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A novel network data envelopment analysis model for evaluating green supply chain management

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ABSTRACT

Green supply chain management (GSCM) has become a method to improve environmental performance. Under stakeholder pressures, forces and regulations, companies need to improve the GSCM practice, which are effected by practices such as green purchasing, green design, product recovery, and collaboration with patrons and suppliers. As companies promote the GSCM, their economic performance and environmental performance will be enhanced. Hence, GSCM evaluation is very important for any company. One of the techniques that can be used for evaluating GSCM is data envelopment analysis (DEA). Traditional models of data envelopment analysis (DEA) are based upon thinking about production as a "black box". One of the drawbacks of these models is to omit linking activities. The objective of this paper is to propose a novel network DEA model for evaluating the GSCM in the presence of dual-role factors, undesirable outputs, and fuzzy data. A case study demonstrates the application of the proposed model. A case study demonstrates the applicability of the proposed model.

1. Introduction

As Bose and Pal (2012) address, in recent years, green supply chain management (GSCM) initiatives have gained substantial prominence. Srivastava (2007) describes GSCM as a combination of environmental thinking and supply chain management (SCM) encompassing product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumer, and end-of-life management of the product. Firms typically expect their suppliers to go beyond environmental compliance and undertake efficient, green product design, life cycle assessment and other related activities. By having extensive supplier selection under their performance evaluation, firms tend to leverage staff resources throughout the firm to eliminate the environmental impacts (Tseng et al., 2009; Tseng, 2010b). Hence, the firms' supplier must satisfy the GSCM criteria under the constraint of incomplete information and subjective human preferences, a phenomenon that has rarely been thoroughly examined (Tseng and Chiu, 2013).

Data envelopment analysis (DEA) is a nonparametric mathematical tool for assessing the relative efficiency of homogeneous decision making units (DMU). DEA has been applied in many sectors such as education, health care, finance, utilities, etc. Traditional studies in DEA consider a DMU as a whole system, while ignoring the operation of individual processes within a DMU. In reality, conventional DEA models consider the DMU as a black box with single-process. However, there are a number of so-called network DEA (NDEA) approaches that consider the whole system as composed by distinct processes or stages, each one with its own inputs and outputs and with intermediate flows among the stages. The NDEA, for the first time, was introduced by Färe and Grosskopf (2000). Then Lewis and Sexton (2004) proposed a multi-stage structure for NDEA. Tone and Tsutsui (2009) proposed a slack based network DEA model, called Network SBM, which could deal with intermediate products. Also, Kao (2009) considered two parallel and series structures for internal parts of DMU.

In some situations there is a strong argument for permitting certain factors to simultaneously play the role of both inputs and outputs. These factors are called dual-role factors. Beasley (1990, 1995), in a study of the efficiency of university departments, treated research funding as dual-role factor. However, as Cook et al. (2006) addressed, the model proposed by Beasley (1990, 1995) has two limitations. The first limitation is that in the absence of constraints (e.g., assurance region or cone ratio) on the multipliers, each DMU will be 100% efficient. The second limitation is that the dual-role factor is considered as a discretionary factor. Cook et al. (2006) developed a new model that has not the abovementioned limitations. To select the best technologies, Farzipoor Saen (2010a) developed a model in the presence of dual-role factor.

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DEA measures the relative efficiency of DMUs with multiple performance factors that are grouped into outputs and inputs. Once the efficient frontier is determined, inefficient DMUs can improve their performance to reach the efficient frontier by either increasing their current output levels or decreasing their current input levels. In conducting efficiency analysis, it is often assumed that all outputs are "good." However, such an assumption is not always justified because outputs may be "bad." For example, if inefficiency exists in production processes where final products are manufactured along with the production of waste and pollutants, then the respective outputs of waste and pollutants are undesirable (bad) and should be reduced in order to improve performance (Farzipoor Saen, 2010b).

DEA sometimes faces with the situation of imprecise data. Generally speaking, uncertain information or imprecise data can be expressed in interval or fuzzy number (Wang et al., 2005). In many settings, it is necessary to consider the existence of fuzzy data when rendering a decision on the performance of a DMU. Very often, it is the case that for a factor such as supplier risk, one can, at most, give his viewpoint on the DMUs from best to worst relative to this attribute. The capability of providing a more precise, quantitative measure reflecting such a factor is generally beyond the realm of reality. In some situations such factors can be legitimately quantified, but very often such quantification may be superficially forced as a modeling convenience. Therefore, the data may be fuzzy.

The objective of this paper is to propose a new network DEA model to evaluate GSCM in the presence of dual-role factors, undesirable outputs, and fuzzy data.

This paper proceeds as follows. In Section 2, literature review is presented. Proposed model and case study are discussed in Sections 3 and 4, respectively. Concluding remarks are illustrated in Section 5.

2. Literature review

In the following subsections, various studies on the GSCM, DEA, undesirable factors, dual-role factors, and fuzzy set theory are briefly summarized.

2.1. Green supply chain management (GSCM)

As Lin (2013) addresses, supply chain (SC) and SCM concepts have been addressed as one of the most significant managerial trends. Supply chain is identified to consist of manufacturers, suppliers, transporters, warehouses, retailers, and customers, all of which directly or indirectly contribute to fulfilling customer requests (Chopra and Meindl, 2001). Based on this definition, Supply Chain Council defines supply chain management to be a process involving suppliers to customers, aiming to manage supply and demand and coordinate activities from raw material purchasing to manufacturing, assembly, warehousing, inventory tracking, order entry and management, and distribution. In other words, SCM ranges from producing to delivering final products or services to the customers. Li and Wang (2007) prove that SCM integrates internal operational decisions and activities with external customer demands to improve competitiveness and profit. Kannan et al. (2009) utilized an integrated model which analyzes and chooses green suppliers based on their environmental performance using the interpretive structural modeling (ISM) and analytic hierarchy process (AHP). Tseng (2010a) used fuzzy set theory with gray possible degree to assess GSCM criteria in the supplier selection. This study investigates the consistency approaches by factor analysis that determines the adoption and implementation of GSCM in Taiwanese electronic industry. The fuzzy AHP method is applied to prioritize the relative significance of four dimensions and twenty approaches among nine enterprises in electronic industry. In addition, Tseng (2010b) examined a set of qualitative and quantitative measurements of ecological practice in knowledge management capability by a new hybrid multi criteria decision-making (MCDM) model to address the dependence relations of criteria with the integration of the analytical network process (ANP) and DEMATEL. Chang et al. (2011) analyze fuzzy DEMATEL approach to identify influential factors in selecting SCM suppliers. To deal with the vagueness of human being's perceptions, Lin (2013) utilizes the fuzzy set theory and decision making trial and assessment laboratory method to form a structural model to find out the cause and effect relationships among criteria.

2.2. DEA and network DEA

DEA is a powerful mathematical method that utilizes linear programming to determine the relative efficiencies of a set of functionally similar DMUs. A DMU is considered efficient when no other DMUs can produce more outputs using an equal or lesser amount of inputs. The DEA generalizes the usual efficiency measurement from a single-input single-output ratio to a multiple-input multiple-output ratio by using a ratio of the weighted sum of outputs to the weighted sum of inputs. A score of one is assigned to the frontier (efficient) DMUs. Charnes et al. (1978) originally proposed the first DEA model known as the Charnes, Cooper and Rhoades (CCR) model.

DEA makes no assumptions concerning the internal operations of a DMU. Rather, DEA treats each DMU as a "black box" by considering only the inputs consumed and outputs produced by each DMU. This perspective is often appropriate and sufficient. For example, if the purpose of the analysis is to identify inefficient DMUs and evaluate the extent of their inefficiency, then a "black box" approach is adequate. However, such an approach provides no insight regarding the sources of inefficiency and cannot provide process-specific guidance to DMU managers to help them improve the DMU's efficiency (Lewis and Sexton, 2004). Many production systems have a network structure, where the production process of the DMU is divided into sub-processes, so that intermediate products are outputs of one sub-process and become the inputs of another sub-process. Considering this, Färe and Grosskopf (1996, 2000) proposed a DEA framework based on the axiomatic production approach of Shephard and Färe (1980). This structure is designed to gauge the efficiency of a DMU. In recent years, network DEA models have been developed by many researchers; for example, Sexton and Lewis (2003), Lewis and Sexton (2004), Färe et al. (2007), Kao and Hwang (2010), Cook et al. (2010), and Yang and Liu (2012). In these studies, efficiencies are measured using the radial model.

2.3. Fuzzy set theory

The theory of fuzzy set has been developed to deal with the concept of partial truth values ranging from absolutely true to absolutely false. Fuzzy set theory has become the prominent tool for handling imprecision or vagueness aiming at tractability, robustness and low cost solutions for real-world problems. According to Zadeh (1975), it is very difficult for conventional quantification to reasonably express complex situations and it is necessary to use linguistic variables whose values are words or sentences in a natural or artificial language. The potential of working with linguistic variables, low computational cost and easiness of understanding are characteristics that have contributed to the popularity of this approach. Fuzzy set algebra developed by Zadeh (1965) is the formal body of theory that allows the treatment of imprecise and vague estimates in uncertain environments.

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