Analysis of Farming Environmental Efficiency Using a DEA Model with Undesirable Outputs

Hsing-Fu Kuo, Hsiang-Leng Chen* and Ko-Wan Tsou

Department of Urban Planning, National Cheng-Kung University, Tainan 701, Taiwan

Abstract

With the idea of sustainable agriculture, farming is not only about the production for food security but also need to consider the impacts for the environment during farming process. Environment issue needs to be considered more for the high-altitude agriculture as they often are located at the reservoir catchment areas which are important for conserving the water resources. There are always conflicts between high-altitude agriculture development and environmental conservation. Because of the extreme climatic events, find out the balance between these two issues becomes an urgent target for the government recently.

Thus, data envelopment analysis (DEA), which can evaluate the decision-making unit with multiple inputs and multiple outputs, was applied to assess economic and environmental factors in this research. The results of farm environmental efficiency score present the land use efficiency of each village under these two conflict issues. It can help government to reveal the un-efficiency area which should be improved first. Furthermore, the slack analysis of DEA reveals that reduction of pollution is the most important issue in the area.

Keywords: Farm development efficiency, eco-efficiency, undesirable output, data envelopment analysis (DEA)

1. Introduction

In the last few decades, agriculture and food security became important issues because of the problems caused by global climate change. For a long term goal, sustainable agriculture is what people want to achieve.

* Corresponding author. Tel: +886-6-2342373 #23; fax: +886-6-2754943
E-mail address: z10010058@email.ncku.edu.tw
It not only needs to consider about the macroeconomics and provision, but also the environment issues such as water conservation, soil protection...etc. are also need to be concerned. (Y.C., Lin et al., 2013; A.J., Picazo-Tadeo et al., 2011.)

Limited land resources in Taiwan have resulted in the conversion of many agricultural production areas into built-up areas through urbanization, and more farming activities could not help but move to area at elevations above 500 meter which called high-altitude agriculture. It was increased by 9665 ha (16.9%) from 1995 to 2006 (Y.C., Lin et al., 2013). Some soil loss and runoff were caused by this change and the extreme climatic events made it even more serious. However, most of high-altitude areas are reservoir catchment areas for conserving the water resources in Taiwan. However, it is always difficult to find out the balance between high-altitude agriculture development and environmental conservation. Thus, this research intends to assess both economic and environment factors by farming environmental efficiency.

2. Materials and methods

2.1. Empirical research area

The study area is in south Taiwan, which has experienced increasing flood events that caused severe damage in the past decade. With global environmental change, the assessment of the environmental impacts and efficiency problems is worthy of our attention. The research area is located in the southwest of Taiwan (E120.3251’~120.9576’, N23.0487’~23.5864’) (see Fig.1(a)). The distribution of land use in 2004 is showed as Fig.1(b), forest land covers the largest area(106481 ha, 70.76%), followed by agriculture use land(27905 ha, 18.54%), other use land(7287 ha, 4.84%), water conservation use land(5547 ha, 3.69%), transportation use land(1446 ha, 0.96%), built-up use land(1325 ha, 0.88%), amusement and rest use land(296 ha, 0.20%), public facility use land(167 ha, 0.11%) and rock salt use land(28 ha, 0.02%).

2.2. DEA with undesirable output

DEA is a multivariate analysis technique for relative efficiency, which can evaluate the decision-making unit with multiple inputs and multiple outputs (Thanassoulis, 1993). As a characteristic of DEA, no prior
knowledge of the production function between the input and output attribute data is required, and no relative weight needs to be set for the attribute data. It is a nonparametric mathematical programming model, and its economic significance indicates the boundary consisting of all of the best possible points. In the concept of the Pareto optimum, the ex post data are used to assess the efficiency. The relative efficiency is assessed by the approach of establishing an efficiency frontier (Bevilacqua and Braglia, 2002).

In accordance with the global environmental conservation awareness, undesirable outputs of productions, e.g., water and air pollutants are being increasingly recognized as dangerous and undesirable. In the presence of undesirable outputs, however, there are often situations that desirable outputs are allowed to be increased and at the same time, while undesirable outputs are allowed to be decreased. So modeling undesirable factors in data envelopment analysis is very important and several authors (Guo and Wu, 2013; Li et al., 2013; Wu et al., 2013) have proposed methods for this purpose.

2.3. **Analysis unit**

Four basic principles were developed to select the spatial analysis units, including the significance of a standard measurement for efficiency assessment and the practical applicability of planning, which reflect the development characteristics of the area for empirical research and meet the restrictions for the number of units for evaluation and decision making. A total of 58 villages, the smallest administrative region in Taiwan, were considered as the decision-making units (DMUs) of analysis.

2.4. **Input and output indicators**

In the process of efficiency evaluation, the selection of representative indicators as the input and output is both very important and difficult (Bosetti and Locatelli, 2006). Due to the complexity of reservoir catchment area, the factors of inputs and outputs between the socio-economy and the environment are often difficult to define.

The major considerations for selecting the indicators are: the indicators related to framing, the indicators for the environmental impact of high-altitude agriculture, the characteristics of the spatial scale in a village, and the representation and usability of data analysis. The outputs are income and production which represented provision of agriculture, and pollution is set for an undesirable output which cause by the farm chemicals. The inputs are agriculture household, farm area and employee (for farming activities). All the data are mainly collected from 2005 Agricultural, Forestry, Fishery and Husbandry Census. (See Table 1.)

| Table 1. Input and output indicators for DEA analysis of efficiency |
|---|---|---|---|---|---|
| **Indicators** | **Units** | **Mean** | **Min** | **Max** | **Std. dev.** |
| **Input** | | | | | |
| (I) Agriculture household | 58 | 169.64 | 5.000 | 358.0 | 82.32 |
| (I) Farm area | 58 | 270.99 | 4.760 | 683.8 | 145.02 |
| (I) Employee | 58 | 381.19 | 9.000 | 877.0 | 214.42 |
| **Output** | | | | | |
| (O) Income | 58 | 83791.60 | 8120.000 | 419878.0 | 83195.55 |
| (O) Production | 58 | 49005.34 | 3650.000 | 219660.0 | 40347.67 |
| (OBad) Pollution | 58 | 0.81 | 0.001 | 4.2 | 1.04 |
3. Result

3.1. Scores of efficiency

The efficiency values calculated with DEA were the relative values ranging from 0 to 1. To compare the difference of the efficiencies of the 58 villages more clearly, the value of efficiency was converted to a percentage for the analysis in this study.

The average efficiency score of the 58 villages was 43.12%, with a maximum efficiency value of 100% and a minimum of 11.62%. A total of 12 villages (20.69%) had an efficiency of 100%. They are Shuilin, Jiadong, Longhu, Guantian, Shenmu, Yongle, Zhonghe, Zhongsha, Zhongzhe, Abangu, Leye and Taihe.

3.2. Patterns and slack analysis of environmental efficiency

When the number of DMUs with differences in a certain input or output indicator increased, most of the DMUs must be able to improve farming environmental efficiency by an increase or decrease of some indicators. Such indicators are the relatively more important indicators for the improvement of the overall efficiency of farm development, and also the reference for subsequent management and improvement strategy.

Therefore, to understand the importance of the direct input and output indicators with effects on the efficiency, the number of DMUs with improvable differences in 6 indicators of inputs and outputs was calculated. The proportion of this DMU number in the total number of 58 DMUs was further calculated and used as the reference to determine the indicators for efficiency improvement. When an increasing number of DMUs had a difference in a certain input or output indicator, this indicator was the focus of efficiency improvement for the future; that is, the reduction in value of the input indicators or the increase in value of output indicators in the future will contribute to the improvement of efficiency value of a DMU.

Based on the calculated difference between the variables, the important indicators of future efficiency improvement were the improvement of the pollution (79.31%), the reduction in farmhouse (77.59%), farm area (77.59 %), employee (77.59 %), and the increase in income (20.69 %) and production (15.52 %).

Fig. 2. (a) Spatial pattern of efficiency score; (b) Distribution of pollution slack
From the viewpoint of environmental protection and development efficiency, the reduction of pollution is the most important issue in this area. In the future, 7 villages nearby reservoirs should try to decrease the pollution to improve the environmental efficiency of farm and make this area to be more sustainable. They are Daqi(41.93 ha/km²), Wangye(28.35 ha/km²), Xixing(18.89 ha/km²), Yushan(14.70 ha/km²), Wanqiu(13.78 ha/km²), Nanshi(12.52 ha/km²) and Mizhi(10.37 ha/km²).

4. Conclusion

Farming environmental efficiency can analyze economic and environment factors at the same time, and find out the most efficiency land use under these two conflict issues. It not only can assess farming production and the resource consumption, but also the undesirable production during farming process, such as pollution. One the other hand, it can consider both people’s request for living and environment conservation. Besides, it is impossible for the government to improve whole reservoir catchment area at the same time, as the limited of budget. According to the result of spatial pattern of efficiency score, the government can improve the villages which get the lower efficiency score first.

With more disaster caused by extreme climatic events, government is trying to reduce farming activates in catchment area by withdraw lands, and it always caused serious protest from the local people. However, the slack analysis reveals that reduction of pollution is the most important issue in the area, and it may be the short-term goal to improve the efficiency value of the village.

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