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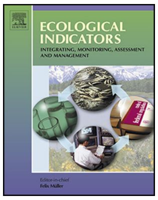

Have Chinese cities achieved the win–win between environmental protection and economic development? From the perspective of environmental efficiency

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ABSTRACT

The development of a regional or national economy is always accompanied by a variety of environmental problems. Using meta-frontier and data envelopment analysis (DEA), this paper investigates the environmental protection mechanisms and economic development of 211 cities in China from the perspective of environmental efficiency. The major conclusions are: (1) the overall environmental efficiency of Chinese cities is low when the most advanced production technology is selected as the reference. Only 10% of cities have achieved a win–win, defined as an effective balance between environmental protection and economic growth. It is possible to increase economy and reduce pollutant emissions at the same time for most of cities. (2) The environmental efficiencies and production technologies of cities in five different groups (based on a widely accepted business index) present significant differences. First-tier cities possess more advanced technology, higher environmental efficiency and, therefore, a higher overall win–win balance between economic development and environmental protection; while the fourth-tier and fifth-tier cities have a relatively large gap between development and protection. (3) To achieve a win–win balance between environmental protection and economic development, the local government of different cities should develop appropriate policies that maximize the use of technology and management practices that enhance both growth and protection.

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1. Introduction

In recent decades, environmental issues have been perceived as obstacles impeding sustainable economic development. The need to effectively address environmental problems and minimize environment deterioration has captured the highest attention of both governments and scholars worldwide. As the largest developing country in the world, China has experienced 30 years of rapid growth, and through reforms and more open access, it has become the world's second largest economy. However, China's rapid development has also consumed large amounts of energy and resources, and has brought on a series of environmental problems. For example, globally, China contributes the largest total emission of carbon dioxide (CO_2) and sulfur dioxide (SO_2).

To ease environment pressure, the Chinese government has strengthened legislation, established criteria, and formulated environmental standards; but the task remains difficult. China ranked 116th among 132 participating countries on the Environmental Performance Index (EPI) published by Yale University in 2012. The World Bank noted that in 2012, 7 of the 10 cities with the highest level of pollution were in China. As is typical with environmental pollution, hazy weather influenced 104 major cities (from 25 provinces) in China during December 2013, and covered nearly half of Chinese land area. Given these factors, the feasibility of achieving a win–win balance between environment protection and economic development in China's urban areas is a hot topic.

Environmental efficiency assessments and upgrade strategies are among the most important ways to improve the environment. When considering inputs and outputs, environmental pollution is considered to be the undesirable output of a process. As such, environmental efficiency assessments should focus on the management of these undesirable outputs. One method considers environmental pollutants as input factors, which in turn impact undesirable outputs under certain environmental loading capacities (Hailu and

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Veeman, 2001). Another method involves considering environmental pollutants as outputs with negative values (Hua et al., 2007). Because these two methods distort actual production processes and assume strong pollutant disposability with zero cost, the methods ultimately lead to large deviations in efficiency assessments.

Given these shortcomings, Färe et al. (1989, 2004), Chung et al. (1997) and other scholars have proposed a different approach. Instead of focusing on the management of undesirable outputs, they proposed that environmental pollutants have weak disposability, and that the environmental efficiency assessments be conducted using data envelopment analysis (DEA). Several relevant studies have been conducted on this basis. Arcelus and Arocena (2005), Zhou et al. (2006, 2007), Camarero et al. (2008), and Halkos and Tzeremes (2009) set carbon dioxide, sulfur dioxide, and other pollutants as undesirable outputs, and empirically analyzed the OECD national environmental efficiency assessment using radial DEA, non-radial DEA and window DEA methods. In contrast, Kumar and Khanna (2009) and Jin et al. (2014) studied the environmental efficiency of major developed countries and APEC countries using the directional distance function and DEA method.

Instead of considering the environmental efficiency of countries and regions, other researchers investigate a specific industry or company. For example, Falavigna et al. (2013) discussed the environmental pollution of Indian agriculture; Chang et al. (2014) investigated the emissions efficiency of carbon dioxide along 27 international flight routes; Sueyoshi and Goto (2012) selected a thermal power plant for a microscopic study, and discussed the possible deviation of the environmental efficiency assessment from different DEA models. Zhang and Choi (2013a) and Zhang et al. (2013) combined meta-frontier and DEA together to consider technology gaps, and discussed the static and dynamic environmental efficiency of a Korean power plant.

Because China is facing serious environmental pollution problems, sustainable development issues are receiving more attention, and research on environmental efficiency is more abundant. With the exception of studies focusing on industry, power, and urban environmental efficiency (Yuan et al., 2013; Zhou et al., 2006), most environmental efficiency studies in China position the 30 Chinese provinces as study units (these studies include Bian and Yang, 2010; Song et al., 2013) and usually focus on the following methods: radial DEA, Shannon-DEA, and Super-DEA.

A notable feature in the research mentioned above is that they assume similar or the same input–output technology in each producing unit, and target environmental pollution reduction as the only goal during the environmental efficiency assessment using the DEA analysis method. Although all countries and regions aim to concurrently reduce environmental pollution and achieve economic development, different countries and regions use a wide variety of production technologies. Specifically, significant differences exist with respect to economic scale, industrial structure, resources, and geographical environment among different Chinese provinces or cities. Hence, the heterogeneity of production technology is an important factor that needs to be considered in an efficiency assessment (Oh, 2010; Chiu et al., 2012). Some scholars have started to engage in this form of reality-based exploration (Wang et al., 2013; Lin and Du, 2013).

Meanwhile, the Chinese government is advocating a development pattern of “strong and rapid.” “Strong” means strengthening environmental protection in production processes; “rapid” means achieving rapid economic development; together, they result in a win–win balance between both environmental protection and economic development. Unfortunately, many researchers focus on current and historical assessments of environmental efficiency, but do not explore the potential for improvement. Given the sharp contrast between “Beautiful China” and “haze China,” as well as pollutant emission reduction targets from the Twelfth Five Year Plan, scientifically assessing environmental efficiency and the decomposition of potential sources would have both practical and theoretical benefits. In this paper, we study major cities in China, investigating the heterogeneity of production technology between cities using meta-frontier analysis, and the assessment and potential decomposition of urban environmental efficiency using the DEA method.

2. Research methods

2.1. Meta-frontier

Different conditions, including variable market conditions, legal constraints, resources, and degrees of openness, often lead decision making units (DMU) to select different kinds of technology, known as “heterogeneity of production technology.” Given this, Hayami (1969) and Hayami and Ruttan (1971) proposed the concept of the “meta-frontier” widely applied in fields such as manufacturing operational efficiency and energy efficiency (O’Donnell et al., 2008; Oh, 2010; Wang et al., 2013). To measure the environmental efficiency of cities in China, we assume N cities are assessed (i.e., NDMUs); each city can produce Q desirable outputs $y = \left(y_1, \ldots, y_Q\right)$ and M undesirable outputs $b = (b_1, \cdots, b_M)$ by P input factors $x = (x_1, \ldots, x_P)$. All cities can be divided into J ($J > 1$) groups with different levels of production technology. The jth group includes N_j DMUs, and fits $\sum_{j=1}^{J} N_j = N$. The DMUs of the jth group possess similar or the same production technology, and together form a group frontier. Meta-frontier is obtained by enveloping all J groups.

Assume T^j and T^m are the production technology sets of the group frontier and meta-frontier, and possess with following properties (Chung et al., 1997): (1) for any j, if an existing input–output combination $(x, y, b) \in T^j$, then $(x, y, b) \in T^m$; (2) if $(x, y, b) \in T^m$, then $(x, y, b) \in T^j$ is satisfied for part of $j \geq 1$; (3) $T^m = \left\{T^1 \cup T^2 \cdots T^J\right\}$ satisfies the over-arching requirements. In contrast with the efficiency calculations performed by O’Donnell et al. (2008) using meta-frontier, the input–output process represented by T^j and T^m includes undesirable outputs such as environmental pollutants. Zhou et al. (2007) refer to T^j and T^m as environment production technologies. In addition to typical characteristics of production technology such as close, boundedness, and convexity, T^j and T^m also possess weak disposability and “null-jointness” as undesirable outputs (detailed description can be referred from Chung et al. (1997) and Oh (2010)).

2.2. Definition of environmental efficiency

Environmental efficiency is further defined by the directional distance function. The directional distance function is a combination of outputs (desired and undesired) and inputs. It is a general form of traditional Shephard distance function (Chung et al., 1997). Eqs. (1) and (2) represent the directional distance functions of group frontier and meta-frontier, respectively.

$$\vec{D}^j(x, y, b; g_y, -g_b) = \sup\left\{\beta^j : \left(y + \beta^j g_y, b - \beta^j g_b\right) \in T^j(x, y, b)\right\} \quad (1)$$

$$\vec{D}^m(x, y, b; g_y, -g_b) = \sup\left\{\beta^m : \left(y + \beta^m g_y, b - \beta^m g_b\right) \in T^m(x, y, b)\right\} \quad (2)$$

In these equations, $g = (g_y, -g_b)$ is the direction vector of the output. The direction vector g seeks the highest expansion in the g_y direction of desirable outputs and the maximum contraction in the g_b direction of undesirable outputs. Direction vector $g = (0, -g_b)$ indicates that an environmental efficiency assessment only requires achieving the reduction of undesirable output. In contrast, the direction vector $g = (g_y, -g_b)$ indicates an environmental efficiency assessment based on the criterions of both “strong and rapid” and a win–win balance between environmental protection and economic development. Obviously, the second assessment

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