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Static and Dynamic Analysis on the Environmental Efficiency of 267 Cities in China during 2004 –2012

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Abstract This study mainly investigates the environmental efficiency of 267 Chinese cities from 2004 to 2012 through a metafrontier, directional and super-efficiency approach. First, we explore the regional and time heterogeneity of environmental efficiency. Then, we compare the technological gap ratio in different regions and years. Lastly, we analyze the technological and management potential in different regions. We determine that the gap between environmental efficiency under group frontier and metafrontier widened from 2009 to 2012, indicating that environmental efficiency varies in different regions in China. The technology gap ratio has decreased in the four regions. This result confirms that the regional heterogeneity of environmental efficiency has increased. Thus, strengthening environmental management is crucial. China must improve green innovation to decrease energy consumption and abate carbon emissions.

Key words Environmental efficiency, Metafrontier, Directional super-efficiency approach, Time and regional heterogeneity

1 Introduction

China has become the largest producer of CO_2 emissions. It must abate its fossil energy consumption and reduce its carbon emissions. Cities contribute substantially to environmental pollution. Hence, examining the environmental efficiency of China's cities is imperative. This study mainly analyzes the environmental efficiency of several cities in China to explore regional and time heterogeneity. The remainder of this paper is organized as follows. In Section 2, we analyze the related literature on environmental efficiency and carbon emission performance. We discuss the methodology and data used in the study in Section 3. In Section 4, we examine environmental efficiency from static and dynamic perspectives. In Section 5, we present the conclusions drawn from the study and discuss policy recommendations.

2 Materials

Considering the increasing levels of environmental pollution, many scholars have focused on environmental efficiency. Chen *et al.* (2015) examined the environmental efficiency in China both horizontally and vertically[1]. Many scholars have also analyzed the determinants of environmental efficiency, such as the international trade and the global financial crisis[2 –3]. Given the increasing volume of carbon emissions, many scholars have also studied carbon emissions and their performance, such as the relationship between environmental research and development investments, the analysis of regional differences, the research on fossil fuel power plants, and the examination of CO_2 performance[4 –8]. Compared with previous studies, the potential contribution of this work is as follows. First, we investigate the environmental efficiency of 267 prefecture-level or higher cities in China from 2004 to 2012 through a metafrontier, directional, and super-efficiency approach. Furthermore, we compare the variability of environmental efficiency in China in different regions and years from the static and dynamic perspectives. Finally, we explore the regional and time heterogeneity of the technological gap ratio.

3 Methodology and data

3.1 Directional distance function DEA has been used in many fields after the pioneering works of Farrell *et al.* (1957) and CCR (1978)[9 –10]. The conventional distance function permits proportionate changes in both desirable and undesirable output, which contradicts our production objective. Fare *et al.* (1994) integrated undesirable output into the DEA model[11]. Chung *et al.* (1997) introduced the directional distance function, which simultaneously determined the maximum expansion of the desirable output and the contraction of the undesirable output[12].

3.2 Super efficiency According to traditional CCR (1978), DMUs are inefficient when they are within the production possibility set; they are efficient when they are on the boundary of the production frontier. However, traditional CCR (1978) has weak discriminating power when DMUs are simultaneously located on the frontier. In this case, comparing the efficiency of different DMUs on the frontier is difficult[13]. Super efficiency can solve this limitation above.

3.3 Metafrontier The traditional DEA frequently disregards the "heterogeneity of production technology". To address this limitation, metafrontier has been adopted by many scholars, who have incorporated group frontier and metafrontier[14 –15]. We have presented several assumptions, that is, N DMUs exist, and all of these DMUs are divided into J groups. In the jth group, the number of DMUs is N_j. The total environmental efficiency potential (*TEEP*)

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of DMUs can be decomposed into technological potential (*TP*) and management potential (*MP*). Technology gap ratio (*TGR*) is defined as the ratio between environmental efficiency under metafrontier (*ME*) and that under group frontier (*GE*).

3.4 Data We use metafrontier directional super efficiency to evaluate the environmental efficiency of 267 cities in China from 2004 to 2012. The desirable output is the gross regional product (GRP). The undesirable output includes industrial wastewater discharge, industrial sulfur dioxide production, and industrial soot discharge. The input includes capital stock and labor. All data are obtained from *China City Statistical Yearbook* from 2005 to 2013. We estimate capital stock through perpetual inventory with the depreciation rate to be 9.6%. According to *China Economic Census Yearbook* (2008), we divide 31 provinces into four different regions. These four regions are the eastern region, the central region, the western region and the northeastern region.

4 Discussions

4.1 Static analysis We evaluate environmental efficiency by using a metafrontier, directional, and super efficiency approach. Fig. 1 presents the time evolution of environmental efficiency under group frontier and metafrontier from 2004 to 2012. GE and ME denote the environmental efficiency under group frontier and metafrontier, respectively. From 2004 to 2006, the gap between environmental efficiency under group frontier and metafrontier narrowed down. From 2006 to 2009, the gap gradually increased. However, the gap widened from 2009 to 2012. Environmental efficiency under group frontier is higher than that under metafrontier.

Fig. 1 Environmental efficiency in different years

4.2 Technology gap ratio The technology gap ratio is assessed using the ratio between environmental efficiency under metafrontier and under group frontier. When the technology gap ratio approaches 1, group frontier moves closer to metafrontier, and the difference between metafrontier and group frontier is smaller. When the technology gap ratio approaches 0, group frontier moves further to metafrontier, and the technology heterogeneity between them increases. In summary, the technology gap ratio in the entire country decreased from 2004 to 2012, which demonstrated that environmental technology heterogeneity increased in China. After 2009, the technology gap ratio in the eastern region is highest, followed by that in the northeastern, western, and central regions.

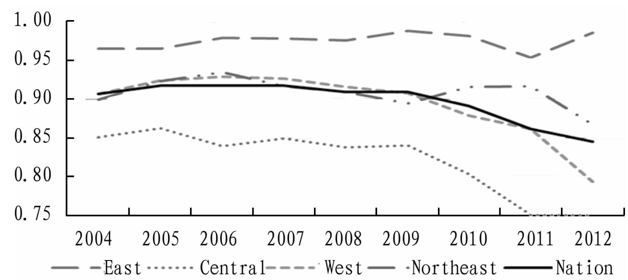

Fig. 2 Technology gap ratio in different regions from 2004 to 2012

4.3 Technological and management potential Fig. 3 shows the average values of technological potential and management potential in different regions. *TP* and *MP* denote the technological potential and management potential, respectively. The western region exhibits the highest *MP*, followed by the eastern, central, and northeastern regions. These results indicate that the west and the east should reinforce environmental regulation by combining command-and-control and market-based incentive approaches to decrease environmental pollution. The central region has the largest *TP*, followed by the northeastern, western, and eastern regions. This outcome indicates that the central and northeastern regions must improve green technology to abate carbon emissions.

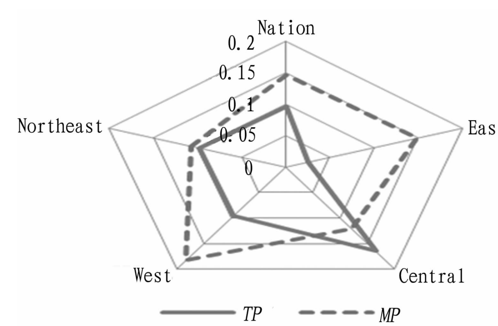

Fig. 3 Technological potential and management potential in different regions

5 Conclusions

Based on the empirical analysis, the regional heterogeneity of environmental efficiency has increased. We posit several policy implications based on the result of the analysis. First, the environmental management can be strengthened by linking command-and-control measures with market-based incentive measures to improve environmental efficiency. Furthermore, the technology gap ratio has deviated among the four regions in China, which indicates that the heterogeneity of environmental efficiency has increased in different regions. Thus, China must downsize pollution-intensive industries and develop clean industries. Finally, technological potential declined from 2004 to 2006, but increased dramatically after 2009. On the average, technological potential is lower than management potential. Thus, China must improve green innovation to decrease energy consumption and abate carbon emissions, which can promote economic sustainable development.

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system, and incorporate ecological environment into the performance assessment, conduct regular inspection, and announce to the public from time to time. Leaders as an example should transform the criterion of taking economic growth as the single indicator to the assessment including ecological and environmental performance.

Current economic growth mode exerts huge impact on ecological environment. We must curb such situation, transform economic growth mode, vigorously develop low carbon economy, and strengthen ecological and environmental protection. This not only conforms to requirement of global climate cooperation, but also conforms to the sustainable development path. Sustainable development is a development mode widely accepted by both developing and developed countries. To realize sustainable development, we should ensure basic ecological process and keep the life maintenance system, and ensure continuous utilization of environment by human beings. Environmental protection is the key point for realizing sustainable development. For this, we should properly treat the relationship between economic development and environmental protection. In conclusion, developing the low carbon economy in Jiangxi Province is of great significance.

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