T.L.B. collected data through field trips in Vietnam, developed and improved the paper, and provided responses for the journal's reviewers and editorial board. All the authors read and approved the final manuscript.

Funding: The authors are grateful to Vietnam International Education Development (VIED) for providing financial assistance to this study.

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

Appendix A

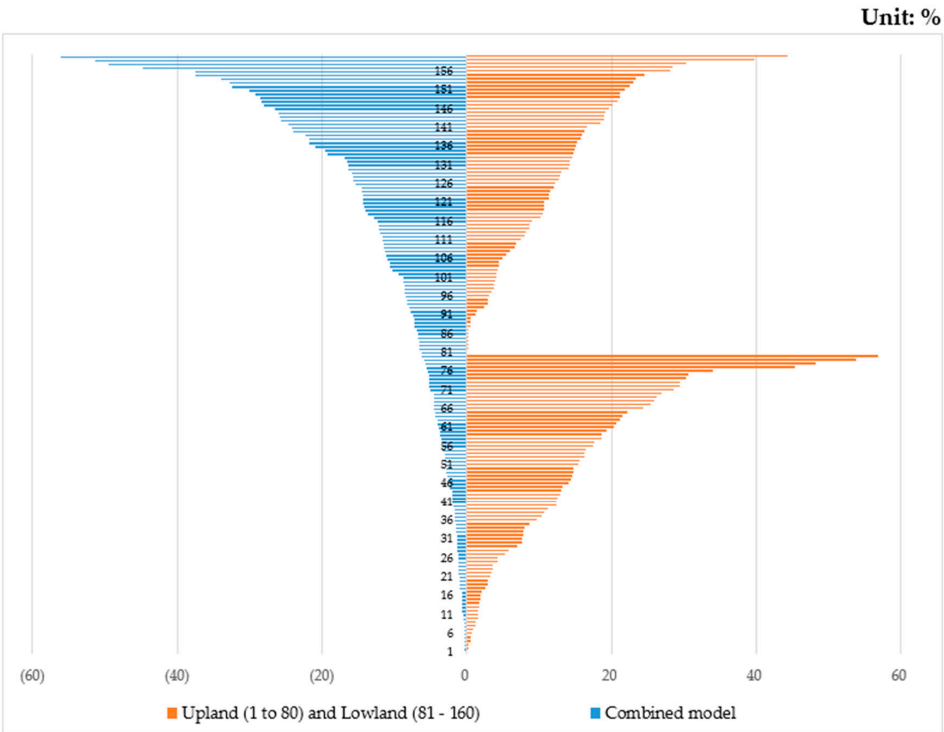


Figure A1. The comparison of observed TE score and the highest technical efficiency case. Note: The real values in the upland and lowland model are converted from negative to positive in order to easier observe.

Table A1. Top-five and bottom-five TE score of SC rice growers in the three SFA models. Unit: %.

Cases	Upland (n = 80)	Lowland (n = 80)	Combined (n = 160)
Highest 1	99,250	99,993	98,864
2	99,194	99,988	98,864
3	98,979	99,987	98,799
4	98,744	99,987	98,691
5	98,677	99,987	98,688
Lowest 1	42,333	55,586	42,830
2	45,503	60,209	47,586
3	50,950	69,765	49,331
4	53,949	71,569	54,032
5	65,289	71,827	61,300

Source: Authors' calculation.

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