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Estimation of eco-efficiency and its influencing factors in Guangdong province based on Super-SBM and panel regression models

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ABSTRACT

Eco-efficiency is an indicator that is tied to economic activities and ecology; it serves as a useful instrument for sustainability analysis. Based on a panel data set for the period 2005–2014, this paper estimated the eco-efficiency of 21 cities in Guangdong province, China by applying a super-slack-based measure (Super-SBM) model that considers undesirable output indicators and a Topsis model. Using a panel data model with fixed effects, the influencing factors on eco-efficiency were also explored. The results indicate that during the study period, the three indexes—resource inputs (RI), economic benefits (EB) and environmental impacts (EI)—showed obvious spatiotemporal differentiation with high values mainly being located in the core region of Guangdong (the Pearl River Delta, PRD) and low values being primarily distributed in the northern area of the province. Influenced by inputs and outputs, the eco-efficiency presented significant disparities among four areas and 21 cities. The highest eco-efficiency was in the eastern area and then in the PRD, areas whose eco-efficiency averaged around 1.16 and 1.10, respectively, while the north had the lowest value, averaging below 1.00. Regional disparity was found to increase and spatial autocorrelation to decrease gradually between 2005 and 2014. The results of the panel data analysis indicate that technical innovation had the greatest positive influence on eco-efficiency, followed by government regulation, openness and population density. Conversely, land-use intensity was identified as the main inhibiting factor among the negative influencing factors, which also included industrial structure and per capita GDP. Interestingly, the study found that a high level of per capita GDP would not necessarily lead to high eco-efficiency. The findings of this study hold important implications for both policy makers and urban planners.

1. Introduction

Three decades of rapid economic development in China has seen an average annual growth rate of around 10.00%, which has made China the second largest economy in the world (Wang et al., 2014, 2015). However, this scale-driven economic development characterized as "high input, high consumption and high emission" has also resulted in inefficient resource utilization and a range of ecological and environmental impacts (Wang and Liu, 2017; Wang et al., 2017). What accompany the considerable economic growth are the increasing energy consumption, long-lasting water and air pollution as well as the increasing severe smog and fog in many cities, especially in high-growth regions, which has ultimately reduced the ability of these regions to achieve "sustainable development" (Zhao et al., 2016). The province of Guangdong is the southern gate into China and has long been at the forefront of reform and opening-up policies. As the booming development of township industries, the ecological environment has been being threatened with large area of farmland being occupied and river being polluted. Further, the inflating population and demands have brought about sharp consumption and left heavy burden on the environment. In recent years, the province is strategically important in new attempts to build world-class agglomeration areas and an economic bay area in cooperation with Hong Kong and Macao through the "one belt, one road" strategy. These efforts have placed great expectations on Guangdong's regional development and on cooperation with other countries. Against this backdrop, research into the relationship between economy and environment in Guangdong is both necessary and meaningful.

With root in ecological economy, the notion of "eco-efficiency" has developed as a valuable instrument for sustainability analysis. The term refers to the empirical relationship between economic activities and environmental costs (Mickwitz et al., 2006), wherein high eco-

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efficiency means realizing the greatest possible economic benefit with the least possible resource inputs and damage to the environment. Since eco-efficiency plays an increasingly significant role in measuring the efficiency of economic activity with respect to natural resources and services, the term has begun to receive increasing attention from the research community. Various methodologies and indicators have been proposed for measuring eco-efficiency. Among the methods used, Data Envelopment Analysis (DEA) is a non-parametric method where inputs and outputs are combined with self-defined weighting coefficients in order to come up with an aggregate score. The technique was first proposed by Charnes et al. (1978), in order to provide an indication of the relative efficiency of decision making units (DMUs) (Lahouel, 2016; Dyckhoff and Allen, 2001; Rashidi and Saen, 2015). Generally, in the actual production process, desirable outputs are accompanied by a range of undesirable outputs, the traditional DEA model, however, only considered the former. Acknowledging this exclusion, many studies have thus actively taken undesirable outputs into account as input variables (Reinhard et al., 2000; Hailu and Veeman, 2001; Pittman, 1981). Amongst such studies, some scholars have used the reciprocal transformation method in order to transform the evaluated value of undesirable outputs into desirable values (Scheel, 2001); others have converted the negative values of undesirable outputs into positive values through a proper vector transformation (Seiford and Zhu, 2005). However, these methods are unable to reflect the actual production process, a problem that may lead to a deviation in results (Liu et al., 2010). Färe et al. (1989) proposed a new DEA model that considered undesirable outputs based on "weak disposability," on the assumption that undesirable outputs could be reduced only if desirable outputs also decreased (Färe and Grosskopf, 2004). This model, however, could not solve the problem of slackness caused by radial and angular choices (Song et al., 2013a). As such, Tone (2001) subsequently provided a non-radial and non-oriented SBM model able to take into account such slackness, which directly addressed input excess and output shortfall in the measurement. Given that undesirable outputs were again not considered in this early SBM model, Tone (2003) extended the model, adding slackness for undesirable outputs into the objective function, so that the constraint of undesirable outputs could be modified (Zhang et al., 2016). Based on the SBM model, Tone (2002) also proposed a super-slack-based measure model (Super-SBM) for more accurate and reliable efficiency evaluation as well as for further ranking of eco-efficiency. Again, undesirable outputs were not considered in Tone's Super SBM model. Besides, Life Cycle Assessment (LCA) is commonly applied to support or be compared with DEA models (Ullah et al., 2016; Avadí et al., 2014). Some studies have also compared the DEA model with Stochastic Frontier Analysis (SFA) (Reinhard et al., 2000). Responding to the methodological development, this paper applies a Super-SBM model that takes into account undesirable outputs to evaluate the eco-efficiency of 21 cities in Guangdong from 2005 to 2014.

Eco-efficiency has been studied at a range of scales, spanning from the micro level to the macro level. Studies at the micro level have mainly focused on companies or firms. For example, by applying eco-efficient practices in a micro-sized auto parts and electrical automotive services enterprise in Brazil, Alves and Medeiros (2015) demonstrated that eco-efficient practices could provide low-cost benefits for small and micro-enterprises. Similar results were reached by Sinkin et al. (2008), who examined the relationship between the adoption of eco-efficient business strategies and firm value. Conversely, a study of small and medium-sized enterprises (SMEs) in Venezuela by Fernández-Viñé et al. (2010) pointed out that the adoption of eco-efficiency practices was not perceived as an incentive to improve competitiveness. Studies at the meso-level have tended to concentrate on the environmental performance of the entire production progress. For example, Angelis-Dimakis et al. (2016) applied a methodological framework to eight water-use systems, in an effort to reveal environmental weaknesses and seek opportunities to improve the eco-efficiency of such systems. Meso-level researches have also been undertaken in relation to specific regions or cities. Chen et al. (2017) measured the environmental efficiency of the Yangtze River Economic Zone (YREZ), finding that cities in the Yangtze River Delta (YRD) show highest environmental efficiency. Li et al. (2010) used measures of ecological footprint in order to evaluate the eco-efficiency of residential developments in three Chinese cities, finding that Shanghai and Beijing were more eco-efficient than Nanjing. With rising levels of consumption and resource dissipation, eco-efficiency is being conceptualized in an increasing range of fields. There have, as such, emerged large numbers of studies undertaken at the national level and even the international level. For example, Lupan and Cozorici (2015) studied the eco-efficiency of the Romanian economy in order to plot a path towards more sustainable development in Romania. By applying a new maximum entropy method, Robaina-Alves et al. (2015) evaluated the eco-efficiency of European countries during the periods 2000–2004 and 2005–2011, revealing lower levels of technical and environmental efficiency in less developed countries. Moutinho et al. (2017) estimated the economic and environmental efficiency of 26 European countries.

Recently, many studies start to explore the influencing factors on eco-efficiency by using various regression models, among which, Tobit regression model is the most widely used. This model has been applied to test the influencing factors on environmental efficiency throughout countries (Zhang et al., 2016; Díaz-Villavicencio et al., 2017) and specific regions (Chen et al., 2017). Malmquist index (Song and Zheng, 2016), spatial panel regression techniques (Guan and Xu, 2016), quantile regression model (Moutinho et al., 2017) and panel data model (Song et al., 2013b) are also used to explore the influencing factors on ecological and environmental efficiency. As to the influencing factors, previous scholarly work on eco-efficiency has shown that the ecological environment, economy, industrial structure, technical development, government regulation, and population are all to some extent relevant factors (Grossman and Krueger, 1994; Bhattarai and Hammig, 2001; Zhang et al., 2016; Li et al., 2013).

To date, much progress has been made in developing DEA and indicators of eco-efficiency, both theoretically and practically. Valuable results have been achieved that have enriched our understanding of the relationship between economy and ecology. However, these existing studies have tended to concentrate on a specific kind of eco-efficiency and have usually addressed either the micro or macro level. Much of the research has applied cross-sectional data rather than panel data in the analysis of the influencing factors on eco-efficiency, which has resulted in the neglect of temporal effects. Moreover, most studies have failed to analyze inputs and outputs indicators, which in fact form the foundation of eco-efficiency. Even, some studies ignore the undesirable outputs in the assessment. Responding to the deficiency, the study applied a Super-SBM model considering bad outputs and used panel data which contain more degrees of freedom and more sample variability. Choosing Guangdong, the gateway province and strategic area, as the study area, we first undertook an assessment of inputs and outputs indicators using TOPSIS method and then studied the spatiotemporal variation of the comprehensive eco-efficiency of 21 cities. Finally, we explored the influencing factors on eco-efficiency. Thus, the paper reveals the characteristics of eco-efficiency from two different perspectives: a spatio-temporal perspective and a global-local perspective. The purpose of this paper is not only to track the eco-efficiency performance of the 21 cities as it changes over time and differs in space, but also to explore the possible influencing factors in order to give some implication for policy making and urban planning.

The rest of the paper is organized as follows. Section 2 details the Topsis model used for assessing inputs and outputs indicators; the Super-SBM model with undesirable outputs used to evaluate eco-efficiency; the method of spatial analysis used for spatial variation analysis and the panel data regression model employed for determining the influencing factors on eco-efficiency. Section 3 provides a comprehensive assessment of resources inputs, economic benefits and their influence on environment. Further, we analyze the results of the eco-