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Evaluating the environmental efficiency of a two-stage system with undesired outputs by a DEA approach: An interest preference perspective

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ABSTRACT

In this study, we propose a new DEA model to evaluate the environmental efficiency of a two-stage system with undesired outputs. The two-stage system consists of two parts: a production subsystem and a pollution treatment subsystem. Different choices for allocating resources to each subsystem represent different interest preferences of decision makers, with the production subsystem corresponding to short-term interests and the pollution treatment subsystem corresponding to long-term interests. Based on a proposed new DEA model, three theorems are established to show the relationships between the interest preference parameter and the change of efficiency scores. An empirical analysis was conducted using the data of 30 provinces and municipalities (eight regions) of China. The empirical results show the effectiveness of the proposed model and the usefulness of the theorems for the real-world data. Optimal efficiency rankings of the eight regions are provided and the efficiency rankings truly reflect the current environmental situations of these eight regions. To examine the economic impacts and facilitate sustainable development, we also analyze the shadow prices for undesired outputs. Corresponding implications of the empirical analysis are also discussed.

1. Introduction

Environmental problems (e.g., global warming, climate change, water pollution) have become one of the most important issues worldwide (Sueyoshi & Goto, 2011a). Large investments have been used to conduct environmental protection and treatment programs in many countries (Zhang, Bi, Fan, Yuan, & Ge, 2008), resulting in many waste recycling and reuse projects being developed. Given the large amount of investment and long construction period of these projects, the real benefit must be a focus of attention for government officials and managers, but the effects of these investment projects have rarely been studied. Therefore, it is difficult to evaluate the change of environmental efficiency brought by these projects. The objective of this study is to propose a new approach to effectively evaluate the performance of such projects. Armed with corresponding data, valuable suggestions can be provided for further development of such projects.

To have a better understanding of the investigated systems, we abstract the systems involved to a general two-stage process model, as shown in Fig. 1. Each stage is an integrated system that includes inputs and outputs. Stage 1 represents the general industrial production subsystem which uses several input resources (X_1) to produce products that are desired (Y_1) and undesired (U_1). Stage 2 indicates the pollution treatment process of environmental protection project. During this stage, by using external input resources (X_2), the undesired output (U_1) is recycled and reused to produce desired outputs (Y_2) and some remaining undesired outputs (U_2). Note that the intermediate product in this two-stage process is the undesired output (U_1) from stage 1.

The two subsystems represent the short-term interest and long-term interest, respectively. The industrial production subsystem in stage 1 provides various kinds of daily necessities such as energy, and supports the normal work and life of humankind currently and in the near future. Therefore, the industrial production subsystem represents short-term interest in the present study. Increasingly, pollution treatment subsystems are being established to respond to the push for "sustainable development" in order to preserve the environment perpetually, so the production treatment subsystem represents long-term interest.

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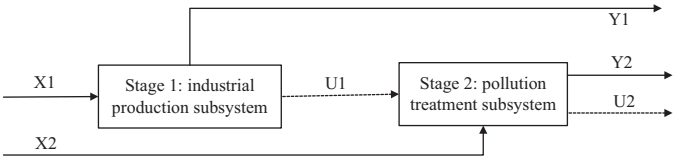

Fig. 1. Simplified two-stage system of production and environmental treatment project (dotted lines represent the undesired outputs).

The subjective interest preference of the decision makers can also be categorized as long-term interest or short-term interest, but every position is actually a mixture of these two interests. In our proposed model, a parameter α indicates the degree of decision makers' subjective short-term interest preference. Practically, a short-term interest preference decision maker is obviously more likely to get profit/revenue from the industrial production subsystem. Therefore, such a decision maker would improve the production technology level of this subsystem by all means, including increasing investment of capital, knowledge, professional workers, and so on. In essence, all of these management policies for improvement can be treated as an increase in one input resource of the industrial production subsystem. In this perspective, the investment proportion of input resources for the industrial production subsystem, which was predetermined by the decision makers, can truly reflect the degree of their subjective short-term interest preference. Therefore, in this study, the value of parameter α is basically equal to the predetermined proportion of input resources invested in production. Correspondingly, the same decision makers' subjective long-term interest preference degree can be indicated by $1-\alpha$.

To evaluate the efficiency of the proposed two-stage model, a new DEA-based model is proposed which considers the degree of decision makers' interest preferences. The efficiencies of the overall two-stage system and subsystems were measured using the proposed approach. We also investigated the efficiency change trends of the two-stage system and the subsystems from the perspective of different interest preferences of decision makers. Based on the proposed model and the two-stage system, three theorems that depict the relationships between the efficiency trends and the interest preference parameter were proven. To give evidence of the utility of this model, an empirical analysis was conducted. All empirical results are analyzed and corresponding implications are discussed.

This study contributes to the current literature of performance and efficiency evaluation with DEA approaches in the following ways. First, few existing studies have explored the efficiency of two-stage systems with undesired intermediate outputs. This paper proposes a weighted two-stage DEA model based on the two-stage system, taking the undesired outputs as an intermediate product. Second, to the best of our knowledge, no published research in this field has studied how decision maker subjective attitudes affect organizational performance or efficiency evaluation. This paper investigates the impacts that decision maker subjective interest preferences have on DMU efficiency changes based on the behavioral research in organization management. In the proposed model, the weight parameter is used to represent the degree of a decision maker's subjective interest preference. Thus both subjective and objective factors are considered. Third, most scholars have ignored the efficiency of systematic environmental protection projects. The present study investigates the comprehensive efficiency of a representative two-stage environmental protection project using the proposed weighted DEA model. The empirical results of this study can provide valuable suggestions for future decision making. Therefore, there are both academic and practical implications to understanding how decision makers' interest preferences affect the comprehensive efficiency of two-stage systems, and how the environmental efficiency changes with the development of policies balancing the economy and the environment.

The rest of the paper is organized as follows. In Section 2, we review the current literature in the field of environmental efficiency measurement and two-stage systems. Then, Section 3 describes the proposed weighted two-stage DEA model, and based on the model we prove three general theorems. An empirical analysis was conducted to explore the current situation of Chinese environmental efficiency, and the results are shown in Section 4, illustrating the applicability of the theorems. The shadow prices of pollutants are derived and analyzed based on the empirical example. A discussion of the empirical results appears in Section 5, followed by conclusions.

2. Literature review

2.1. Environmental efficiency

Ecological efficiency can be defined as follows: "Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing environmental impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity" (Dyckhoff & Allen, 2001). Ecological efficiency has aroused increasing attention from government, practitioners, and scholars in recent years.

Many studies have been conducted to explore environmental efficiency. Cooper, Huang, Li, Lelas, and Sullivan (1996) summarized more than 100 previous studies in air pollution alone. The Yale Center for Environmental Law & Policy has established an environmental performance index (EPI), which focuses on two broad objectives: (1) reducing environmental stresses on human health, (2) promoting ecosystem vitality and soundly managing natural resources (Esty et al., 2006). Most of the EPI indicators can only partially reflect environmental characteristics and are somewhat subjective. Some researchers, however, have tried to explore an appropriate way to construct a comprehensive EPI. Diaz-Balteiro and Romero (2004) proposed an index of sustainability to evaluate natural systems with a multiple criteria decision-making approach, and this index of sustainability can be used to reach balances or compromises between ecological solutions of balanced sustainability and engineering solutions of aggregate sustainability. However, the production efficiency theory is becoming increasingly important because an EPI value can be directly obtained by calculating the environmental efficiency (Zhou, Poh, & Ang, 2007). Pittman (1983) first proposed a productive efficiency measurement approach, but one limitation of his work is that the prices of pollutants or shadow prices are difficult to measure.

To find an appropriate way to measure the efficiency of environmental performance, many researchers have used the data envelopment analysis (DEA) approach. Zhou, Ang, and Poh (2008) presented a literature survey on the application of DEA in the field of energy and environmental evaluation over three 8-year periods: 1983–1990, 1991–1998, and 1999–2006. The results show that an increasing number of researchers are focused on modeling electricity utilities, environmental performance, and energy efficiency.

Various kinds of DEA models have been proposed and applied to measure environmental performance. Zhou, Ang, and Poh (2006) modeled environmental performance by a slacks-based efficiency approach based on DEA techniques and applied measures to model CO_2 emissions. Munksgaard, Christoffersen, and Keiding (2007) proposed a DEA-based environmental performance index taking into account the effect of environmental damage cost of