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The efficiencies of resource-saving and environment: A case study based on Chinese cities

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A B S T R A C T

In spite of its rapid economic development, China is faced with serious issues of resource shortage and environmental pollution. This paper is aimed at exploring the issues of resource shortage and environmental pollution in Chinese cities by means of efficiency evaluation. Through the Super-efficiency general directional distance function (GDDF) model, this paper calculates the urban efficiencies of resource-saving (UERS) of 197 Chinese cities from 2011 to 2015. Furthermore, considering the environmental problems, it applies the Super-efficiency GDDF model with undesirable outputs, and accesses the urban efficiencies containing environmental factors (UEEF). The empirical results are listed as follows. (1) Most of the Chinese cities exhibited comparatively low UERS and UEEF, indicating great potential for the reduction of resource consumption and environmental pollution; (2) Those groups with higher levels of resource-saving efficiency tend to have poorer environmental efficiency. This means that many cities achieve good economic performance at the expense of the environment; (3) In order to realize the sustainable economic and social development, we should not only save resources, but also reduce the emission of pollutants.

1. Introduction

Along with the rapid development of economy, China's urbanization has undergone a period of swift growth since the introduction of the reform and opening-up policy. According to the National Bureau of Statistics of China, the permanent population in urban areas has increased from 302.0 million to 771.1 million from 1990 to 2015 (the urban population proportion calculated has increased from 26.4% of all to 56.1%) [1]. However, the contradiction among urban development, resource shortage and environmental pollution is becoming increasingly acute. With the rapid urban development, the problems of resource shortage and environmental pollution have become increasingly serious. For example, the dependence on imported crude oil increased to more than 50% in 2009, which is the international security cordon [2]. According to BP Statistical Review of World Energy, China's coal consumption, the highest of all countries, constituted about 50.01% of global coal consumption in 2015 [3]. And in the December of 2016, nearly one-third of China's land area was affected by haze, with up to 108 prefecture-level cities reaching the level of "heavy pollution", thus taking its toll on the lives of Chinese residents [4].

Therefore, how to save the resource and protect the environment during the fast growth of Chinese cities has become a hotspot issue. The Chinese government has paid close attention to making policies, regulations and standards with regard to resource-saving and environmental protection. The central government proposed the concept of green development in the thirteenth Five-year Plan for Economic and Social Development of the People's Republic of China and further formulated the thirteenth Five-year Plan for Ecological Environmental Protection of China [5,6]. In the thirteenth Five-year Plan for Ecological Environmental Protection of China, the key technology of resource recycling and the concept of balance sheet of natural resources are proposed to save natural resources. Also, abundant restrictive environmental indicators are

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raised in the plan to increase the level of ecological civilization. For example, one of the indicators states that the ratio of superior air quality days of the year in cities at the prefectural or higher levels should be increased to 80% by 2020 [6]. Besides, local governments have also started contributing more concrete strategies to respond to the call of the central government.

Sustainable development is defined by the Bruntland report as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" [7]. It looks increasingly crucial to look at the topic of sustainable development from the perspective of cities. Main human activities, such as economic and residential activities, happen in cities where most energy is consumed and most waste and pollutants are produced. Therefore, it is much more efficient to deal with this problem from a city level [8]. Successful cities must develop a mutually beneficial relationship between economic development and the environment.

Considering the importance of resource and environment for regional development, various scholars have begun to study the efficiency of resource and environment from different perspectives. A large quantity of research methods are applied to estimate the efficiency of resource or environment, such as Analysis Hierarchy Process (AHP) [9,10], Stochastic Frontier Analysis (SFA) [11–13], Multiple Regression Model [14,15] and so on. Nevertheless, an increased number of scholars started adopting Data Envelopment Analysis (DEA) models to evaluate the efficiency of resource and environment performances. DEA, a non-parametric approach to evaluate the relative efficiencies of a set of decision making units (DMUs), is first proposed by Charnes, Cooper [16]. Compared with other methodologies, the main advantage of DEA is that it does not require the assumption that there are some functional relationships between inputs and outputs [17].

In terms of resource efficiency, most of the existing literature focus on energy resources. Hu and Wang [18] introduced a new index of total-factor energy efficiency (TFEE) by using DEA and analyzed energy efficiencies of 29 administrative regions in China for the period 1995–2002. The TFEE index rankings confirm the scenario that energy efficiency can eventually improve with economic growth. Honma and Hu [19] accessed the regional total-factor energy efficiency (TFEE) of 47 prefectures in Japan during 1993–2003 by employing the DEA, and discovered that energy efficiency and per capita income show a U-shaped relation which is similar to the environmental Kuznets curve (EKC). Cui, Kuang [20] applied DEA and Malmquist index to compute energy efficiencies of nine countries during 2008–2012, and then analyzed the important influencing factors of energy efficiency by the Regression model. Rather than investigating the energy efficiencies of countries or regions, other scholars employ DEA models to analyze specific industrial sectors or companies. Wei, Liao [21] applied DEA Malmquist Index Decomposition to access energy efficiency of China's iron and steel sector during the period1994–2003. Azadeh, Amalnick [22] evaluated the energy efficiency of some energy intensive manufacturing sectors by applying DEA, and the assessment of DEA model is verified by principal component analysis (PCA) and numerical taxonomy (NT). Hernández-Sancho, Molinos-Senante [23] adopted a non-radial DEA model to evaluate the energy efficiency in Spanish wastewater treatment plants, and found that the differences among the plants depended on plant size, quantity of organic matter removed and type of bioreactor aeration. Cui and Li [24] calculated the energy efficiencies of 11 airlines from 2008 to 2012 by employing the Virtual Frontier Benevolent DEA Cross Efficiency model.

On the city's environmental efficiency, the core issue that the existent literature focus on is how to deal with the environmental pollutants. The existent ways to handle environmental pollutants, which are regarded as the undesirable outputs, can be divided into the following five main types. (1) Regarding the undesirable outputs as the inputs [11]. (2) Transforming undesirable outputs into desirable outputs by different functions [25]. (3) Hyperbolic measure using the reciprocal transformation of undesirable outputs [26]. (4) Slack-based measure (SBM) model [27]. (5) A DEA model based on the directional distance function (DDF) [28]. The first method doesn't reflect the real production process although it can make the undesirable outputs own the property of "the litter, the better" [25]. The second method can only be used under variable returns to scale because of the strong convexity constraints [29]. The hyperbolic measure can be calculated by approximate linear mathematical programming model, but the result may be biases [26]. And the SBM model lacks translational invariance and ignores the radial characteristics of inputs and outputs [30].

The DDF model has the widest application in environmental efficiency [31–33]. It allows us to expand desirable outputs and reduce inputs and/or undesirable outputs at the same time based on a given direction vector [28]. However, the DDF model is not always consistent to a radial DEA model, and omitting the existence of slacks leads to overestimated efficiency [34,35]. Thus the outcome of this model may not be accurate or even have errors [27]. Another disadvantage of the DDF model is that the direction vector's definition is complicated and frequently arbitrary [36].

The general directional distance function (GDDF) model is extended from the DDF model. Compared with the DDF model, the GDDF model is compatible with the radical model and SBM model by specific selection of the direction vector [37–39]. And to some extent, the GDDF model can weaken the arbitrariness because the result of the GDDF model is independent on the length of its direction vector.

In this context, the object of this study is to jointly access the resource-saving (UERS) and urban efficiencies containing environmental factors (UEEF) of 197 Chinese cities during the 2011–2015 periods and obtains the rankings of each city according to the two efficiencies by applying the Super-efficiency GDDF model. We have included a map as Fig. 1 showing the location of sample cities and comparing their average gross industrial output value. Furthermore, we will discuss the UERS and UEEF of six city groups of China, providing a reference for city groups with serious resource waste and environmental pollution. Also, for each specific Chinese city, the strategy matrix of four city categories is made to offer strategic emphasis on resource-saving or environmental protection.

The empirical results of this study indicates: (1) Most of the Chinese cities exhibited comparatively low UERS and UEEF, indicating great potential for the reduction of resource consumption and environmental pollution; (2) Those groups with higher levels of resource-saving efficiency tend to have poorer environmental efficiency. This means that many cities achieve good economic performance at the expense of the environment; (3) In order to realize the sustainable economic and social development, we should not only save resources, but also reduce the emission of pollutants.

The remainder of this study is organized as follows. Section 2 describes the Super-efficiency GDDF model and introduces the undesirable outputs into GDDF model. Section 3 discusses the problem description. Section 4 is an empirical analysis of the UERS and UEEF of 197 Chinese cities from 2011 to 2015. Section 5