Computers and Operations Research 100 (2018) 343–367

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

# Assessing sustainability of supply chains by chance-constrained two-stage DEA model in the presence of undesirable factors

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ARTICLE INFO

*Article history:*
Received 17 March 2016
Revised 3 March 2017
Accepted 3 October 2017
Available online 4 October 2017

*Keywords:*
Sustainability of supply chain
Chance-constrained data envelopment analysis (DEA)
Intermediate products
Efficiency
Two-stage DEA model
Undesirable data
Stochastic data

ABSTRACT

Sustainable supply chain is recognized as a key component of corporate responsibility. Despite conventional data envelopment analysis (DEA) models that view decision making units (DMUs) as black boxes, two-stage DEA models take into account intermediate measures within a DMU. However, there might be stochastic data. Objective of this paper is to present a new stochastic two-stage DEA model in the presence of undesirable data. We present some linear models that obtain lower and upper bounds of efficiencies of stages 1 and 2. Also, we propose a linear model that calculates overall efficiency of DMUs. Meanwhile, we extend our proposed model for dealing with stochastic data in the presence of undesirable data. A case study demonstrates applicability of our approach.



## 1. Introduction

It is well known that supply chain management (SCM) is an integral part of most businesses and is essential to company success and customer satisfaction (Bowersox). Bowersox (1996) defined supply chain management as "all those activities associated with transformation and flow of goods and services, including their attendant information flows, from sources of materials to end users." In recent years, sustainability has received more attention in SCM literature with triple bottom-lines describing sustainability in SCM with social, environmental, and economic initiatives (Büyüközkan and Çifçi, 2011; Clift, 2003; Gauthier, 2005; Martins et al., 2007). Sustainability reflects economic, environmental, and social performance of an organization. Sustainability factors play 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). 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 Sutherland (2008) proposed a methodology that reviewed metrics, indicators, and frameworks of social impacts and initiatives to evaluate social sustainability of supply chains. Fierce competition in markets forces Iranian pasta factories as food supply chains to have a quick response to customers' requirements. Pasta is the most important cereal product in terms of variety, shapes, nutritive value, and manner of consumption. Pasta supply chains produce and supply different kinds of pastas using raw materials to meet its customers' requirements. Main raw material in producing pasta is Semolina flour and determining the most sustainable pasta supply chain is our main aim. To this end, this paper applies data envelopment analysis (DEA) technique.

DEA is an effective non-parametric evaluation method for measuring relative efficiency of a set of decision making units (DMUs) that use multiple inputs to produce multiple outputs (Charnes et al., 1978). Typically, DEA assumes a single stage production process that transforms inputs to final outputs (Toloo and Tichý, 2015; Tavassoli et al., 2014; Farzipoor Saen and Zohrehbandian, 2008; Shabanpour et al., 2017). However, there is an increasing literature body that is devoted to efficiency assessment in multistage production processes. Castelli et al. (2010) provided a comprehensive categorized overview of models and methods developed for different multi-stage production architectures. As discussed in many DEA studies, DMUs can have a two-stage structure where the first stage uses inputs to generate outputs that then become the inputs to the second stage. The first stage outputs are

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https://doi.org/10.1016/j.cor.2017.10.002
0305-0548/

referred as intermediate measures (Du et al., 2014; Ebrahimnejad et al., 2014; Izadikhah and Farzipoor Saen, 2016a; Kao and Hwang, 2008; Liu et al., 2015; Ma, 2015; Toloo et al., 2015). Our motivation for developing a two-stage DEA model is due to special structure of pasta supply chains. In pasta supply chains, we deal with two-stage supply chains such that the first stage supplies Semolina flour and the second stage produces pasta.

In real world, there are many undesirable inputs and outputs such as $CO_2$ emission in producing electricity, noise, etc (Färe and Grosskopf, 2004). For example, "rate of inferior raw materials" and "average of consumer prices" are undesirable outputs of the first and second stages, respectively. Also, "depreciation of fixed assets" is an undesirable input. DEA has recently made a substantial contribution in analyzing undesirable outputs.

On the other hand, in real world, there might be stochastic data. Classical DEA models assume that inputs and outputs are deterministic. Unfortunately, real world situations are often not deterministic, and some factors such as supplies' volume and demands are usually changing (Tavana et al., 2014). Hence we should deal with the supplier evaluation problem under uncertainty. As Wu and Lee (2010) and Roostaee et al. (2012) addressed, suppliers face with considerable uncertainty in terms of demand for their products. Uncertainty manifests itself in unknown selling price and in unknown duration of marketing period. As a result, the main objective of this paper is to develop a new stochastic two-stage DEA model considering undesirable input-intermediate-output. We present some linear models that set lower and upper bounds of efficiencies for two stages. Then, we propose a linear model that calculates overall efficiency of DMUs. Main contributions of this paper are as follows:

- By extending the idea of Liu et al. (2015), our proposed two-stage DEA model considers undesirable factors in which there are two kinds of intermediate products: (i) some intermediate outputs are undesirable for the first stage, but are desirable inputs for the second stage; (ii) some intermediate outputs are desirable for the first stage, but are undesirable inputs for the second stage.
- We develop a two-stage DEA model that simultaneously considers stochastic data and undesirable data.
- We develop a stochastic two-stage DEA model in presence of undesirable data for evaluating sustainability of SCM.

The paper unfolds as follows. Section 2 presents literature review. Our new two-stage DEA model in the presence of undesirable factors is presented in Section 3. The stochastic version of our proposed model is presented in Section 4. Section 5 provides a case study. Finally, concluding remarks are given in Section 6.

## 2. Literature review

### 2.1. Sustainable supply chain models

Sustainable SCM is management of environmental, social, and economic impacts, and encouragement of good governance practices throughout lifecycles of goods and services. Objective of sustainable SCM is to create, protect, and grow long-term environmental, social, and economic values for all stakeholders in supply chain. Goebel et al. (2012) and Vachon and Klassen (2007) investigated influence of ethical culture on supplier selection in context of sustainable sourcing. Traditionally, companies consider criteria such as price, quality, flexibility, and supplier reputation when evaluating supplier performance. 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). Scholars have tried to incorporate sustainability factors into supplier selection problem. Here, we list main criteria of sustainability. In Table 1, a summary of criteria are reported.

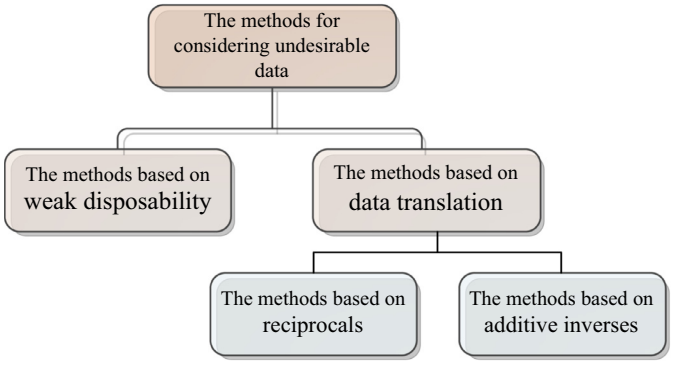


**Fig. 1.** The various methods of considering undesirable data.

### 2.2. DEA and SCM

Given importance of assessing sustainability, Bai and Sarkis (2010) utilized grey system and rough set theory. Kleinsorge et al. (1992) used DEA to track performance of suppliers. Weber (1996) used DEA for evaluating suppliers in a baby food manufacturing company. Table 2 summarizes previous works for supplier selection using DEA.

### 2.3. Two-stage DEA models

Färe and Grosskopf (1996) and Färe and Whittaker (1995) were pioneers in the field of two-stage DEA models and applied an input-oriented two-stage DEA model to study relative efficiency of dairy production. Up to now, a couple of authors have presented two-stage DEA models. Table 3 summarizes previous works for two-stage DEA models.

### 2.4. Undesirable data in DEA

In practice, DMUs may generate undesirable outputs such as pollution, noise, etc. There are a couple of DEA approaches that can handle this situation. Fig. 1 shows various methods for considering undesirable data in DEA.

From Fig. 1, it is clear that there are two main methods for considering undesirable data; (i) methods based on weak disposability, (ii) methods based on data translation. See Table 4 for a breif survey in DEA models that deal with undesirable data. As is seen, many previous works dealt with undesirable data based on additive inverses.

### 2.5. Stochastic DEA

Traditional DEA models assume that the inputs and outputs are deterministic. However, real-world problems are often not deterministic, and some factors are usually stochastic. Chance-constrained programming is a kind of stochastic optimization approach to handle uncertainty in inputs and outputs. Sengupta, (1987) was the pioneer in this subject who developed the stochastic version of DEA model. After that Retzlaff-Roberts and Morey, (1993) applied goal-programming approach to develop stochastic DEA model. Table 5 shows DEA works related to stochastic data.

### 2.6. Gaps in literature

In this paper, we present a new two-stage DEA model's structure and a linear model that calculates overall efficiency of DMUs.