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Evaluating sustainability of supply chains by two-stage range directional measure in the presence of negative data

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ABSTRACT

Assessing sustainability of supply chains is a critical and increasingly complex problem. In recent years sustainability has received more attention in supply chain management (SCM) literature with triple bottom lines including social, environmental, and economic factors. Conventional data envelopment analysis (DEA) models consider decision making units (DMUs) as black boxes that consume a set of inputs to produce a set of outputs and do not take into consideration internal interactions of DMUs. Two-stage DEA models deal with such DMUs. However, existing two-stage DEA models are applicable only in technologies characterized by positive inputs/outputs. This paper aims to build and present a new two-stage DEA model considering negative input-intermediate-output data. Some numerical examples along with some theorems and properties are given to show capability of proposed method. The proposed ideas are used in a case study where 29 Iranian supply chains producing equipment of expendable medical devices are evaluated in terms of sustainability.

1. Introduction

Outsourcing and supply base reduction have increased reliance of buyers on their suppliers (Ballew and Schnorbus, 1994; Handfield and Nichols, 1999; Shaverdi et al., 2013). Tseng and Chiu (2013) identified appropriate environmental and non-environmental criteria for supply chain management (SCM) and developed a new method using grey relational analysis. In recent years sustainability has received more attention in SCM literature with triple bottom lines including social, environmental, and economic factors (Büyüközkan and Çifçi, 2011; Clift, 2003; Gauthier, 2005; Martins et al., 2007). Sustainability reflects economic, environmental, and social performance of an organization (Floridi et al., 2011). Sustainability factors play a critical role for long-term achievement of a SCM and purchasing process becomes more complicated with social and environmental pressures (Bai and Sarkis, 2010; Seuring and Müller, 2008). Nowadays, global concerns about sustainability have increased substantially. Activists, media, consumers, and non-governmental organizations are stimulating corporations to extend their responsibility and consider sustainability in their decisions and operations (Govindan et al., 2015). Sustainable operations are needed to create value and customer care, and these may be implemented by focusing on social development, environmental protection, and economic development (Lin et al., 2015; Sridhar and Jones, 2013). However, to deal with sustainability there is a need to incorporate social factors such as social equity and employee health. Hutchins and

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Sutherland (2008) proposed a methodology that reviewed metrics, indicators, and frameworks of social impacts and initiatives to evaluate social sustainability of supply chains.

Data envelopment analysis (DEA) is a non-parametric method for measuring relative efficiency of a set of decision making units (DMUs) that use multiple inputs to produce multiple outputs (Shabani et al., 2012). Typically, a single stage production process is assumed to transform inputs to final outputs and is treated as a black box. In contrast to the black-box approach, real-world production systems often have network structure. There is an increasing literature body that is devoted to efficiency assessment in multistage production processes. Castelli et al. (2010) provided a comprehensive review of models and methods developed for different multi-stage production structures. In recent years, many researchers studied various DEA models for evaluating efficiencies of two-stage systems. However, all previous studies have discussed two-stage DEA models with nonnegative data. There is no discussion, except for Lu et al. (2014), on two-stage DEA models in the presence of negative data. Our proposed model is quite different from Lu et al. (2014). In real world, in some cases, the inputs, intermediate measures, and outputs may have negative values such as loss when net profit is an output variable; or in efficiency evaluation of universities, rate of educational growth can be considered as an output which can take a negative value (Kazemi Matin and Azizi, 2011).

In this paper, we propose a new DEA model for measuring efficiency of DMUs in the presence of negative data and prove some important properties for the proposed model. Then, based on the proposed model, we develop a two-stage DEA model where each DMU is composed of two sub-DMUs in series, and all intermediate measures are considered as inputs of sub-DMU in stage 2. We present a single linear DEA model for solving a two-stage DEA model in the presence of negative data and present some interesting properties. By solving the proposed single model, we can calculate the efficiency of sub-DMUs in the first and second stages and also we assess overall efficiency of DMUs. Our proposed model has many useful properties. For instance, it is always feasible and bounded. Main contribution of this paper is to develop a new two-stage non-radial DEA model for handling negative data.

The paper unfolds as follows. Literature review is presented in Section 2. Section 3 reviews some required concepts. The proposed model for measuring the efficiency in the presence of negative data is appeared in Section 4. Section 5 shows the proposed two-stage DEA model. Case study is given in Section 6. Finally, in Section 7 concluding remarks are presented.

2. Literature review

2.1. Sustainable supply chain management

Following comprehensive definition of sustainable supply chain management (SSCM) was given by Ahi and Searcy (2013):

"The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term".

SSCM comprises environmental, social, and economic practices. SSCM includes product design, material selection, manufacturing, packaging, transportation, warehousing, distribution, and consumption. Therefore, as addressed by Badurdeen et al. (2009), SSCM is a process of involvement in planning and management of sourcing, procurement, conversion, and logistics activities during pre-manufacturing, manufacturing, use, and post-use stages in product life cycle among companies by considering the social and environmental factors. Goebel et al. (2012) and Vachon and Klassen (2007) investigated influence of ethical culture on supplier selection in the context of sustainable sourcing. The first step in developing a sustainable supply chain is to re-define basic structure of entire supply chain by incorporating sustainability concerns into design and management of supply chain (Govindan et al., 2015). Traditionally, companies consider criteria such as price, quality, flexibility, and supplier reputation when evaluating performance of supply chains. Sustainability factors play a critical role for long-term achievements of a SCM and purchasing process becomes more complicated with social and environmental pressures (Bai and Sarkis, 2010; Seuring and Müller, 2008). In Fig. 1, sustainability factors are shown (Büyüközkan and Çifçi, 2011; Martins et al., 2007).

To incorporate sustainability factors into supplier selection problem, Bai and Sarkis (2010) utilized grey system and rough set theory. Amindoust et al. (2012) listed sustainable supplier selection criteria and sub-criteria and based on those criteria and sub-criteria a methodology was proposed to rank suppliers. Indeed, in the last two decades, academicians have increasingly focused on SSCM as is evidenced by numerous articles that have appeared in leading academic journals (Ahi and Searcy, 2013; Govindan et al., 2013; Seuring, 2013). Although a consensus definition for sustainable supply chains does not exist, SSCM can be defined as incorporating various dimensions of social, economic, and environmental factors into SCM (Ahi and Searcy, 2013).

Organizations should add environmental and social aspects to traditional assessment of supply chains (Amindoust et al., 2012). In Table 1, a summary of criteria are reported.