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Developing a novel model of data envelopment analysis–discriminant analysis for predicting group membership of suppliers in sustainable supply chain

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ABSTRACT

The objective of this paper is to present a novel model of data envelopment analysis–discriminant analysis (DEA–DA) for predicting group membership of suppliers in sustainable supply chain context. Our new model can predict group membership of the suppliers with respect to the nature of factors including inputs, outputs, and efficiency of each supplier. To demonstrate applicability of this new DEA–DA model, using a case study, the initial DEA–DA model developed by Sueyoshi (1999) is analyzed and compared with our proposed model. The results of the analysis show that our new DEA–DA model presents more precise prediction of sustainable suppliers' group membership.

1. Introduction

Sustainable supply chain management (SSCM) is an integration of sustainable development and supply chain management (SCM) in which sustainability is defined with regard to environmental, social, and economic factors [14]. Sustainable supply chain not only takes into account economic factors, but also green and social factors. In past decade, due to sharp decline in natural resources and the ever-increasing assets of huge organizations, sustainability in supply chain has captured growing attention as a crucial social responsibility of the companies [10]. The SSCM has recently attracted growing attention of organizations and research centers. Having considered the three major social, economic, and environmental factors, sustainable supply chain has turned into the most popular and widely-applied approach in the supply chain. The SSCM is a concept ensuring environmentally friendly practices in traditional supply chains [7]. Supply chain sustainability influences an organization's supply chain or logistics network in terms of environmental, risk, and waste costs [13]. To implement sustainability in operations, it is essential to incorporate sustainability in each stage of an organization's supply chain. One aspect of the SSCM is to manufacture sustainable products in which procuring sustainable items plays a key role. Accordingly, sustainable procurement can aid a manufacturer to move towards sustainable manufacturing [9]. Due to the changing expectations of organizations' stakeholders, companies are increasingly responsible for the actions of their suppliers. For companies that aim at implementing sustainable strategies it is necessary to look at upstream. In other words, if a company is capable of selecting among various suppliers, it can apply its purchasing power to make its suppliers comply with green supply chain standards. When it comes to managing suppliers, companies need to make sure about the high quality of the inputs from suppliers as well as the minimal water and energy usage which, in turn, results in less pollution and defects. In addition, they should audit their suppliers and make sure they are improving the supply chain metrics [12]. Effective supply chain management involves considering multiple tiers of partners carefully, particularly with regard to sustainability issues. Organizations increasingly urge their sub-suppliers to comply with social and environmental efforts [11]. At the moment, with the ever-growing knowledge about sustainability in enterprises, selecting sustainable suppliers would be the most vital component in managing a sustainable supply chain [2].

Data envelopment analysis–discriminant analysis (DEA–DA) predicts group membership of decision making units (DMUs). DEA–DA has had a number of applications. Here we name only a couple of applications of DEA–DA such as ranking the efficiency of DMUs [18], predicting suppliers' group membership in automotive

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industry [5], predicting customers' group membership and classifying them based on customers' pyramid [8], evaluation of quality control processes [15], presenting a new goal programing for handling the issue of multi-group classification through integrating ideal goal programing and DEA–DA [3], evaluation of business failure in construction industry [17], and predicting clients' loans using DEA–DA and neural networks [6]. However, none of the above-mentioned works have dealt with nature of the selected factors for predicting group membership of DMUs.

In this paper, various sustainability factors are considered for predicting the suppliers' group membership. Accordingly, suppliers are classified based on the social, economic, and environmental factors, simultaneously. Numerous studies have been done to assess performance of suppliers. Given Sueyoshi's [16] DEA–DA model, Boudaghi and Farzipoor Saen [5] predicted suppliers' group membership in supply chain. However, they did not deal with the nature of inputs and outputs of suppliers. The weakness of Sueyoshi [16] model is that it ignores the nature of inputs and outputs; i.e., it considers inputs and outputs of each supplier as factors with similar nature.

All classic DEA–DA models deal with factors similarly. In other words, classical DEA–DA models predict the group membership of observations without considering nature of factors. Some factors are decreasing (inputs) and some are increasing (outputs). As a result, we get unreasonable and false conclusions. For example, assume that a manager wants to predict group membership of 50 branches given sales volume, level of satisfaction of buyers, and cost. Sales volume and satisfaction of buyers are good factors (outputs) while cost is bad factor (input). As a result, nature of factors is not similar. Former DEA–DA models deal with good and bad factors in the same way. In this paper, we propose a novel DEA–DA model to predict group membership of observations given nature of inputs and outputs.

Now, question is how important is recognition of the nature of factors for predicting group membership of DMUs. To answer this question, imagine a business manager wants to predict group membership of 100 suppliers given cost, quality, delivery time, and experience. Nature of price and delivery time are not similar to nature of quality and experience. It is clear that supplier that is more experienced and provides high quality material along with less price and delivery time has higher priority. Our new DEA–DA model can take into account nature of inputs and outputs while previous DEA–DA models do not care about nature of inputs and outputs and they deal with inputs and outputs in the same way.

Given the nature of inputs, outputs, and efficiency, this paper proposes a new DEA–DA model for predicting the suppliers' group membership in the SSCM context. Since in this paper we wish to predict the sustainable suppliers' group membership, the social, economic, and environmental factors are taken into account. To demonstrate the advantages of this new DEA–DA model, using a case study, the DEA–DA model developed by Sueyoshi [16] is compared with our proposed model. Given inputs, outputs, and efficiency of suppliers, we will show that our new DEA–DA model precisely predicts the group membership of suppliers. The contributions of this paper are as follows:

- For the first time, we extend a new DEA–DA model based on BCC model.
- For the first time, we develop a sort of DEA–DA model that takes into account nature of factors in terms of inputs, outputs, and efficiency scores.
- For the first time, we apply DEA–DA in assessing sustainability of suppliers.
- Our proposed DEA–DA model predicts group membership of DMUs accurately.

This paper in organized as follows: Section 2 elaborates the DEA–DA model developed by Sueyoshi [16]. Section 3 presents the case study and analyzes the results of Sueyoshi's model. Section 4 introduces our new DEA–DA model. Section 5 analyzes sensitivity of Sueyoshi's model and our proposed DEA–DA model. Finally, in Section 6 conclusions are presented.

In next section, we describe former DEA–DA model and explain weakness of this model.

2. Analyzing the two-stage DEA–DA model of Sueyoshi [16]

2.1. The first stage of DEA–DA model

To predict the group membership of the DMUs, Sueyoshi [16] presented the DEA–DA model in which he integrated the additive and discriminant analysis models. Suffering from the drawback of not considering the nature of factors, Sueyoshi's DEA–DA model is discussed here to be revised. The rationale behind this is to reconfigure the model so that it would not only precisely and objectively predict the suppliers' group membership, but also maintains the nature of inputs, outputs, and efficiency. Model (1) outlines the first stage of the DEA–DA. In this model, the existing overlap of the two groups (G_1 and G_2) is identified. It is assumed, in this model, that n DMUs ($j = 1,\ldots,n$) exist. Each DMU has k independent factors ($i = 1,\ldots,k$) that characterize its performance. z_{ij} indicates each DMU's record. In the DEA–DA, through certain statistical approaches, it is already known to which group each DMU belongs. The G_1 and G_2 include n_1 and n_2 DMUs, respectively. Therefore, $n_1+n_2=n$. d is a threshold value, and α_i ($i = 1,\ldots,k$) for $j \in G_1$ and $\beta_i(i=1, \ldots, k)$ for $j \in G_2$ are estimates (weights). d, α_i, β_i, s^+_{1j}, s^-_{2j}, s^-_{1j} and s^+_{2j} are unknown and should be estimated by model (1). Slacks, s^+_{1j} and s^-_{2j} indicate deviations from G_1 and G_2, respectively. Each slack shows the distance between $\sum_{i=1}^{k} \alpha_i z_{ij}$ and $\sum_{i=1}^{k} \beta_i z_{ij}$ from the threshold value (d). Likewise, additional slacks (s^-_{1j} and s^+_{2j}) represent proper classification as follows:

$$s^-_{1j} > 0 \leftrightarrow \sum_{i=1}^{k} \alpha_i{}^* Z_{ij} > d^*, \quad j \in G_1,$$
$$s^+_{2j} > 0 \leftrightarrow \sum_{i=1}^{k} \beta_i{}^* Z_{ij} < d^*, \quad j \in G_2,$$

Moreover, η creates a gap between the two groups. η is determined by decision maker. We assume η is equal to 1 in Models (1) and (2). Optimal solution (α_i^*, β_i^*, and d^*) forms two piecewise linear functions for separating the two groups.

$$\begin{aligned} \min \quad & \sum_{j\in G_1} S^+_{1j} + \sum_{j\in G_2} S^-_{2j} \\ s.t. \quad & \sum_{i=1}^{k} \alpha_i Z_{ij} + S^+_{1j} - S^-_{1j} = d, \quad j \in G_1, \\ & \sum_{i=1}^{k} \beta_i Z_{ij} + S^+_{2j} - S^-_{2j} = d - \eta, \quad j \in G2 \\ & \sum_{i=1}^{k} \alpha_i = 1, \\ & \sum_{i=1}^{k} \beta_i = 1, \end{aligned} \tag{1}$$

all slacks ≥ 0, $\alpha_i \geq 0$, $\beta_i \geq 0$, d: unrestricted in sign.

The stage 1 outlines process in which the overlap is identified. Two kinds of wrong classifications are identified here; i.e. DMUs in G_1 are classified into G_2 and/or vice versa. In model (1), all of the factors are connected to each other by two piecewise linear functions; i.e. $\sum_{i=1}^{k} \alpha_i = 1$ and $\sum_{i=1}^{k} \alpha_i Z_{ij}$ as well as $\sum_{i=1}^{k} \beta_i = 1$ and $\sum_{i=1}^{k} \beta_i Z_{ij}$. In other words, the observations (DMUs) are all connected and form two piece-wise linear hyperplanes in