Measurement and Analysis of Ecological Efficiency in Fujian Province Based on DEA-Malmquist Index Model

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Abstract. Under the new normal, the economic growth model of resource and environment consumption is unsustainable, and improving ecological efficiency has become an inevitable choice for high-quality economic development. Based on this, on the basis of constructing the input-output evaluation system of ecological efficiency at the city scale, this study uses DEA-Malmquist model to calculate the ecological efficiency and its dynamics of 9 cities in Fujian Province from 2009 to 2018. The results show that there are differences in ecological efficiency among different regions in Fujian Province, and the ecological efficiency of Fuzhou, Xiamen and Ningde all reach the best level. The ecological efficiency of inland areas in Fujian Province is obviously lower than that of coastal areas such as Fuzhou and Xiamen, which indicates that the coordination between inland areas and coastal areas should be strengthened. In addition, the coordination degree of regional production management and technological progress in Fujian Province is not high. Therefore, when the governments at all levels of Fujian Province plan the industrial development strategy, they should fully consider the development path suitable for improving the ecological efficiency, and finally realize the development strategy that green water and green mountains are the golden mountains and silver mountains.

Keywords: Data envelopment analysis method, Malmquist index, Regional ecological efficiency, City scale.

1. Introduction

China's economy has entered a new stage of high-quality development. The protection of "green water and green mountains" is an important connotation of high-quality development. With the rapid development of urbanization and industrialization, driven by short-term economic interests, the problems of resource shortage, environmental pollution, ecological degradation are more prominent, which have become the bottleneck restricting the sustainable development of regional economic system [1]. Therefore, in the current period of social and economic transformation, how to coordinate the relationship among economic development, resource conservation and ecological protection, and clarify the key factors and the importance of regional ecological efficiency is particularly important.
The term "ecological efficiency" was first put forward by Sturm in 1989 [2]. It is an important indicator to measure the coordination degree and sustainable development level of economy resource environment composite system [3]. Specifically, ecological efficiency can be understood as the ability to produce more products and services with less resource consumption and less environmental cost [4]. At present, ecological efficiency has become an environmental performance measurement tool with great policy significance. Domestic and foreign scholars' research on ecological efficiency mainly focuses on the following aspects: (1) Construction of ecological efficiency evaluation index. For example, Chen et al., (2019) used employment, fixed assets investment and total energy consumption to represent resource consumption [5]. Liu Yang et al. (2019) incorporated technology input elements into the resource consumption layer, further enriching the resource input system [6]. (2) Ecological efficiency measurement method. The most commonly used measurement methods are data envelopment analysis (DEA)[7], SBM model and stochastic frontier model (SFA) [8]. For example, Hu Weiwei et al. (2017) used DEA model to calculate the ecological efficiency of 9 cities in Fujian Province from 2006 to 2014 [9]. Qiu Lixin et al. (2020) used Super-SBM model to quantitatively measure the ecological efficiency of 69 counties in Zhejiang Province from 2010 to 2018 [3]. Yang Chen calculated the industrial ecological efficiency of 31 provinces in China based on DEA Malmquist model and its convergence [10]. (3) Application practice of ecological efficiency. It is found that the underdeveloped urban network has a negative effect on the ecological balance of urban areas [11]. It can be seen that the existing literature on ecological efficiency research results are relatively rich, which provides an important reference for us to further explore the ecological efficiency of Fujian Province. However, through literature review, it is found that there are still the following aspects that can be optimized: first, the regional research object focuses on the large-scale macro level, and the research of small and medium-sized cities and counties is still insufficient; second, the research of Fujian Province is less. On the other hand, it is impossible to identify the single factor and double factor that lead to the improvement of regional ecological efficiency.

Fujian Province, as the first ecological civilization experimental area in China, is also one of the earliest provinces to implement the reform and opening-up policy. In recent years, due to its rapid urbanization and industrialization process, coupled with unreasonable resource consumption, human activities and too many short-term economic behaviors, the ecological environment in local areas of Fujian has been affected to varying degrees [12]. Therefore, Fujian Province, which has relatively limited endowment of ecological resources, is still very dependent on resource consumption, especially non-renewable resource consumption [13]. How to ensure economic growth, continuously improve people's living standards and protect the quality of ecological environment is a topic worthy of our in-depth study. Therefore, this study takes 9 cities in Fujian Province as research objects, and uses DEA-Malmquist index model to quantitatively measure the ecological efficiency level of Fujian Province from 2009 to 2018, in order to provide scientific basis for the coordinated development of regional economy and ecology.

2. Research methods and data sources

2.1. Index system of ecological efficiency measurement

Ecological efficiency emphasizes to obtain more economic output and ecological protection with less resource consumption and environmental pollution. Therefore, according to the principles of scientificity, comprehensiveness, objectivity and quantification, and referring to previous studies, this study constructed the regional ecological efficiency evaluation index system as shown in Table 1.
Table 1 Eco-efficiency evaluation index system at the municipal scale in Fujian Province

| Indicators       | Category            | Concrete composition                                                                 | Indicator description                                      |
|------------------|---------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------|
| Input index      | Resource efficiency | Land efficiency                                                                      | Total GDP/land area of construction area                   |
|                  |                     | Water efficiency                                                                      | Total GDP/total water consumption                          |
|                  |                     | Energy efficiency                                                                     | Total GDP/energy consumption                              |
|                  |                     | Labor efficiency                                                                       | Total GDP/employment                                       |
|                  |                     | Exhaust emission rate                                                                 | Total GDP/ SO2, NOx, smoke (dust) emissions                |
| Output indicators| Environmental efficiency | Wastewater discharge rate                                                                 | Total GDP/industrial wastewater discharge, chemical oxygen demand COD |
|                  |                     | Comprehensive utilization rate of solid waste                                        | Solid waste utilization/solid waste generation and storage in previous years |
| Economic value   |                     | Regional GDP                                                                          | Regional GDP in                                           |

2.2. DEA model

Charnes et al. put forward the concept of data envelopment analysis (DEA) in 1978. Traditional CCR model was put forward by Charnes, Cooper and Rhodes in 1978 to evaluate the scale and technical effectiveness of DMU. BCC model is established on the basis of CCR model, which is suitable for the case of variable returns to scale. In order to ensure the rigor of the study, this study adopts the BCC model of dual type under the guidance of input, and its calculation formula is as follows:

\[
\begin{align*}
\min \{ \theta \} \\
\sum_{j=1}^{n} X_j \lambda_j + S^- = \theta X_{j0} \\
\text{s.t.} \sum_{j=1}^{n} Y_j \lambda_j - S^+ = Y_{j0} \\
\sum_{j=1}^{n} \lambda_j = 1 \\
\lambda_j \geq 0; S^- \geq 0; S^+ \geq 0
\end{align*}
\] (1)

In the formula, \( X_{j0} \) represents \( j_0 \) DMU input vectors, \( Y_{j0} \) represents \( j_0 \) DMU output vectors, \( \theta \) represents input reduction ratio, \( \lambda \) represents the coefficient of linear combination of decision-making units, and \( S^- \) and \( S^+ \) represent input redundancy rate and output shortage rate, respectively. If \( \theta=1, S^- = S^+ =0 \), then the \( j_0 \) unit is called DEA valid. If \( \theta=1 \), \( S^- \) and \( S^+ \) have non-zero values, then the \( j_0 \) unit is called DEA weakly effective. If \( \theta<1 \), then the \( j_0 \) unit is called DEA invalid.

2.3. Malmquist Index

In order to make up for the defect that DEA model can only measure body efficiency statically, Malmquist index is used in this study to deeply analyze the dynamic changes of regional ecological efficiency. Malmquist index is a method to measure the total factor productivity (TFP) of decision-making units from a dynamic perspective, which indicates the change of production efficiency from \( T \) to \( t+1 \). It decomposes regional ecological efficiency into pure technical efficiency, scale efficiency and technological progress, among which pure technical efficiency and scale efficiency constitute comprehensive technical efficiency [15]. The model is as follows:
\[ M_{0}^{t+1} = \left[ \frac{D'(x_{0}^{t}, y_{0}^{t+1})}{D'(x_{0}^{t}, y_{0}^{t})} \times \frac{D'^{t+1}(x_{0}^{t+1}, y_{0}^{t+1})}{D'^{t+1}(x_{0}^{t}, y_{0}^{t})} \right]^{\frac{1}{2}} \]  

(2)

In the formula, \((x_{0}, y_{0})\) and \((x_{0}^{t+1}, y_{0}^{t+1})\) represent the vector of input and output from \(t\) to \(t+1\), \(D'(x_{0}^{t}, y_{0}^{t+1})\) represents the eco-efficiency level of the \(t+1\) period expressed by the technical level of the \(t\) period, and \(D'^{t+1}(x_{0}^{t+1}, y_{0}^{t+1})\) represents the ecological efficiency level of the \(t+1\) period. The technical level of the period represents the current ecological efficiency level.

2.4. Data source
The data of this study mainly come from the statistical yearbook of Fujian Province, Water Environment Bulletin of Fujian Province and statistical yearbook of Chinese cities. Considering the availability, continuity and feasibility of the data, the sample of this study is the panel data of nine cities in Fujian Province from 2008 to 2018.

3. Research results and analysis

3.1. Static analysis of urban ecological efficiency
According to formula (1), the ecological efficiency level of 9 cities in Fujian province was measured by using MaxDEA 8.0 operation platform, as shown in table 2.

| Area     | Comprehensive technical efficiency | Pure technical efficiency | Scale efficiency | Trend   |
|----------|-----------------------------------|----------------------------|-----------------|---------|
| Fuzhou   | 1.000                             | 1.000                      | 1.000           | -       |
| Xiamen   | 1.000                             | 1.000                      | 1.000           | -       |
| Putian   | 0.997                             | 1.000                      | 0.997           | Decline |
| Sanming  | 0.916                             | 1.000                      | 0.916           | Rise    |
| Quanzhou | 0.979                             | 1.000                      | 0.979           | Rise    |
| Zhangzhou| 0.896                             | 1.000                      | 0.996           | Decline |
| Nanping  | 0.947                             | 0.995                      | 0.952           | Rise    |
| Longyan  | 0.882                             | 0.956                      | 0.965           | Decline |
| Ningde   | 1.000                             | 1.000                      | 1.000           | -       |
| Mean value| 0.961                             | 0.994                      | 0.978           |         |

It can be seen from table 2 that the average comprehensive technical efficiency (i.e. ecological efficiency) of Fujian Province is 0.961, which indicates that there is still room for progress. In terms of comprehensive technical efficiency, the efficiency of Zhangzhou and Longyan is significantly lower than that of other cities, and the improvement measures need to be strengthened in this area, while the other seven cities should be optimized to the best ecological efficiency on the basis of maintaining the existing level. Among them, only Fuzhou, Xiamen and Ningde are DEA efficient (its comprehensive technical efficiency is 1), which shows that the input and output of these regions are optimal. From the perspective of ecological scale efficiency: Quanzhou, Sanming and Nanping are on the rise, which shows that the ecological construction in these areas has improved. On the contrary, Putian, Zhangzhou and Longyan showed a downward trend. Therefore, the three cities need to further integrate various resources to achieve the best scale efficiency and improve the ecological scale. In addition, except Nanping and Longyan, the pure technical efficiency of the other seven cities is 1, which shows that the conversion rate of ecological science and technology is better. Therefore, all regions should strengthen technical input, strengthen communication with each other, learn from the measures of the best level.
regions, and make up for the shortcomings, so as to improve the ecosystem and achieve the best level of scale efficiency.

In addition, according to the level of relative DEA inefficiency, the cities in Fujian Province can be divided into two levels: the first level is slightly non-DEA efficiency, and the measure standard is that the ecological efficiency value is above 0.9, including Nanping, Sanming, Quanzhou and Putian; The second layer is medium non-DEA efficiency, and the measure standard is ecological efficiency value between 0.85 and 0.9, including Zhangzhou and Longyan.

3.2. Dynamic analysis of urban ecological efficiency
In order to better analyze the dynamic change process of ecological efficiency in 9 cities in Fujian Province, Malmquist index model was constructed to further analyze it, and the results are shown in Figure 1.

![Figure 1](image-url) The average annual Malmquist index and its decomposition efficiency in Fujian Province from 2009 to 2018

As shown in Figure 1, the value of technological progress has little change on the whole, basically floating around 1.000. It can be seen that the achievements of science and technology investment in ecological construction in Fujian Province are relatively stable in recent years. The net technical efficiency value is 1.000 in most years, but it decreases in some years, and the net technical efficiency value is relatively low in some years. This shows that the production management level of Fujian has not significantly improved the ability of technological progress. Compared with the other three indicators, the value of technical efficiency fluctuates more obviously, which indicates that the degree of technological change is larger, which can indirectly reflect the continuous replacement of technology. In addition, the scale efficiency of each year changes around 1.000, with little difference between them, indicating that the actual production scale is close to the optimal scale, and the value of more than half of the years is more than 1, indicating that the production scale has reached the optimal level or even exceeded the optimal level. On the whole, the ecological efficiency of Fujian Province has fluctuated over the years, and we can see that we attach importance to ecological efficiency and strive to achieve and maintain the optimal level.
4. Main conclusions and policy recommendations

This paper uses DEA model and Malmquist index analysis, based on the input-output panel data of Fujian Province from 2009 to 2018 to calculate the ecological efficiency of Fujian Province.

(1) There are differences in the level of ecological efficiency among regions. This study found that the ecological efficiency of Fuzhou, Xiamen and Ningde reached the best level, and the number of regions was one third of that of Fujian Province. However, two-thirds of the cities have invalid DEA. In addition, the ecological efficiency of inland areas in Fujian Province is significantly lower than that of Fuzhou, Xiamen and other coastal areas, which indicates that the regional coordination between inland areas and coastal areas needs to be strengthened. Therefore, all regions should make full use of their own advantages in resources and environment, improve the level of economic green growth and improve the unbalanced state of regional green development. At the same time, all regions should strictly abide by the standards of relevant indicators of environmental protection, implement environmental protection measures from details, strictly control industrial pollution emissions, investigate and change the emissions of over-standard factories, and improve the comprehensive utilization rate of the three wastes. In addition, while protecting the environment, we should take appropriate measures to deal with environmental construction and create a good ecological environment. Implement the reward and punishment system, reward and protect and actively respond to the behavior of ecological civilization construction, and punish some areas or departments for inaction for economic interests.

(2) The coordination degree of regional production management and technological progress in Fujian Province is not high. The average value of pure technical efficiency of nine cities in Fujian Province is 0.982, which is lower than the average value of the change index of technological progress, indicating that the coordination degree of production management and technological progress in the construction of ecological civilization in Fujian Province needs to be further strengthened. Generally speaking, all regions should continue to maintain the correctness of resource allocation, improve ecological efficiency, improve the conversion rate of science and technology investment, and constantly improve the level of specialization. The industrial development model under ecological civilization is different from the traditional industrial development model. Therefore, in ecological construction, we should increase investment in scientific research and development, encourage the development of relevant technological innovation mechanisms, and reduce the ecological environment burden in the process of economic development through scientific and technological innovation. At the same time, when planning the industrial development strategy, we should fully consider taking the development path suitable for improving ecological efficiency, and finally realizing green water and green mountains is the development strategy of Jinshan Yinshan.

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