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Assessing regional eco-efficiency from the perspective of resource, environmental and economic performance in China: A bootstrapping approach in global data envelopment analysis

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ABSTRACT

Eco-efficiency has been receiving increasing attention across the world. This paper proposes an extended data envelopment analysis model, which combines global benchmark technology, directional distance function and a bootstrapping approach to investigate the dynamic trends of regional eco-efficiency in China from 2003 to 2014. Moreover, a developed slacks-based measure is utilized to decompose the performance fluctuations into resource, environmental and economic efficiency. Then, the key factors responsible for the changes in eco-efficiency are explored using the global Malmquist–Luenberger index. The empirical results demonstrate an upward trend of eco-efficiency in China. During the study period this trend was high in eastern and northern areas but low in northwestern areas. However, it should be noted that some eco-efficient regions still consume much land, water and energy and emit much environmental pollutants in absolute terms. The whole of China performs well on the economic front, while resource and environmental performances are not encouraging, particularly on environmental efficiency. The eastern and northern regions have experienced the greatest advances in both resource and environmental efficiency, while the undeveloped areas have not shown much progress, which further widens the gaps between developed areas and undeveloped areas. The decomposition of productivity growth indicates that technical progress is the decisive factor in promoting China's eco-efficiency, while decreasing management level is the major obstacle hampering the improvement in eco-efficiency.

1. Introduction

Economic activities use material resources, labor and capital to produce desirable goods and services, but simultaneously trigger additional effects on the natural environment and inevitably result in the generation of pollution, such as greenhouse gases and waste water (Murty et al., 2012; Robaina-Alves et al., 2015). That's to say, if resources are used inefficiently during the production process, this will lead to lower economic outputs and higher emission levels. Generally, the environmental economics literature reveals three broad features of pollution that economists aim to capture: first, the generation of pollution seems to accompany with the processes of consumption and production; second, pollution requires the absorptive capacity of the environment; third, the generation of pollution and the consequent use of natural resources for its disposal generate external effects on both consumers and producers and hence need policies to regulate production process (Murty et al., 2012). In this paper, we confine ourselves to studying the specification of the technology set that best captures the link between production of intended outputs, the consumption of natural resource and the generation of pollution.

Economic efficiency reflects the ability of a production unit to obtain maximal output from a given set of inputs and the production technology. However, it does not imply resource and environmental efficiency. Production processes rely on resource inputs, hence inefficient economic activities may result in excessive use of resource and high levels of pollution emissions. Thus, resource and environmental efficiency cannot be separated from economic efficiency. Furthermore, for policymaking it is necessary to have indicators in this context. Indicators of resource, economic

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and environmental efficiency compare the evolution of regions or sectors, set goals and implement effective policies, either globally or locally. Blühdorn and Welsh (2007) suggest that we are in a new era which needs to create an eco-friendly society and maintain the sustainable development of human beings. The study of eco-efficiency, joining the economic, resource and environmental parameters together, may respond, or at least illuminate the sustainability of these theories (Robaina-Alves et al., 2015).

Eco-efficiency was first proposed as an instrument for sustainability analysis by Schaltegger and Sturm (1990) and was subsequently popularized by the World Business Council for Sustainable Development (WBCSD) (Schmidheiny, 1992). According to the WBCSD, eco-efficiency is achieved by "the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to the level at least in line with the Earth's estimated carrying capacity" (Stigson, 2000). In other words, it reflects the ability to produce more goods and services while consuming fewer natural resources and inflicting less impact on the environment (Kuosmanen, 2005; Kharel and Charmondusit, 2008). Until now, eco-efficiency has been viewed at differing scales, such as at the national economy (Jollands et al., 2004; Rashidi and Saen, 2015; Gómez-Calvet et al., 2016), at the regional scale (Kielenniva et al., 2012; Yu et al., 2013), at the scale of industrial sectors (Korhonen and Luptacik, 2004; Wang et al., 2011; Fujii and Managi, 2013; Park and Behera, 2014; Yu et al., 2016; Masuda, 2016) and at the level of companies (Côté et al., 2006; Hahn et al., 2010; Fernández-Viñé et al., 2013; Passetti and Tenucci, 2016).

It is important to find a suitable way to measure eco-efficiency. The ratio approach (Callens and Tyteca, 1999; Huppes and Ishikawa, 2005; Wursthorn et al., 2011; Yu et al., 2013), the material flow analysis (Pelletier et al., 2008; Wang et al., 2016) and the frontier approach (Korhonen and Luptacik, 2004; Kuosmanen and Kortelainen, 2005; Picazo-Tadeo et al., 2012; Robaina-Alves et al., 2015; Gómez-Calvet et al., 2016) are generally applied to measure eco-efficiency. The ratio approach defines eco-efficiency as the ratio between the economic value of the goods or service being produced and the environmental impacts of them, which can be calculated only if the numerator and the denominator can be integrated into a certain value (Zhang et al., 2008). With regard to life cycle assessment, it is generally restricted by data availability, especially when there are many estimated entities. By contrast, data envelopment analysis (DEA) appears to be the most widely adopted approach incorporating various inputs and outputs in different dimensions without definitive weights to aggregate the indicators (Dyckhoff and Allen, 2001; Kuosmanen and Kortelainen, 2005), moreover, related data is generally accessible (Huang et al., 2014).

To obtain accurate results, many researchers have tried to improve DEA models to measure eco-efficiency or similar concepts, such as energy efficiency and environmental efficiency. The conventional DEA model only uses economic outputs as the single desirable output and ignores environmental pollutants. Along with the increasing concern on eco-efficiency in terms of sustainability of resource, environment, and economy, some scholars have tried to incorporate environmental factors into the total-factor framework. In order to simultaneously maximize the desirable outputs and minimize the undesirable outputs and inputs, Fare and Grossopf (2010) developed a more generalized non-radial and non-oriented directional distance function based on a slacks-based measure (SBM). So far, this generalized directional distance function has been widely utilized to measure efficiency (Zhou et al., 2012; Wang et al., 2013; Zhang et al., 2013).

It is interesting to analyze regional eco-efficiency in China. As we all know, China has experienced a high rate of economic growth over the past few decades. Meanwhile, the indicators of natural resource and environmental pressure reveal a different picture, which have posed a threat to sustainable development in terms of economic, social and ecological stability. There is an emerging consensus in policy circles that China should steer away from the "pursuit of economic growth at all costs" that is certainly detrimental to the long-term sustainable development of the country. The assessment of eco-efficiency is able to provide a scientific basis and a certain reference value for this transformation (Mickwitz et al., 2006). Considering regional diversity in China, it is beneficial to estimate eco-efficiency at regional level. As a matter of fact, there have been several studies focusing on regional eco-efficiency in China. Zhang et al. (2008) illustrated the pattern of regional industrial systems' eco-efficiency in 2004. Chen (2008) measured the efficiency of 29 provinces using factor analysis to aggregate five indicators into one to evaluate the differences in regional eco-efficiency. Yang (2009) used DEA to estimate regional eco-efficiency of China from 2000 to 2006 and the results showed that whole eco-efficiency of China changed little. Wang and Wu (2011) conducted spatial difference analysis and convergence analysis of regional eco-efficiency from 1995 to 2007. Li and Hu (2012) studied the ecological total-factor energy efficiency in 30 regions between 2005 and 2009. Yu et al. (2013) reported the dynamics of China's eco-efficiency and decoupling level during the 1978–2012 using the ratio between the value of what was produced and the environmental impacts of the product or service. Yin et al. (2014) used a super-efficiency DEA model to assess eco-efficiency of 30 Chinese provincial capital cities. Huang et al. (2014) investigated the dynamics of regional eco-efficiency in China from 2000 to 2010 by applying a comprehensive DEA model combining benchmark technology, undesirable output, super efficiency and slacks-based measure. Chu et al. (2016) constructed a two-stage DEA network approach to estimate eco-efficiency analysis of 30 Chinese regions in 2013 and verified that the majority of these regions in China had poor ecological performance. On the whole, the studies mentioned above generally divided China into three areas and reached similar results: average eco-efficiency of the eastern area is higher than those of the central and western areas and the eastern area is experiencing more rapid growth of eco-efficiency than the other areas.

This paper expands previous studies on the DEA measurement approach and empirical research of regional eco-efficiency in China. Firstly, in most of the existing studies, contemporaneous or cross-phase benchmark technologies were applied to construct the single-phase reference production sets, which lead to models lacking stability and results deviating from the practical production activity. If the sample sets under evaluation are different, the frontiers and benchmarks may change accordingly. At the same time, the obtained results based on different benchmark technologies are not available for comparability and circularity (Pastor and Lovell, 2005). Secondly, most of the studies measured eco-efficiency through building up the objective function using ratio which simultaneously takes into account both desirable and undesirable outputs, while more details behind the eco-efficiency values remain unknown. Eco-efficiency is a comprehensive indicator which reflects the economic, resource and environmental conditions (Robaina-Alves et al., 2015), yet these performances have not been analyzed in the previous literature. Thus, it becomes necessary to base economic, the resource and the environmental policies on an eco-efficiency assessment. Third, as a nonparametric frontier estimation approach, DEA is based on a finite sample of observations and does not provide confidence intervals over estimates, and thereby has built-in limitations such as small sample's estimation bias and the lack of statistics test (Simar and Wilson,

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