

Technical efficiency of rice productivity in Indonesia

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Abstract. The government has provided a lot of assistance to increase rice productivity. However, studies in this area are still rare. This study aims to determine the level of technical efficiency of various types of agricultural machinery assistance and subsidised fertilisers for rice productivity. The study method used is stochastic frontier analysis at the provincial level based on realisation data of government assistance in 2017–2021 on rice productivity for 2018–2021. The technical efficiency value of rice productivity in 2018–2021 has been efficient. The technical efficiency average is 0.82 and decreased by 0.44% annually. The variables that have a significant effect are subsidised nitrogen fertiliser, subsidised phosphorus fertiliser, small combine harvesters (CH), vertical dryers (VD), and small and medium-scale rice milling units (RMU). Subsidised nitrogen fertilisers and medium-scale RMU are significant with a positive sign, while phosphorus, small CH, vertical dryer, and small-scale RMU are significant with a negative sign. Based on the results, increasing rice productivity can be carried out by adding nitrogen fertiliser assistance, increasing medium-scale RMUs, reducing phosphorus elemental fertilisers, not adding VD (unless integrated with medium-scale RMUs), and small CH due to no longer being effective in increasing rice productivity.

1 Introduction

Agricultural tools and machinery support production for efficiency from preparation to post-harvest. The Ministry of Agriculture has distributed equipment and machinery for pre-harvest, harvest, and post-harvest in the last ten years. Pre-harvest agricultural tools and machinery consist of two-wheeled tractors, four-wheeled tractors, water pumps, rice transplanters, cultivators, hand sprayers, and excavators. Agricultural tools and machinery used for harvesting include pedal threshers, power threshers, and combine harvesters.

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Modern post-harvest agricultural tools vertical and horizontal dryers, small, medium, and large-scale rice mills (RMUs), and other supporting equipment and supplies.

Agricultural tools and machinery have become increasingly important due to technological advancements and labour scarcity. Using agricultural tools and machinery can indirectly increase production by improving labour efficiency, land preparation, planting speed, and yield loss.

Even though a large amount of government aid is directed towards the rice industry by providing tools and machinery, studies and evaluations show that these resources have not been fully utilised to their potential [1–4]. This study aims to evaluate the technical efficiency of different agricultural equipment and machinery and subsidised fertilisers on rice productivity. The optimal use of agricultural tools and machinery is expected to increase farmers' production and income, making the analysis results helpful in formulating policy recommendations.

2 Methodology

2.1 Materials

The study utilises secondary data in the form of statistical data from 2017–2021, sourced from various entities such as the Statistics Indonesia (BPS), Directorate General of Agricultural Infrastructure and Facilities, Directorate General of Food Crops, Agency for Agricultural Extension and Human Resource Development, Center for Agricultural Data and Information, and other relevant agencies at the provincial and district/city levels. The information in this dataset includes several factors that affect rice production. These include the amount of rice produced, the volume of subsidised fertiliser used, the number of combine harvesters, threshers, dryers, and rice milling units, the number of households engaged in rice farming, the size of irrigated rice fields, the number of rainy days per year, the availability of agricultural equipment and machinery services, and the occurrence of plant diseases, pests, floods, and droughts. This data can help farmers make informed decisions to improve their rice yields. In this study, the data is detailed at the provincial level, and the following distinctions are made: (1) fertiliser consists of nitrogen, phosphorus, potassium, and organic fertiliser; (2) combine harvesters are divided into large, medium, and small scale, (4) thresher is divided into power thresher and pedal thresher, (5) dryer is represented by vertical dryer, and (6) rice milling unit is divided into large, medium, and small scale.

2.2 Methods

Efficiency in productivity is measured through technical analysis using the Cobb-Douglas Stochastic Production Frontier function. The Stochastic Production Frontier was introduced by Aigner et al. [5] and further by others such as Kumbakhar et al., Battese et al., Coelli et al., and Greene [6–12].

$$Y_i^* = h(x_i, j_i) \exp(v_i - u_i) \tag{1}$$

where: Y_i^* = productivity of 1st province; x_i = variable input vector for productivity; j_i = fixed input vector productivity; $\exp(v_i - u_i)$ = pooled error term.

Productivity efficiency is derived from the ratio of predicted, observed, or actual productivity (Y_i^*) to maximum predicted productivity (Y_i):

$$\text{Productivity efficiency} = \frac{\text{Actual productivity}}{\text{Maximum productivity}} = \frac{(x_i, z_i) \exp(\hat{v}_i)(\hat{u}_i)}{(x_i, z_i) \exp(\hat{v}_i)} \tag{2}$$

$$\text{Productivity efficiency} = \frac{(x_{i,j})\text{exo}(v_i - u_i)}{(x_{i,j})\text{exp}\left\{\frac{v_i}{\sigma}\right\}} = \frac{\text{exp}\left\{\frac{v_i}{\sigma}\right\}(v_i - u_i)}{\text{exp}\left\{\frac{v_i}{\sigma}\right\}(v_i)} = \text{exp}(-u_i) \quad (3)$$

The stochastic error term comprises two separate, independent elements, “*v*” and “*u*”. The error term (*v*) represents random variation in productivity due to external factors beyond the farmers' control, such as omitted explanatory variables, measurement errors, statistical noise, and random effects. The variable (*u*) represents agricultural inefficiency, the difference between actual productivity and the maximum possible value given the stochastic productivity frontier. When *u* = 0, it indicates that productivity is operating at maximum efficiency or 100%. If *u* < 0, productivity is working below the efficiency frontier. Both *v* and *u* are assumed to be normally distributed with zero mean and constant variance and are independent variables.

Productivity efficiency model-functional specification

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \dots + \beta_{14} \ln X_{14i} + v_i - u_i \quad (4)$$

where:

- Y_i = Productivity equivalent to rice (ton/ha)
- X_1 = Total of subsidised fertiliser nitrogen (ton)
- X_2 = Total of subsidised fertiliser phosphor (ton)
- X_3 = Total of subsidised fertiliser kalium (ton)
- X_4 = Total of subsidised fertiliser organic (ton)
- X_5 = Total of large CH (unit)
- X_6 = Total of medium CH (unit)
- X_7 = Total of small CH (unit)
- X_8 = Total of power thresher (unit)
- X_9 = Total of pedal thresher (unit)
- X_{10} = Total of vertical dryer (unit)
- X_{11} = Total of small RMU (unit)
- X_{12} = Total of middle RMU (unit)
- X_{13} = Total of large RMU (unit)
- X_{14} = Number of rice farming households (unit)
- i = 1-N province
- $\beta_j = j = 0$ is the constant; $j = 1-14$ is the parameter coefficient
- \ln = logarithm of natural number
- $v-u$ = error term

$$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 > 0$$

Productivity inefficiency model-functional specification

$$[U_i] = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + e_i \quad (5)$$

where:

- U_i = Productivity Inefficiency
- Z_1 = Area of rice fields with functioning irrigation networks (ha)
- Z_2 = Number of rainy days (day)
- Z_3 = Total of UPJA (unit)
- Z_4 = Total of large RMU (unit)
- Z_5 = Extent of pest attacks (ha)
- i = 1-N provinsi
- $\delta_j = j =$ is the constanta; $j = 1-5$ is the parameter coefficient
- e_i = error term

$$\delta_1, \delta_2, \delta_3, \delta_4, \delta_5 < 0$$

The SPF functions in equations (4) and (5) were estimated using the maximum likelihood estimation (MLE) method with Frontier 4.1 software, an appropriate tool for estimating stochastic frontier functions.

3 Results and discussion

Using machinery for harvesting and post-harvest activities is crucial for increasing productivity in paddy and rice crops. These machines include combine harvesters, power threshers, pedal threshers, vertical dryers, and RMUs. Studies have confirmed the significant positive impact of machinery on productivity [13–16]. The combined harvester is the most effective machine in increasing productivity [13]. Additionally, tractors and rice transplanters increase productivity by allowing for efficient processing and planting [15,17].

According to the analysis of productivity functions using the maximum likelihood estimation (MLE) method, it was found that only a few variables out of the 14 were considered to have a significant impact on frontier production. Specifically, nitrogen, phosphorus, small CH, vertical dryer, small-scale RMU, and medium-scale RMU were found to be influential. Nitrogen and medium-scale RMU positively affected rice productivity and were significant at the α level of 1%. On the other hand, phosphorus, vertical dryer, and small-scale RMU hurt rice productivity and were also significant at the α level of 1%.

After analysing the data, it appears that the use of machinery, particularly government-provided machinery, does not significantly impact productivity. The machinery seems to be not being used to its full potential, possibly due to several issues identified in studies. These issues include inadequate support for recipients, weak institutional structures, insufficient management capacity, unsuitable business scale requirements, poor spare parts support, and incompatibility with local social, cultural, and agroecosystem conditions. Moreover, there is a shortage of skilled operators and verifiers, and assistance is often provided in overcrowded areas with minimal resources. Donors and beneficiaries also encounter transportation costs and limited operational financing support [1,3,4,18–20].

The productivity function estimation results (Table 1) indicate that the nitrogen fertiliser variable is the most responsive compared to the others. If all other factors remain the same, productivity can be increased by adding nitrogen fertiliser. It has been observed that adding fertiliser with phosphor elements can lead to a decrease in productivity. This indicates that the soil already has excessive amounts of phosphor. Small CHs and RMUs are no longer effective in improving efficiency, as too many exist. Many small RMUs have ceased operations as they are less efficient and unable to compete with medium and large RMUs. Additionally, vertical dryers are ineffective as beneficiaries struggle to manage the assistance received. However, using medium-scale RMUs has shown positive effects in increasing rice productivity.

The technical efficiency value of rice productivity in Indonesia in 2018–2021 reached an average of 82%. This indicates that there is still room for an efficiency improvement of 18%. The highest technical efficiency in Java Island is in West Java Province (98%), while the lowest is in D. I. Yogyakarta Province (91%). Meanwhile, outside Java, the highest technical efficiency was in South Sumatra Province (53.6%), and the lowest was in Riau Islands Province (7.7%). In general, provinces outside Java have a lower level of technical efficiency, and on average, the space for increasing productivity is relatively higher than outside Java (A 1).

The study found that the average technical efficiency value for productivity is 82%, meaning there is room for improvement of 18% by enhancing significant factors. Inefficiency is believed to stem from various factors, including the area of rice fields with proper

irrigation, the number of rainy days, the quantity of rainfall, the number of UPJA, the area of puso land, and the area of land affected by pest attacks, floods, and drought.

Table 1. Estimation results of rice productivity function using MLE method in Indonesia, 2018–2021.

| Input variable | Coefficient | Std-error | t-ratio |
|--|-------------|-----------|-----------------------|
| (Constant) | 1,502 | 0,137 | |
| Nitrogen (LnX ₁) | 0,189 | 0,043 | 4,382 ^{***} |
| Phosfor (LnX ₂) | -0,126 | 0,053 | -2,372 ^{***} |
| Kalium (Ln X ₃) | -0,053 | 0,071 | -0,742 |
| Organic (Ln X ₄) | 0,033 | 0,020 | 1,642 |
| Large CH (Ln X ₅) | 0,033 | 0,021 | 1,539 |
| Middle CH (Ln X ₆) | 0,009 | 0,018 | 0,515 |
| Small CH (Ln X ₇) | -0,060 | 0,025 | -2,384 ^{**} |
| Power thresher (Ln X ₈) | 0,028 | 0,017 | 1,594 |
| Pedal thresher (Ln X ₉) | 0,002 | 0,026 | 0,081 |
| Vertical dryer (Ln X ₁₀) | -0,051 | 0,012 | -4,152 ^{***} |
| Small RMU (Ln X ₁₁) | -0,116 | 0,038 | -3,040 ^{***} |
| Middle RMU (Ln X ₁₂) | 0,093 | 0,028 | 3,338 ^{***} |
| Large RMU (Ln X ₁₃) | 0,006 | 0,010 | 0,602 |
| Rice farmer households (Ln X ₁₄) | -0,007 | 0,012 | -0,570 |
| Sigma-square (σ^2) | 0,02 | | |
| Gamma (γ) | 0,99 | | |
| L-R test | 40,66 | | |
| Log LF OLS | 89,84 | | |
| Log LF MLE | 110,175 | | |
| CRTS | | | |

Note : ^{***} Significant at $\alpha=1\%$, ^{**} Significant at $\alpha=5\%$

The analysis results indicate that only the UPJA variable significantly affects technical productivity efficiency (see Table 2). Among these significant factors is only the number of UPJA. As the number of UPJAs increases, inefficiency reduces and efficiency increases. The higher number of UPJAs results in more agricultural tools and machines being available for rent, making it easier for farmers to access and utilise them. As a result, farm businesses that rely on these tools and machines can operate more efficiently and increase productivity.

The ability of UPJA to manage agricultural tools and machinery with government assistance is critical to increasing efficiency, in line with the research of Hidayah et al. and Kusnadi et al. [21,22]. Studies have shown that the introduction of UPJA has positively impacted the income and production of rice farmers [23,24]. UPJA is a group of farmers who own or operate an agricultural machinery services business. Its goal is to establish systems and organisations for machinery services in food and horticulture crop production centres that prioritise profit [25]. The Agricultural Machinery Services Unit (UPJA) is a social engineering program encouraging farmers to use agricultural machinery [26]. It also offers a solution to farming problems in areas where land ownership is limited and individual machinery ownership is not financially feasible [27]. The implementation of UPJA involves

a series of initiatives aimed at supporting and promoting agro-industrial businesses in food crop farming, particularly lowland rice. Economically, the UPJA program is expected to significantly improve the income and well-being of rural farming communities [20].

Table 2. Results of estimating the stochastic frontier inefficiency function.

| Input variable | Coefficient | Std-error | t-ratio |
|--|-------------|-----------|-----------|
| (Constant) | 0,247 | 0,459 | |
| Area of rice fields with functioning irrigation networks (Z_1) | -0,003 | 0,024 | -0,123 |
| Number of rainy days (Z_2) | 0,124 | 0,118 | 1,049 |
| Total rainfall (Z_3) | -0,069 | 0,075 | -0,907 |
| Total UPJA (Z_4) | -0,059 | 0,012 | -4,990*** |
| Land area affected (Z_5) | -0,003 | 0,067 | -0,049 |
| Extent of pest attacks, floods and droughts (Z_6) | 0,141 | 0,098 | 1,443 |
| Gamma (γ) | 0,9915 | | |

Note: *** Significant at $\alpha=1\%$

4 Conclusions and policy recommendations

4.1 Conclusions

There is still a lot of potential for improving rice productivity with the help of existing technology. The national average technical efficiency is only 82%, leaving room for an 18% increase. This opportunity for improvement is not limited to Java. To achieve this, some factors that should be addressed include increasing the allocation of subsidised nitrogen fertiliser, limiting the allocation of subsidised phosphorus fertiliser, introducing medium and large combine harvesters, reducing the use of vertical dryers, increasing the number of medium-scale RMUs, decreasing the number of small-scale RMUs, and expanding the capacity of UPJA.

4.2 Policy recommendations

To enhance productivity, attention should be focused on the provinces beyond Java since they have the potential to increase productivity more than Java. The government should refine the agricultural equipment planning, procurement, and distribution system by involving the central and regional authorities equally. This will ensure that farmers receive the appropriate equipment based on location and needs.

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Appendix

A 1. Improvement in technical efficiency of rice productivity in Indonesia from 2018 to 2021.

| Province | Technical efficiency |
|-------------------------|----------------------|
| Aceh | 0.5942 |
| North Sumatra | 0.4799 |
| West Sumatra | 0.6369 |
| Riau | 0.2643 |
| Jambi | 0.3262 |
| South Sumatra | 0.5364 |
| Bengkulu | 0.4572 |
| Lampung | 0.7394 |
| Bangka Belitung Islands | 0.7453 |
| Riau Islands | 0.0771 |
| DKI Jakarta | 0.1741 |
| West Java | 0.9044 |
| Central Java | 0.8776 |
| DI Yogyakarta | 0.6809 |
| East Java | 0.8757 |
| Banten | 0.8223 |
| Bali | 0.6276 |
| West Nusa Tenggara | 0.5032 |
| East Nusa Tenggara | 0.4566 |
| West Kalimantan | 0.4769 |
| Central Kalimantan | 0.3496 |
| South Kalimantan | 0.4574 |
| East Kalimantan | 0.5928 |
| North Kalimantan | 0.2787 |
| North Sulawesi | 0.2963 |
| Central Sulawesi | 0.7078 |
| South Sulawesi | 0.7676 |
| Southeast Sulawesi | 0.5171 |
| Gorontalo | 0.5144 |
| West Sulawesi | 0.4139 |
| Maluku | 0.4701 |
| North Maluku | 0.2864 |
| West Papua | 0.1559 |
| Papua | 0.6978 |
| Indonesia | 0.5224 |