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Original Article

Using the Malmquist Productivity Index to Evaluate the Technical Efficiency of Agricultural Production: A Case Study of Papaya Production in Taiwan

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Abstract *- The study uses Data Envelopment Analysis to evaluate papaya production in key Taiwanese cultivation zones from 2018-2021. Papaya yield is output, whereas seeds, labor, capital, fertilizers, and pesticides are inputs. Estimated county-level technical efficiency ratings measure production. The Malmquist Productivity Index explain productivity trends in which Nantou has the greatest mean technical efficiency, whereas Pingtung has the lowest and is falling. This study shows regional and temporal variability in Taiwanese papaya production efficiency. Prioritizing technical diffusion, input reallocation, and agricultural extension services can boost lagging regions' production to best practice.*

Keywords *- Agricultural production, Data envelopment analysis, Malmquist productivity index, Papaya efficiency, Taiwan, technical efficiency.*

1. Introduction

Taiwan is a tropical and temperate climate country that cultivates various crops, including tropical fruits such as papaya. The cultivation of papaya is economically significant due to consistent year-round production and high yields [1]. The major papaya production is in Tainan, Pingtung, and Kaohsiung County. Domestic consumption dominates papaya demand in Taiwan, with only a small portion exported [2]. This robust internal market has driven significant growth in papaya consumption of 6–11% annually from 2019 to 2020 [3].

Recognizing papaya's potential, the Taiwanese government has implemented strategies to boost production, including subsidies for farmers [4] and facilitating domestic and international market access. Growth of productivity is a primary criterion indicating the advancement of production units. Productivity denotes the utilization and integration of productivity variables within a manufacturing unit. Agricultural production such as rice production in Taiwan was very efficient but exhibited regional variations and an overall decline [5]. Thus, measuring efficiency is essential for estimating the production frontier to evaluate efficiency among different areas. Against this backdrop, this study aims to evaluate papaya production using DEA and analyze productivity trends from 2018 to 2021 through the Malmquist Productivity Index with the primary papaya-producing counties in Taiwan.

2. Literature Review

Data Envelopment Analysis has developed as a non-parametric technique for estimating efficiency of DMUs against the best practice frontier, obviating the need for a pre-established production function linking inputs and outputs [6]. The agricultural sector has experienced substantial applications of DEA in evaluating many performance parameters, including production efficiency [7] productivity [8], and land usage [9] at regional scales. Several expansion techniques had been tried by researchers, [10] demonstrated the integrated use of DEA and the policy analysis matrix to evaluate the profitability and competitiveness of maize, rice, and soybean cultivation in Ghana. As well as, [11] employed DEA to evaluate the ecological efficiency of community forest management in Chiang Mai, Thailand. [12] developed DEA-based indices to evaluate the overall efficiency on technical and energy-saving target ratios, facilitating the examination across 30 provinces in China from 1997 to 2014. [13] enhanced these endeavors by utilizing DEA in Turkish agricultural farms, highlighting the constraints of conventional variable and constant returns to scale models when confronted with a much larger number of outputs relative to decision-making units. [14] employed a bootstrap-DEA approach to examine agricultural efficiency within the European Union. This technique, renowned for its reliability in relative efficiency evaluations, revealed that numerous member states exhibited either increasing or decreasing returns to scale, suggesting opportunities for improved input utilization and production efficiency through output and input-oriented strategies. [15] studied the productivity trend of maize agriculture in Ghana utilizing MPI model. [16] examined the technical efficiency of farmers, revealing a relatively high efficiency among barley growers. The MPI indicates the average in total productivity change throughout the designated analysis period. The literature underscores the efficacy of DEA and the Malmquist output Index as analytical instruments for evaluating temporal variations in agricultural output, affirming their appropriateness for the aims of this study.

3. Data and Methods

3.1. Data Collection

This study used secondary data from the Ministry of Agriculture [17] to calculate DEA scores and MPI efficiency. The dataset contained 6 counties: Nantou, Yunlin, Chiayi, Tainan, Kaohsiung, and Pingtung from 2018 to 2021.

Table 1. Variables used in papaya production

Variables	Units	Definitions
Yield (y)	Kilogram	Quantity of papaya production
Seedling (x_1)	Seedling	Number of papaya seedling per county
Labor (x_2)	Man-Day	Amount of family labor used per county
Facility Fee (x_3)	($NT)	Cost for using facility
Pesticides (x_4)	Liter	Number of agrochemicals used in liter
Fertilizer (x_5)	Kilogram	Amount of fertilizer used in kilogram

3.2. Data Envelopment Analysis

The approach employed in this study is Data Envelopment Analysis [18]. One well recognized linear programming technique used to assess the efficiency of DMUs. The DEA is a mathematical programming technique introduced in 1978 by [6], while its roots can be traced back to Farrel's foundational work [17] or even to Debreu's, who established the "coefficient of resource utilization" in the early 1950s [19]. DEA is a nonparametric approach used to measure the efficiency of DMUs that share a homogenous structure. Its purpose to determine the efficiency measurements among units [20]. It is specifically designed to handle situations when there are several input and output variables [21], formulate and solve linear programming problems for each DMU, and calculate efficiency scores and identify efficient/inefficient DMUs. It assigns scores within the range of "0" to "1" and does not possess any parametric attribute [22]. The DEA allows for the identification of the kind of returns to scale (increasing, decreasing, or constant) in cases when the production allows for non-constant returns to scale.

3.3. CCR Input-Oriented Model

The fundamental principle behind the constant returns to scale model is the optimization of the ratio between weighted multiple outputs and weighted multiple inputs. To assess the relative efficiency, it is expected that their efficiency scores should be equal to or less than 1. Furthermore, it is anticipated that the assigned weights for both inputs and outputs should be either 0 or positive.

Min θ

Subject to

$$\sum_{j=1}^{n} x_{ij}\lambda_j = \theta x_{io} \qquad ; i = 1,2,\dots,m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j = y_{ro} \qquad ; r = 1,2,\dots,s$$

$$\lambda_j \geq 0 \qquad ; j = 1,2,\dots,n \qquad (2)$$

In this section, the explanation of the computation of DEA efficiency scores via mathematical symbols. (θo) is a set of decision-making units (j = 1, ..., n) is calculated outputs (y_rj, r= 1, ..., s) and inputs (x_ij, i = 1, ..., m) using the given formula.

3.4 Malmquist Productivity Index (MPI)

The Malmquist Productivity Index is initially proposed in the literature by [23]. It is originated on the distance function and serves as amount index for analyzing input consumption. [24] integrated concepts from [18] about efficiency measurement and from [25] regarding productivity measurement to create MPI. The Total Factor Productivity (TFP) index has demonstrated its effectiveness as a reliable method for quantifying the changes in DMUs productivity. The DEA uses the MPI to decompose productivity change by computing distance functions between periods into efficiency change and technical change components. MPI could be written as shown in Equation 3 [26].

$$\boldsymbol{M}(\boldsymbol{y}^{t+1},\boldsymbol{x}^{t+1},\boldsymbol{y}^{t},\boldsymbol{x}^{t}) = \left[\left(\frac{D_i^t(x^{t+1},y^{t+1})}{D_i^{t+1}(x^{t+1},y^{t+1})}\right)\left(\frac{D_i^t(x^t,y^t)}{D_i^{t+1}(x^t,y^t)}\right)\right]^{\frac{1}{2}} \times \frac{D_i^{t+1}(x^{t+1},y^{t+1})}{D_i^t(x^t,y^t)} \qquad (3)$$

$$M = TC \times EC$$

Assume an increase in productivity if that M is larger than 1 indicates that is not change in productivity. If M equals to 1 indicates, and M is smaller than 1 means decreasing in productivity. If EC is larger than 1 suggests an increase in papaya production efficiency, the value of EC equals to 1 mean papaya production remains consistent in the period. However, if the value of EC is less than 1 indicates a decrease in papaya production. If TC is more than 1 means technological progress, whereas if TC equals to 1 means there is no change in technology and if TC is less than 1 means decreasing in technology.

4. Results and Discussion

The efficiency scores were calculated using MaxDEA Ultra software. The following section examined and analysed each efficiency category, followed by a summary of the results. This section presents a comprehensive look at the statistical measures related to papaya production in Taiwan. It specifically highlights data collected from six counties over a span of four years, as displayed in Table 2. According to the data, the average output of papaya production is approximately 56,720 kg. Based on the input data, the average number of seedlings is 1,609 seeds. Furthermore, there are approximately 275 contract labours on average. The estimated average facility fee is approximately $NT160,134. Moreover, the average quantity of pesticides used is approximately 12,987 liters. Finally, the result estimated the average fertilizer use to be approximately 2,347 kg.

4.1. Outcome of DEA Model

Figure 1 presents the Technical Efficiency (TE) of papaya production in 6 counties located in Taiwan. From 2018 to 2021, the Technical Efficiency scores were 0.990, 0.921, 0.940, and 0.910. The findings of this study were determined that the technical efficiency in Nantou from 2018 to 2021 was consistently at its highest level, with a perfect average TE score of 1.000. Following were two counties, Chiayi, and Yunlin with impressive TE scores of 0.991 and 0.990, respectively. Pingtung has the lowest efficiency score, with a minimum TE score of 0.869. Furthermore, the TE score for papayas remained consistently high from 2018 to 2021, with an average of 0.940. Based on the data, it appears that it has achieved a technical efficiency of 94% and there is room for improvement by reducing each input, potentially increasing its efficiency score by 6%. According to the findings, the potential need to improve the performance of papaya production in Taiwan.

It appears that these agricultural establishments have the capacity to reallocate their resources effectively, ensuring a steady level of production and making use of current technologies. Table 3 displays the productivity trend of papaya production from 2018 to 2021. The mean values for EC, TC, and TFP change in papaya-producing counties in Taiwan were 1.090, 0.973, and 1.060, respectively. The findings indicated a rise in the total factor productivity of papaya production. Furthermore, papaya production has seen notable improvements in technology and efficiency, except for years like 2019 and 2021. During these periods, there was a noticeable decrease in technological progress

Table 2. Descriptive statistics of variables

Variables	Mean	St. Deviation	Min	Max
Output:				
Yield	56,720	7,794	46,044	77,333
Input:				
Seedling	1,609	74	1,439	1,714
Labor	275	14	251.63	309.75
Facility Fee	160,134	4,219	154,213	170,531
Pesticides	128,987	12,230	108,302	160,867
Fertilizer	2,347	1,313	1,229	6,739

Table 3. MPI summary of annual means

Year	EC	TC	TFP	Productivity Trend
2019	1.133	0.931	1.057	Increasing
2020	1.019	1.021	1.041	Increasing
2021	1.118	0.966	1.081	Increasing
Mean	1.090	0.973	1.060	Increasing

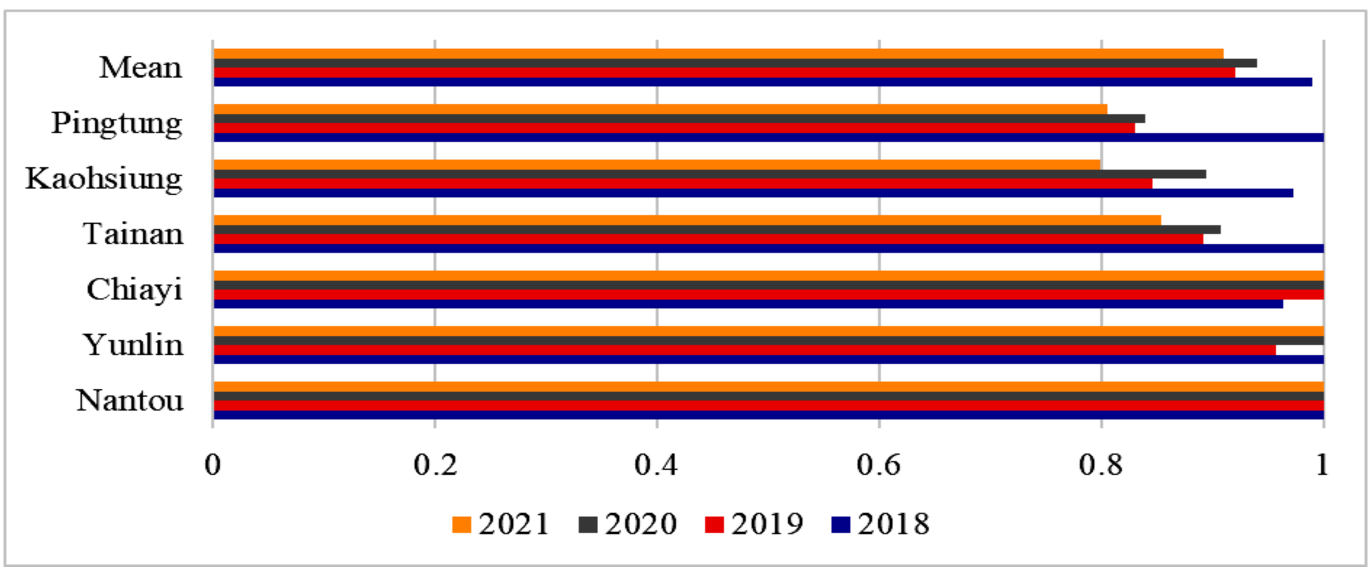

Fig. 1 Technical efficiency score of papaya production in Taiwa

Table 4. MPI summary of county means

County	EC	TC	TFP	Productivity Trend
Nantou	1	1.148	1.148	Increasing
Yunlin	1.001	1.079	1.079	Increasing
Chiayi	1.013	1.087	1.101	Increasing
Tainan	0.950	1.082	1.027	Increasing
Kaohsiung	0.940	1.073	1.006	Increasing
Pingtung	0.934	1.071	0.997	Decreasing
Mean	0.973	1.090	1.060	Increasing

Table 4 analyses the efficiency changes in papaya production among counties from 2018 to 2021. Through the application of MPI decomposition, there was a noticeable upward trend in Total Factor Productivity (TFP) in Nantou, Yunlin, Chiayi, Tainan, and Kaohsiung. There has been a noticeable enhancement in both efficiency and technology. On the other hand, Pingtung experienced a decrease below 1, highlighting the requirement to improve performance and efficiency. In addition, the MPI evaluated efficiency over four years. Moreover, the analysis of this study found that papaya production in Taiwan has improved in technical efficiency, technology, and productivity growth during this study.

5. Conclusion

This study systematically evaluated the production efficiency of papaya cultivation in Taiwan using a non-parametric Data Envelopment Analysis (DEA) methodology. By examining papaya production data from the Council of Agriculture across six major producing counties over the four years of 2018–2021, the study offers valuable insights and best practices for decision-making and resource management within the papaya industry. The findings showed that Nantou exhibited the highest efficiency ratings, showing it as the most effective county for papaya production compared to the other counties. Across Taiwan, the average technical efficiency score for papaya production during the study was 0.940, suggesting that the production achieved 94% of the output. This highlights the possibility for further optimization by fine-tuning the allocation and utilization of inputs. Furthermore, an analysis of the Total Factor Productivity (TFP) revealed a significant increase over the four years, with an average efficiency score of 1.060. Five of the six counties of Nantou, Yunlin, Chiayi, Tainan, and Kaohsiung demonstrated notable improvements in both efficiency and technological advancements.

These findings showed opportunities for improvement, particularly regarding establishing and maintaining consistent production standards. Ultimately, this study provides valuable insights for stakeholders, including farmers, producers, and government agencies, developing strategies to enhance efficiency by adopting advanced technologies. By utilising these ideas that are driven by data, the papaya sector in Taiwan has the potential to continue to succeed, contributing to the economic growth and food security of all society.

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