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Environmental efficiency evaluation based on data envelopment analysis: A review

Malin Song [a,*], Qingxian An [b], Wei Zhang [c], Zeya Wang [a], Jie Wu [b]

[a] School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu, PR China
[b] School of Management, University of Science and Technology of China, Hefei, PR China
[c] School of Economics, University of Jinan, Jinan, PR China

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ABSTRACT

The paper aims to investigate the achievements of the theoretical and practical basis of environmental policy analysis in order to study their works and point out the future possible research direction. It sorts out researches about environmental efficiency assessment and reviews the works about the theory and application of efficiency analysis around the world. It is suggested that environmental efficiency evaluation theory under small samples and DEA method with undesirable outputs will further extend the research on environmental efficiency evaluation. Also, this review confirms that more studies in methods and their applications in this area are in urgent need.

Contents

1. Introduction

Environmental issues have become one of the most important problems related with social and economic sustainable development. Evaluating environmental efficiency in different regions and sectors has strong practical implications. This work not only benefits for people understand the difference among their environmental performances, but also provides an objective reference point for improving environmental performances. However, the current evaluation methods for environmental efficiency are mostly based on the determination of the inputs and outputs evaluation index. Some evaluation methods (such as the data envelopment analysis, Stochastic Frontier Analysis) are proposed based on the macro data or micro data. Finally, the environmental efficiency is measured. Because environmental efficiency evaluations are very complex, the negligence of application scenarios and invariably using some specific traditional evaluation methods may lead to the following disadvantages in practice: (1) failure to take into account environmental efficiency for small samples results in imprecise evaluation; (2) the selection of the variables has a great deal of subjectivity; and (3) some curing and non-dynamic evaluation methods can not deal with the change of socio-economic environment. Solving these problems is important for the development of environmental efficiency evaluation methods.

Now, measuring environment efficiency has become an essential direction in research. So far, scholars have proposed several quantitative models to solve the complex environmental problems [1]. More and more people have generally recognized the importance of environmental efficiency evaluation because it can provide designers and public policy makers with quantitative information for performance evaluation, policy analysis and public

* Corresponding author. Tel.: +86 15805521822; fax: +86 0552 3173187.
E-mail addresses: songml@aufe.edu.cn, songmartin@163.com (M. Song).

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communication. All of these benefits will make the decision of environmental policy-making more scientific, empirical and systematic than before.

So far, there have been many quantitative analysis techniques in environmental efficiency evaluation, among which the production efficiency analysis has drawn widespread interests in recent years. Modern production efficiency analysis began to be applied in the study of environmental problems in 1980s, and with more concerns on the environmental problem. The efficiency evaluation method is widely used in environmental evaluation systems [2]. Data envelopment analysis (DEA) is an effective non-parametric method for evaluating the relative effectiveness of the decision making units (DMUs) [3,4]. The exact functional relationship (refer to function formula) between inputs and outputs need not be considered in DEA technology. DEA does not need decision maker to provide the information on weights. The weights can be gained through a programming, that is, no pre-estimated parameters are needed. Therefore, the weights can avoid being subjectivity. But the traditional DEA efficiency model only considers the desirable outputs while neglecting the undesirable outputs in the actual production process. In fact, the undesirable output is usually produced companied with the desirable outputs. For example, in a thermal power plant, it is inevitable that undesirable outputs will be generated in the power generation process, such as the emissions of carbon dioxide. The output maximization assumption of the traditional DEA efficiency model can not be applied for this scenario. Therefore, how to consider the undesirable outputs in the traditional DEA efficiency model becomes a topic with great theoretical significance and application value. To deal with this issue, many scholars have worked on the environmental efficiency and gained a lot of achievements [5–11]. Concluding the current works and pointing out some interesting and valuable directions for measuring the environmental efficiency are urged, so this review is believed to be necessary and timely.

The rest of this paper is structured as follows. Section 2 reviews major related researches. Section 3 introduces the DEA models with undesirable output and classifies them into several parts. Finally, concluding remarks are given in Section 4.

2. Origin of environmental efficiency evaluation

Comprehensive evaluation on the environmental efficiency traces to the time when researchers focused on the limited energy and the carbon dioxide emissions generated in the production. By simulating the carbon dioxide emissions scenario, early researchers provided some advice for energy policy in the future. Edmonds and Reilly thought that the establishment of a global energy environment evaluation model is very important for energy analysis and environmental decision-making, and they proposed the global energy and economic development model which can predict changes for the next one hundred years [12]. Additionally, they gave the specific structure of the model and explained the results of this model. By analyzing the quantitative relationship between the global natural gas distribution and carbon dioxide, Reister proposed that the main determinant of carbon dioxide emissions was the energy supplier, so the key to controlling carbon dioxide emissions is to control its source [13]. Harvey believed that the increase of carbon dioxide concentration would promote the effects of photosynthesis. Based on this, he developed a formula to analyze the impact that the carbon dioxide volume fraction on the carbon preservation parameters of photosynthesis, and further studied the global carbon cycle model through simulating carbon dioxide fertilization effect [14]. Gustavsson et al. indicated the government can establish efficient energy end-use technologies, cogeneration and a recycling economy through the implementation of policies. The energy system can still reduce carbon dioxide emissions by 75% through end-use technologies, cogeneration and circular economy without increasing water and power consumption under sustaining economic growth [15]. Kamiuto built a simple model including the air, the biosphere and the hydrosphere to describe the global carbon cycle, and he found that since the chaos deforestation and the changes in land use around 1875, the original "big tank" which absorbed carbon dioxide has reduced or disappeared, thus changing the carbon dioxide emission rate [16]. Svendsen took Denmark as an example and proposed that carbon trading should be introduced into plants in the private sector, and management department of the public power sector should be built, in order to reduce carbon dioxide emissions by 25% by 2005; Meanwhile, the carbon tax would reach US$50 per family, the transportation sector and private plants were not included at that time [17]. Yang and Zhang introduced five approaches of calculation methods of carbon dioxide emission from bio-energy utilization, which were summarized from the perspective of resources and utilization [18]. However, most of the above works are qualitative. The quantitative evaluation for environment system with multiple inputs and outputs is badly needed as the impact factors on carbon dioxide emissions compose a complex system.

Soon after, some researchers have begun to pay attention to reducing greenhouse gas emissions, and have presented some multi-objective decision analysis models and Integrated Assessment of Climate Protection Strategies (ICLIPS) evaluation methods. Färe et al. introduced environmental efficiency variables based on the decomposition of total factor productivity in the pollution variables and input–output efficiency variables, and formed the environmental efficiency variables, giving the calculation methods as well [7]. Diesendorf built models considering ethical principles, target groups, evaluation and implementation strategy, in which all levels of government, business and community organizations in collaborative efforts are involved. He indicated that the most important thing is to speed up community participation and empowerment in order to form a better atmosphere to promote the implementation of sustainable development policies and coordination of environmental protection and socio-economic development [19]. Zaim and Taskin established the environmental benefits variables using a non-parametric method for each OECD member country, and measured the output they sacrificed to achieve better environmental benefits [20]. Voorspools et al. investigated several types of possible indirect sources of greenhouse gases, and used life cycle assessment to measure two different types [21]. Their empirical results suggested that nuclear power produces minimal greenhouse gas emissions, followed by wind power in coastal areas, and the worst among the three was photovoltaic power. Matthews designed an evaluation method for bio-fuel production systems of energy and carbon budget [22]. He thought that further research should validate the input assumptions and evaluate the integrity and utility of the budget, as well as the energy generation systems. Sands and Leimbach also proposed core methods for Integrated Assessment of Climate Protection Strategies (ICLIPS), in which they use agriculture and land-use models, using the carbon emissions evaluation program where the land use changes were the main cause for the overall greenhouse gas emissions [23]. In their simulation, land-use changes significantly affected carbon emissions. Pasurka calculated the changes in nitrogen oxides and sulfur dioxide emissions with the inputs changes of technology, fuel and non-fuel by using the new decomposition model and the distance function. Besides, he suggested that the major emissions of sulfur dioxide decreased with the changes of output groups, while nitrogen oxides decreased along with the fuel consumption