Universitas Muhammadiyah Malang, East Java, Indonesia

Agriecobis
(Journal of Agricultural Socioeconomics and Business)

p-ISSN 2662-6154, e-ISSN 2621-3974 // Vol. 7 No. 02 March 2024, pp. 81-88

Research Article

Factors Affecting Technical Efficiency in Potato Farming: A Data Envelopment Analysis (DEA) Study in East Java, Indonesia

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ARTICLE INFO

Article history
Received February 29, 2024
Revised April 3, 2024
Accepted May 1, 2024
Published May 3, 2024

Keywords
Data Envelopment Analysis (DEA)
Potato Farming
Technical Efficiency
Tobit Regression Analysis

ABSTRACT

Potato farming has a crucial role in promoting the agricultural sector of East Java, Indonesia, with significant consequences for regional economic growth and acting as the main source of income for farmers. However, the primary challenge that potato farmers face involves improving production efficiency in order to strengthen the sustainability and competitiveness of the agricultural industry. This study aims to analyze the technical efficiency of potato farming in East Java and identify the factors affecting this efficiency. The study focuses on the areas of Sumberberantas and Wonokerso in East Java, which serve as key centers for growing potatoes. The study includes a group of 82 farmers as respondents, with 40 from Sumberberantas and 42 from Wonokerso. Data Envelopment Analysis (DEA) is a method that systematically examines levels of technical efficiency. It is complimented by Tobit Regression Analysis, which assists in identifying the relevant elements affecting efficiency. The findings indicate that the average technical efficiency score is 0.840, suggesting that farmers have the potential to increase their efficiency by up to 16%. Gender and land area for potato farming are identified as crucial factors affecting technical efficiency, while age, education, and farming experience have no effect.

INTRODUCTION

The horticulture sector plays a vital role in Indonesia's economic growth. One significant measure of this is the contribution of horticultural products to the country's GDP, which stands at 1.58% (BPS, 2023). Moreover, the wide variety of horticultural goods presents lucrative business opportunities and job prospects. According to data from the Statistics Indonesia (BPS), out of 135.6 million employed individuals aged 15 and above in February 2022, about 40.64 million were engaged in agriculture by March 2022, accounting for nearly 30% of the total workforce. Thus, fostering the horticulture sector is poised to drive economic development and bolster the national economy.

Among these horticultural products, potatoes stand out as a crucial commodity with substantial potential for development both nationally and regionally. Enhancing the competitiveness of potatoes is crucial for advancing Indonesia's horticulture sector. Potato cultivation plays a significant role in supporting the agricultural sector in East Java, providing a vital income source for many local farmers and contributing to the regional economy. However, one of the primary challenges faced by potato farmers is improving production efficiency to ensure the sustainability and competitiveness of the agricultural industry. Agricultural science, as defined by Soekartawi (2002), involves the efficient allocation of resources to maximize profitability within a specific timeframe. Additionally, according to Shinta (2011), a farmer achieves technical efficiency compared to peers when employing the same inputs results in higher physical outputs.

Increasing production requires the optimal use of inputs without causing harm to the environment. Farmers aim to increase productivity and profitability but may encounter reduced productivity due to various factors, including inefficient input use, land degradation from pesticide misuse, inappropriate pharmaceuticals, and the use of inferior seeds. Assessing the technical efficiency of production factor utilization in potato farming provides farmers with valuable insights for adjusting input levels appropriately. Therefore, this study aims to analyze the technical efficiency levels of potato farming in East Java and identify the factors influencing this efficiency.

METHOD

The investigation into the technical efficiency of potato farming in East Java employed a multistage sampling approach. Initially, two regencies, Batu and Probolinggo, were purposively selected due to their significance as centers of potato production within East Java. Subsequently, the selection of sub-districts was conducted randomly, guided by information sourced from pertinent institutions such as the Department of Agriculture, Agricultural Extension Agency, and BPS data. The chosen sub-districts from each regency encompassed Bumiaji representing Batu and Sumber representing Probolinggo. Following this, one village was randomly chosen from each sub-district: Sumberberantas and Wonokerso. The study unfolded between July and November 2023, encompassing activities ranging from location surveys to data collection, processing, and analysis.

The sampling technique employed in this study is simple random sampling. As elucidated by Beins (2012), simple random sampling entails affording every member of the population an equal opportunity of being selected as a sample. The determination of the sample size was conducted utilizing the Slovin formula. According to information gleaned from village officials, there are 344 potato farmers in Sumberberantas and 626 in Wonokerso. The calculation of the sample size for farmers was executed using the Slovin formula:

$$n = N / (1+Ne\ 2)$$

Where:
n = sample size
N = population size
e = error (degree of error of respondent data)

With a predetermined margin of error of 15%, the total number of sampled farmers based on these computations amounts to 82 farmers in total, comprising 40 farmers from Sumberberantas and 42 farmers from Wonokerso. The data collection methodology employed in this study encompasses two approaches: primary data collection utilizing observation and interviews, and secondary data collection involving literature review and documentation.

Methods for Analyzing the Level of Allocative Efficiency of Potato Farming

The analysis of technical efficiency in potato farming across East Java was conducted utilizing the Data Envelopment Analysis (DEA) method. Employing the DEA formula under the assumption of Variable Returns to Scale (VRS), a variant of the DEA method, enables the measurement of relative efficiency among decision-making units (DMUs), typically referred to as potato farmers in this study, while accommodating varying scales among these units. The efficiency score is derived from the comparison of inputs and outputs within each DMU. In this context, a technical efficiency score of one signifies optimal efficiency, whereas a score below one indicates relative technical inefficiency.

In this study, potato production serves as the output variable, while the input variables encompass land area (m2), seed quantity (kg), chemical fertilizer amount (kg), manure quantity (kg), solid pesticide quantity (kg), liquid pesticide volume (l), and labor hours (HOK). The DEA formula under VRS is expressed as follows:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\ \theta \\ &St - yi + Y\lambda \geq 0, \\ &\theta_{xi} - \text{X}\,\lambda \geq 0, \\ &N1'\,\lambda = 1 \\ &\lambda \geq 0 \end{aligned}$$

Where:
N1'λ=1 is a convexity constraint.

In the equation for technical efficiency (TE), Yi represents the total potato production of farmer i, Xi is an Nx1 vector denoting the total inputs for farmer i, Y represents a 1xM vector representing production, N is an NxM matrix depicting total inputs utilized, λ stands for an Mx1 vector of weights, and s is a switch. The DEA model applied in this study is characterized as an input-oriented DEA model, given that farmers exert greater control over inputs compared to output generation.

Furthermore, this study adopts a variable return to scale (VRS) approach due to the inherent variability observed in agricultural operations, such as seasonal fluctuations and technological advancements, which can influence production scale. This method is deemed more realistic in modeling efficiency, considering that agriculture does not consistently operate at a uniform scale. Consequently, employing the VRS in DEA model is deemed more precise and pertinent to capturing the diverse operational dynamics encountered in agricultural settings.

Factors Affecting the Technical Efficiency of Potato Farming

The analysis of factors influencing the technical efficiency of potato farming in East Java employed Tobit Regression Analysis utilizing Stata 14.2. Tobit Regression is a regression model that assumes independent variables are unrestricted in value, while non-independent variables are constrained. In essence, Tobit Regression incorporates censoring on the non-independent variable during its computation. In this study, the technical efficiency value serves as the censored variable, constrained within the range of 0.00 and 1.00.

The variables considered to impact technical efficiency, derived from prior research and tailored to the research site's conditions, encompass age, gender, education level, farming experience, and the land area dedicated to potato cultivation. The Tobit model utilized in this study is formulated as follows:

$$TE = \beta 0 + \beta 1\ X1 + \beta 2X2 + \beta 3\ X3 + \beta 4\ X4 + \beta 5\ X5 + \varepsilon$$

Where:
TE = Technical efficiency score (0-1)
X1 = Age
X2 = Gender
X3 = Education
X4 = Farming experience
X5 = Land area for Potato Farming
ε = Error
β = Estimated parameter

RESULTS AND DISCUSSION

Analysis on Technical Efficiency of Potato Farming

The utilization of Data Envelopment Analysis (DEA) method in this study is aimed at elucidating the diverse impacts of inputs on potato production in East Java, particularly in the villages of Sumberberantas and Wonokerso. The DEA analysis in this study adopts the Variable Return to Scale (VRS) assumption, intending to assess the proportion of output that can vary with the proportional addition of inputs. This concept of returns to scale is symbolically represented by α and β, where α signifies the proportional addition of inputs and β

denotes the proportional addition of output. If β > α, it indicates Increasing Returns to Scale (IRS), while β < α implies Decreasing Returns to Scale (DRS) outcomes (Cooper et al., 2011).

The variables considered in this study primarily comprise two categories: output and input. Potato production serves as the output (Y) and is utilized as an indicator of technical efficiency, influenced by various input variables. The input variables encompass land area (X1), seeds (X2), chemical fertilizer (X3), manure (X4), solid pesticide (X5), liquid pesticide (X6), and labor utilization (X7).

The application of the Variable Return to Scale (VRS) approach in DEA is justified by the suboptimal utilization of inputs in potato farming at the research site, owing to limited resources and other associated factors. The VRS approach in DEA assumes that the ratio between input and output additions is not uniformly consistent, thereby allowing for the flexibility of input and output changes to either enhance (Increasing Returns to Scale/IRS) or diminish (Decreasing Returns to Scale) efficiency values. The distribution of potato farming production scale is detailed in Table 1 below.

Table 1. Scale Distribution in Production of Potato Farming

Scale Distribution	Number of Farmers	Percentage (%)
Decreasing Return to Scale (DRS)	18	22
Constant Return to Scale (CRS)	28	34
Increasing Return to Scale (IRS)	36	44
Total Sampel	82	100

Source: Primary Data, 2024 (processed)

According to Table 1, the analysis reveals that the majority of respondent farmers operate on an Increasing Returns to Scale (IRS) production scale, comprising 36 farmers, accounting for 44% of all respondents. Farmers operating under IRS conditions indicate that the increase in output surpasses the increase in inputs utilized. Conversely, 18 farmers, constituting 22% of all respondents, operate on a Decreasing Returns to Scale (DRS) production scale. This signifies that the increase in potato output is smaller than the increase in production inputs.

The disparity in technical efficiency values derived from the VRS model facilitates the categorization of scale efficiency into Constant Return to Scale (CRS), Increasing Return to Scale (IRS), or Decreasing Return to Scale (DRS). In the IRS category, the augmentation in output exceeds the increase in inputs provided. Conversely, in the DRS category, the rise in output is inferior to the augmentation in inputs supplied. Meanwhile, in the CRS category, every unit increase in input consistently yields an output equivalent to the input.

IRS and DRS represent inefficient scenarios, with IRS indicating that the DMU has not achieved maximum production, necessitating an increase in business scale (additional inputs). Conversely, DRS signifies an inefficient scenario where the DMU's production scale is excessively large, warranting a reduction in production scale (Huguenin, 2012).

Based on the data processing results using DEAP version 2.1 software with the VRS model, the technical efficiency level values are generated. The distribution of technical efficiency in potato farming is depicted in Table 2 below:

Table 2. Distribution of Technical Efficiency of Potato Farming under VRS Model

Efficiency Level	Technical Efficiency Score	Total (Person)	Percentage (%)
Very Low	0.278 – 0.459	4	5
Low	0.460 – 0.641	13	16
Medium	0.642 – 0.823	13	16
High	0.824 – 0.999	14	17
Full Efficient	1	38	46
Total		82	100
Average Score of TE		**0.840**	
Maximum Score of TE		**1.00**	
Minimum Score of TE		**0.278**	

Source: Primary Data, 2024 (processed)

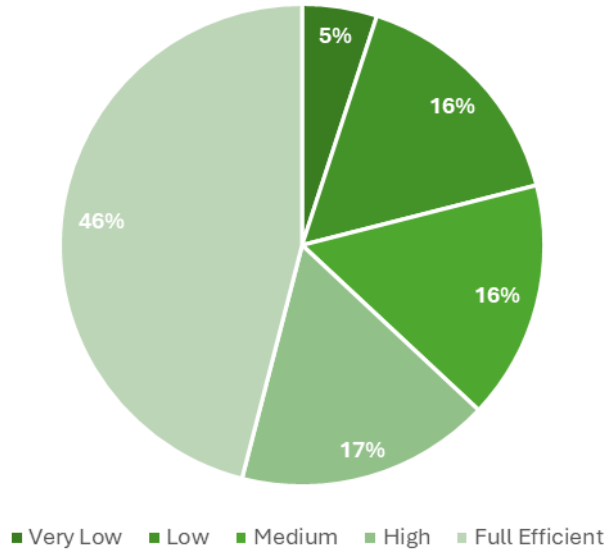

Figure 1. Technical Efficiency Level
Source: Primary Data, 2024 (processed)

According to Table 2, employing the VRS approach in DEA, the majority of farmers are operating at full efficiency, indicated by a value of 1.00, comprising 38 farmers or 46% of all respondent farmers. There are 4 individuals (5%) operating at a very low efficiency level, 13 individuals (16%) at a low efficiency level, 13 individuals (16%) at a medium efficiency level, and 14 individuals (17%) at a high efficiency level. The average technical efficiency value of potato farming in the study area stands at 0.840. Farmers who haven't achieved efficient potato farming practices may reference those who have attained technical efficiency.

Factors Affecting the Technical Efficiency of Potato Farming in East Java

In Data Envelopment Analysis (DEA), some farmers may still fall short of achieving technical efficiency. This shortfall can stem from various factors beyond the mere utilization of farmer inputs, including internal factors inherent to the farmers themselves. To explore the impact of these internal factors on farmers' technical efficiency, Tobit Regression Analysis can be employed.

In the analysis of factors influencing the technical efficiency of potato farming, the technical efficiency values obtained from DEA calculations are regressed against several socio-economic variables. The Tobit Regression utilizes both dependent and independent variables. The dependent variable in Tobit Regression is the technical efficiency value, ranging from 0 to 1, while the independent variables consist of socio-economic factors such as age (in years), gender, education (in years), farming experience (in years), and the land area for potato farming (in square meters).

The outcomes of Tobit Regression analysis for potato farming in East Java, focusing on Sumberberantas and Wonokerso, are depicted in Table 3 below.

Table 3. Hasil Analisis Regresi Tobit Usahatani Kentang

Variable	Coefficient	Probabilities (Pr>|t|)
Age	-0,0037061	0,412
Gender	0,2743542	0,116**
Education	0,0085688	0,484
Farming Experience	0,0033843	0,471
Land area for Potato Farming	-0.0000298	0,017*
Pseudo R2	0.1006	
Prob > chi2	0.1311	
*Significance at 5% true level		
**Significance at 15% true level		

Source: Primary Data, 2024 (processed)

Table 3 presents the outcomes of Tobit Regression Analysis concerning the influence of socioeconomic factors on the technical efficiency of potato farming. To assess the significance of each independent variable (socioeconomic factors) and the dependent variable (technical efficiency), it's imperative to examine the prob> |t| values. A prob> |t| value less than α = 15% suggests significance, indicating that the independent variable exerts a noteworthy impact on the dependent variable. Conversely, if prob> |t| exceeds α = 15%, it implies that the independent variable lacks significance in influencing the dependent variable (Winarso et al., 2021).

The explanation of Table 3's Tobit Regression Analysis results is detailed as follows:

1. Pseudo R2

According to Table 3, the pseudo R2 value is 0.1006. This indicates that the variables including age, gender, education, farming experience, and land area planted with potatoes collectively explain approximately 10.06% of the variation in technical efficiency of potato farming. The remaining 89.94% of the variation is attributed to other factors not included in the model. Generally, a higher percentage of Pseudo R2 suggests a better-fitting model (Nurhadirat & Zain, 2018).

2. Prob > chi2

The Prob > chi2 value in the Tobit model represents the error rate, indicating the model's overall goodness of fit. In this case, the Tobit model exhibits an error rate of 13.11%. Given that this value is lower than the chosen significance level of α = 15%, it suggests that the model is statistically significant and suitable for analyzing socioeconomic factors influencing technical efficiency. Therefore, the Tobit model is deemed feasible for investigating the impact of socioeconomic variables on technical efficiency.

3. Partial Test

The partial test is conducted to assess whether the individual variables of age, gender, education, farming experience, and land area planted with potatoes have a significant impact on the technical efficiency of carrot farming. This is achieved by examining the probability value (p-value) associated with each variable, with significance levels typically set at 0.05 (5% error rate) or 0.15 (15% error rate).

a. Age

Based on the findings presented in Table 3, it appears that the variable representing the age of farmers exhibits a probability value of 0.412, surpassing both the 5% and 15% error rates. Consequently, the variable of age is deemed statistically insignificant in its effect on the technical efficiency of potato farmers. Moreover, the coefficient associated with the age variable is -0.0037061. This implies that as farmers age, there's a decrease in technical efficiency by approximately 0.0037061 units.

These results align with previous research by Ningsih et al. (2015), which suggests that advancing age correlates with a decline in physical abilities among farmers, consequently diminishing their overall performance and efficiency. Similarly, findings from Artamevia et al. (2023) also support this notion, highlighting a negative coefficient associated with the age variable. This decline in efficiency is attributed to the diminishing ability of older farmers to comprehend and adopt agricultural technologies, alongside a decrease in vitality and productivity levels.

b. Gender

Based on the information provided in Table 3, the probability value associated with the gender variable is 0.116, which falls below the 15% error rate threshold. Therefore, the gender variable is considered statistically significant in its influence on the technical efficiency of potato farmers. The coefficient for the gender variable is 0.2743542, indicating that an increase in the proportion of male farmers corresponds to a rise in technical efficiency by approximately 0.2743542 units.

These findings are in line with the research conducted by Taiwo et al. (2014), which suggests that male farmers tend to exhibit higher levels of efficiency compared to their female counterparts. This may be attributed to various factors such as differences in access to resources, decision-making power, and labor allocation within farming households.

c. Education

Based on the results presented in Table 3, the probability value associated with the education variable is 0.484, exceeding both the 5% and 15% error rate thresholds. Consequently, the education variable is deemed statistically insignificant in its impact on the technical efficiency of potato farmers.

The coefficient for the education variable is 0.0085688, indicating the magnitude of its effect on the technical efficiency of farmers. The average education level of farmers in this study is 6 years, which corresponds to completion of elementary school. This educational attainment may influence farmers' attitudes towards innovation acceptance. Research by Maryanto et al. (2018) suggests that individuals with lower levels of education may exhibit reluctance towards adopting new innovations introduced by extension workers, thereby potentially reducing farmers' efficiency.

Additionally, formal education may not significantly impact efficiency as it primarily focuses on general knowledge rather than specialized agricultural information (Sholeh, 2013). Hence, the level of education alone may not determine farmers' efficiency levels in potato farming.

d. Farming Experience

Based on the data provided in Table 3, the probability value associated with the farming experience variable is 0.471, surpassing both the 5% and 15% error rate thresholds. Therefore, the variable of farming experience is considered statistically insignificant in its influence on the technical efficiency of potato farmers.

The coefficient for the farming experience variable is 0.0033843, indicating the magnitude of its effect on farmers' technical efficiency. This suggests that farming experience has a minimal impact on the technical efficiency of potato farmers.

These findings are consistent with the research conducted by Nyagaka and Obare (2010), which suggests that while age and experience may not directly affect technical efficiency, they may indirectly influence decisions regarding the utilization of production inputs. Similarly, research by Kune et al. (2016) supports this notion, indicating that the positive sign of the coefficient for farming experience does not necessarily translate into a significant real-world effect. This could be attributed to the fact that farmers often adhere to traditional and hereditary practices in planting and cultivation, minimizing the direct impact of farming experience on technical efficiency.

e. Land area for Potato Farming

Based on the data in Table 3, the probability value associated with the variable representing the land area for potato farming is 0.017, which falls below the standard error rate of 0.05. Consequently, the land area variable is deemed statistically significant in its impact on the technical efficiency of potato farmers.

The coefficient for the land area variable is -0.0000298, indicating the magnitude of its effect on farmers' technical efficiency. This suggests that for every 1 square meter increase in land area dedicated to potato farming, there is a corresponding decrease in technical efficiency by approximately 0.0000298 units.

These findings align with the notion that land area plays a crucial role in determining the scale of farmers' operations, thereby influencing their overall efficiency levels (Pradnyawati and Cipta, 2021). As farmers expand their land holdings for potato cultivation, they may encounter challenges in effectively managing larger farming operations, potentially leading to a decline in technical efficiency.

CONCLUSION

Based on the analysis of the technical efficiency of potato farming in East Java, it can be concluded as follows:

1. The analysis utilizing the DEA approach with the VRS assumption indicates a prevailing state of technical inefficiency in potato farming across East Java. While 46% of farmers achieve full efficiency (1.00), a significant portion operates below optimal levels: 5% at very low efficiency, 16% at low efficiency, 16% at medium efficiency, and 17% at high efficiency. The average technical efficiency across the study area stands at 84%, suggesting a potential improvement opportunity of 16% to attain maximum efficiency.
2. Significant factors influencing technical efficiency include gender and the land area dedicated to potato farming. An increase in male farmers positively impacts efficiency, while expanded land area dedicated to

potato cultivation negatively affects efficiency. Conversely, age, education, and farming experience did not demonstrate significant effects on technical efficiency.

Based on the conclusions, it is suggested that farmers optimize input usage in potato farming, ensuring compliance with recommended guidelines for chemical fertilizers and pesticides. Additionally, knowledge-sharing initiatives among farmers could facilitate the adoption of best practices, thereby narrowing the efficiency gap across the research area. By implementing these suggestions, potato farmers in East Java can work towards enhancing technical efficiency and overall agricultural productivity.

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