Measurement 53 (2014) 277–296

Contents lists available at ScienceDirect

Measurement

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

A new two-stage Stackelberg fuzzy data envelopment analysis model

Madjid Tavana [a,b,*], Kaveh Khalili-Damghani [c]

[a] Business Systems and Analytics Department, Lindback Distinguished Chair of Information Systems and Decision Sciences, La Salle University, Philadelphia, PA 19141, USA

[b] Business Information Systems Department, Faculty of Business Administration and Economics, University of Paderborn, D-33098 Paderborn, Germany

[c] Department of Industrial Engineering, Faculty of Industrial Engineering, South-Tehran Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article history:
Received 13 January 2014
Received in revised form 21 February 2014
Accepted 27 March 2014
Available online 4 April 2014

Keywords:
Two-stage DEA
Fuzzy set
Efficiency decomposition
Leader–follower
Stackelberg game
Banking

ABSTRACT

Data Envelopment Analysis (DEA) is a widely used mathematical programming approach for evaluating the relative efficiency of Decision Making Units (DMUs). Conventional DEA methods treat DMUs as "black boxes", focusing entirely on their relative efficiencies. We propose an efficient two-stage fuzzy DEA model to calculate the efficiency scores for a DMU and its sub-DMUs. We use the Stackelberg (leader–follower) game theory approach to prioritize and sequentially decompose the efficiency score of the DMU into a set of efficiency scores for its sub-DMUs. The proposed models are linear and independent of the α-cut variables. The linear feature allows for a quick identification of the global optimum solution and the α-cut independency feature allows for a significant reduction in the computational efforts. Monte Carlo simulation is used to discriminately rank the efficiencies in the proposed method. We also present a case study to exhibit the efficacy of the procedures and to demonstrate the applicability of the proposed method to a two-stage performance evaluation problem in the banking industry.

1. Introduction

Data Envelopment Analysis (DEA) is a non-parametric mathematical programming approach that evaluates a group of Decision Making Units (DMUs) with comparative efficiencies. DEA generalizes the Farrell [24] 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 [15]. Although DEA can evaluate the relative efficiency of a set of DMUs, it cannot identify the sources of inefficiency in the DMUs because conventional DEA models view DMUs as "black boxes" that consume a set of inputs to produce a set of outputs. A two-stage DEA model extends the basic DEA methodology by considering two sub-DMUs in a main DMU and allowing a "look inside" the DMU to study the sources of inefficiencies [59]. The sub-DMUs are related through a series relation and all the outputs of the first sub-DMU in Stage 1 are used as inputs of the second sub-DMU in Stage 2. The outputs of the first sub-DMU, known as "intermediate measures", are considered as the inputs of the second sub-DMU and no extra inputs are supplied for the second sub-DMU except for the outputs of the first sub-DMU [19,55].

In addition, the conventional DEA methods such as CCR [14] and BBC [7] require accurate measurement of both the

* Corresponding author at: Business Systems and Analytics Department, Lindback Distinguished Chair of Information Systems and Decision Sciences, La Salle University, Philadelphia, PA 19141, USA. Tel.: +1 215 951 1129; fax: +1 267 295 2854.

E-mail addresses: tavana@lasalle.edu (M. Tavana), kaveh.khalili@gmail.com (K. Khalili-Damghani).

URLs: http://tavana.us/ (M. Tavana), http://kaveh-khalili.webs.com (K. Khalili-Damghani).

http://dx.doi.org/10.1016/j.measurement.2014.03.030
0263-2241/

inputs and outputs. However, the observed values of the input and output data in real-world problems are often imprecise or vague. Imprecise or vague data may be the result of unquantifiable, incomplete, and/or non-obtainable information. In recent years, many researchers have formulated DEA models to deal with the uncertain input and output data. One way to manipulate uncertain data in DEA is via probability distributions. However, probability distributions require either *a priori* predictable regularity or *a posteriori* frequency determinations which are difficult to construct. Cooper et al. [20] has studied this problem in the context of interval data. However, many real-life problems use linguistic variables that cannot be represented with interval values. An alternative approach is to represent the imprecise or vague values by membership functions of fuzzy set theory. Fuzzy set algebra developed by Zadeh [67] is the formal body of theory that allows the treatment of imprecise estimates in uncertain environments.

In this study, we propose an efficient method for solving two-stage fuzzy DEA problems and demonstrate the applicability of the proposed method in the banking industry. The proposed model has the following unique features: (1) it is independent of the α-cut variables (minimizing the computational efforts); (2) it does not require the step-size of α-cut variables based on heuristic rules and trial and error; (3) it is linear (producing global optimum solutions); and (4) it uses a procedure based on the Monte Carlo simulation method to discriminately rank the efficient DUMs and sub-DMUs.

In Section 2, we review performance measurement in the banking industry and examine the two-stage DEA models in the literature. In Section 3, we review the conventional two-stage DEA method. In Section 4, we present the details of the two-stage fuzzy DEA method proposed in this study. In Section 5, we present a case study to exhibit the efficacy of the procedures and to demonstrate the applicability of the proposed method to a two-stage performance evaluation problem in the banking industry. In Section 6, we conclude with our conclusions and future research directions.

2. Literature review

Evaluating the overall performance and monitoring the financial condition of commercial banks has been the focus of numerous research studies since the early works of Greenbaum [28] and Benston [10]. DEA has been widely used to measure the relative efficiency of a set of bank branches that possess shared functional goals with disproportionate inputs and outputs [3–6,16,18,35,46,49,50,55,57,58,63]. Rho and An [55] extended two-stage DEA models by considering input and output slacks. They applied their model to the data from the banking industry and compared the results with those of the previous two-stage DEA models. Akther et al. [2] proposed a two-stage DEA model with a slacks-based inefficiency measure and directional technology distance function for evaluating the performance of private commercial banks in Bangladesh. Paradi et al. [53] proposed a two-stage DEA model for simultaneously benchmarking the performance of bank branches along different dimensions. They used a modified slacks-based measure to aggregate the obtained efficiency scores from stage one and generated a composite performance index for each bank branch. Their approach improved the validity of the performance assessment method and enabled branch managers to clearly identify the strengths and weaknesses in their operations. See Liu et al. [47] for a recent survey of DEA application.

Two fundamental input–output systems are used to calculate the bank efficiencies [30]: the production approach [22,27,54] and the intermediation approach [8,9,26,31,32,48,60,61]. There is no commonly accepted approach for measuring the efficiency in the banking industry, which is why different efficiency scores are obtained using similar data [11].

Favero and Papi [25] used a sample of 174 banks and they tried to determine which of the two DEA models are more appropriate for describing the efficiency level in banking: constant returns to scale (CRS) or variable returns to scale (VRS). Pastor et al. [52] used DEA and a non-parametric approach to estimate the efficiency in the European and U.S. banking systems. They chose three outputs (loans, other productive assets, and deposits) and two inputs (non-interest expenses and personal expenses) to estimate the efficiency level in their study. Yildirim [65] used the DEA methodology to study the technical and scale efficiencies of the Turkish commercial banks. Casu and Girardone [12] used DEA to study the efficiency of the Italian banking system. Isık and Hassan [33] showed that DEA methodology could be utilized to analyze the performance of banks in transition countries. Özkan-Günay and Tektas [51] used nonparametric DEA methodology to conduct a similar study. Yildirim and Philippatos [66] evaluated the efficiency level of commercial banks in central and East-European countries by employing the stochastic frontier approach (SFA) and DFA techniques. Halkos and Tzeremes [29] proposed a bootstrapped DEA-based procedure to pre-calculate and pre-evaluate the short-run operating efficiency gains of a potential bank merger or acquisition.

Conventional DEA models consider the system under study as a black box which consumes inputs and produces outputs [4]. In such cases, using single-stage DEA may result in inaccurate efficiency evaluation [55]. In contrast, a two-stage DEA model allows one to further investigate the structure and processes inside the DMU, to identify the misallocation of inputs among sub-DMUs and generate insights about the sources of inefficiency within the DMU [23,44].

Seiford and Zhu [56] developed a two-stage DEA method characterized by profitability and marketability for evaluating commercial banks. In the first stage, they measured profitability by using labor and assets as inputs, and profits and revenue as outputs. In the second stage, they measured marketability by using the profits and revenue (outputs from Stage 1) as inputs, and market value, returns and earnings per share as outputs. Zhu [68] applied the same two-stage process to the Fortune Global 500 companies. Casu and Molyneux [13] used the non-parametric DEA approach to