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Environmental efficiency analysis of the Yangtze River Economic Zone using super efficiency data envelopment analysis (SEDEA) and tobit models

Nengcheng Chen [a, b, *], Lei Xu [a], Zeqiang Chen [a]

[a] State Key Laboratory of Information Engineering in Surveying, Mapping, and Remote Sensing, Wuhan University, Wuhan 430079, China
[b] Collaborative Innovation Center of Geospatial Technology, Wuhan 430079, China

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A B S T R A C T

Environmental efficiency (EE) assessment is an efficient way to evaluate the degree of coordination between economy and environment. Most of the studies measured country- or region-level EEs, while the EE disparities among cities were not well investigated. By incorporating the socioeconomic and remote sensing data, this study measured the static and dynamic EEs of 11 provinces and 131 cities in the Yangtze River Economic Zone (YREZ) in China based on a super efficiency data envelopment analysis (SEDEA) and Malmquist index (MI) methods during 2003–2014. The influential factors of EE imbalance in the YREZ area were explored by the panel tobit model. Results show that large gaps exist in city's environmental efficiency. Cities in the Yangtze River Delta (YRD) show higher EEs than that in the Chengyu Urban Agglomeration (CUA) and Urban Agglomeration in the Middle Reaches of the Yangtze River (UAMR) areas. 15 cities have an EE below 0.2 and only 2 cities above 1 in 2014. The overall average EE exhibited a declining trend during 2003–2014. The number of cities below the average environmental efficiency increased from 70 (53.4%) to 83 (63.4%) over the time period studied. The MI results indicate that management and scale optimization level is the main factor hindering total factor productivity (TFP) growth. The tobit experiment reveals that GDP per capita played a negative impact on EE for most of the YREZ area during 2003–2014. The degree of opening up and industrial structure acted positively on city's environmental efficiency. These conclusions may be a helpful reference for decision makers to coordinate the economy and environment in the YREZ area.

1. Introduction

On September 25, 2014, the State Council of China announced the Guidance [1], which relies on the golden waterway to promote the development of the Yangtze River Economic Zone (YREZ). This guidance issued a series of measures to accelerate the extension of the economic growth space from coastal to inland areas and build a new support region for the Chinese economy. However, in recent years, environmental pollution has become a serious problem thwarting social and economic sustainable development. Under the new round of reform and development boom, the Chinese government needs to pay more attention to both economy and environment to create a coordinated, interactive, efficient and advanced YREZ demonstration area.

China's economy has grown, with an annual average Gross Domestic Product (GDP) growth rate of 9.5% over the past two decades [2]. The rapid economic development also brings a series of environmental issues. In recent years, long-lasting, severe smog and fog haze have occurred in many cities in China, especially in January 2013 [3] due to energy consumption and pollutant emissions. China accounted for one-quarter of global carbon dioxide (CO_2) emissions in 2011 and 80% of the world's rise in CO_2 emissions since 2008 [4]. The Chinese government has released some environmental regulations and laws to protect the environment. However, it seems hard to ease the heavy environment stress in the context of enormous economic growth. How to effectively enhance both economic development and environmental protection

* Corresponding author. State Key Laboratory of Information Engineering in Surveying, Mapping, and Remote Sensing, Wuhan University, Wuhan 430079, China.
E-mail address: cnc@whu.edu.cn (N. Chen).

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remains a problem in China.

Environmental efficiency (EE) evaluation is an efficient way to assess the degree of coordination between economy and environment. Understanding the coordination degree would be helpful for the regional industrial transfer, development planning and industrial cooperation. This study aims to evaluate the regional disparities of EE and explore the influential factors of them in the YREZ area. The rest of the paper is organized as follows. Section 2 reviews some relevant studies on environmental efficiency. Section 3 describes the methods, data and variables used in this study. Section 4 discusses the empirical results and Section 5 concludes this study.

2. Literature review

In recent years, how to effectively promote economic development without destroying environment has attracted much attention. Environmental efficiency, proposed by World Business Council for Sustainable Development (WBCSD) in 1992 [5], is a comprehensive index measuring the environmental impact accompanied with economic development. The basic concept of environmental efficiency refers to the ratio of economic products or services and environmental resources consumption or emissions. This concept highlights that pursue of economic development should not rely on the cost of environmental deterioration.

Environmental efficiency assessment is one of the most important ways to quantitatively evaluate the performance of and interaction between economy and environment. Many efficiency analysis techniques have been proposed to calculate environmental efficiency. Based on the production possibility frontier theory, these methods can be mainly divided into two types: parametric and nonparametric. The representatives of the parametric and nonparametric methods are stochastic frontier analysis (SFA) [6,7] and data envelopment analysis (DEA) [8,9], respectively. SFA employed regression analysis to estimate the relationship between inputs and outputs. The efficiency of peer decision making units (DMUs) is decomposed into two parts: a stochastic error term and a systematic inefficiency term. In contrast to SFA, DEA method does not need to specify the functional relations between inputs and outputs. DEA is a nonparametric approach for measuring the relative efficiency of DMUs that have multiple inputs and outputs. Compared with SFA, DEA is easier to use in various circumstances with multiple variables [10–14].

In the traditional DEA model, the undesirable outputs (e.g. pollutants) in the production processes are not considered. However, the comprehensive EE evaluation should incorporate undesirable outputs and minimize them [15] as they are harmful to the environment. When taking the undesirable outputs into consideration, we should minimize the inputs and maximize the desirable outputs and at the same time, reduce the emissions of undesirable outputs as much as possible. Färe et al. [16] proposed a nonparametric DEA approach to deal with undesirable outputs based on the weak disposability of inputs and outputs. The weak disposability assumes that reducing of undesirable outputs would reduce desirable outputs as well in some degree. Another technique to deal with undesirable outputs is to take them as environmental inputs [17–19] because emissions such as carbon dioxide (CO_2) can also be regarded as a kind of resource consumption. The third way to model the undesirable outputs is to transform the undesirable data into desirable outputs first, and perform EE analysis using the traditional DEA [20]. This way suffers from convexity constraints and can only be applied under VRS assumption [21].

The Charnes-Cooper-Rhodes (CCR) DEA [8] is a linear programming model to measure EE under the assumption of constant returns to scale (CRS). The CRS condition assumes that the ratio of increased production is equal to the ratio of increased factors of production, while the Banker-Charnes-Cooper (BCC) DEA [9] assumes variable returns to scale (VRS). For both the CCR and BCC models, the efficiency scores fall between 0 (worst) and 1 (best). The traditional CCR-DEA model cannot clearly discriminate between these DMUs when they are simultaneously on the frontier of production, often leading to difficulty in further evaluations and comparisons. Andersen and Petersen [22] proposed a super efficiency DEA (SEDEA) method to distinguish efficiency among efficient DMUs and then sort their relative efficiencies. The SEDEA method was developed and used in numerous studies [23–26].

DEA approach measures the relative efficiency among different DMUs at a specific time. However, it cannot measures efficiency changes by years. The Malmquist productivity index (MI) [27,28] was proposed to measure the total factor productivity (TFP) growth between two different periods. Technological progress and technical efficiency were regarded as two main factors driving TFP change. Technical efficiency can further be decomposed into pure technical efficiency and scale efficiency, representing managerial and scale levels, respectively. Therefore, in addition to DEA method, the MI approach was also used in this study.

Numerous literature have studied environmental efficiency using the DEA method. Table 1 listed some of the existing studies on environmental efficiency. The majority of them focused on the country-level or provincial-level EEs, while few of them paid much attention to the city-level EE analysis. Understanding city-level EEs can help us gain a better understanding of regional imbalance, which is beneficial for making decisions towards regional development strategy, especially for economic zones. There are also some researchers focusing on city-level EE assessment. Wang et al. [29] measured the EEs of 211 cities in China in 2008 from a perspective of environmental protection and economic development based on meta-frontier and DEA methods. Regional EEs between provinces were investigated and five-tier EE groups were obtained. However, the efficiency gaps or disparities among cities were not clear and the inter-annual EE variations were not analyzed. Wang et al. [30] studied the energy-saving and emissions reduction performance in 209 Chinese cities in 2008, but the specific cities were not given to see clearly the EE distributions and variations. And the dynamic environmental efficiency by years was not explored.

In order to gauge a clear picture of city-level EE differences, especially for the YREZ area, this study measured the static and dynamic EEs for both provincial- and city-level areas during 2003–2014 based on the SEDEA and Malmquist index (MI) methods. The SEDEA method can further compare the efficient DMUs whose efficiency scores are all 1 in the traditional DEA models. The potential factors contributing to regional and city-level EE disparities were explored using the panel tobit model. Song et al. [31] studied the EEs of 29 provinces in China during 1998–2009 based on slacks-based measure (SBM) DEA and tobit approaches, and the findings indicated that GDP per capita plays a positive impact on environmental efficiency. In this study, the results showed just the opposite. The conclusions indicate that GDP per capita acted negatively on environmental efficiency in the YREZ area during 2003–2014. Besides, different from the general undesirable outputs (CO_2, SO_2 and waste) in the existing literature (Table 1), we incorporated ground-level fine particulate matter (PM2.5) from aerosol optical depth (AOD) retrievals to reflect the environmental impacts because the statistical data in emissions may not be accurate due to emission factors uncertainty [32]. The surface PM2.5 concentrations measured by in-situ sensors or satellite instruments may truly represent the environmental status under economic activities.