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A two-stage data envelopment analysis model for measuring performance in three-level supply chains

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ABSTRACT

Data Envelopment Analysis (DEA) has been widely used to evaluate supply chain performances. In conventional DEA, supply chains are represented as black boxes where only the initial inputs and final outputs are considered to measure their efficiency. However, an integrated model measuring both the efficiency of the entire supply chain and that of all its components at all levels is essential for a comprehensive evaluation. This study presents a two-stage DEA method to evaluate the performance of a three-level supply chain including suppliers, manufacturers and distributors. The proposed model can be used both under the constant returns to scale and the variable returns to scale assumptions and can be easily implemented for comprehensive analysis of multi-level supply chains. We present a numerical example to demonstrate applicability of the proposed model and exhibit the efficacy and effectiveness of the proposed algorithms and procedures. In particular, the numerical results demonstrate that the entire supply chain is "comprehensively" efficient only if efficient supplier–manufacturer and manufacturer–distributor relationships are established.

1. Introduction

In the era of globalization, supply chains play a fundamental role in the development of an organization and in its goal of profit maximization. Competitive forces in today's business environment require organizations and companies to rely on organized methods to manage their processes more systematically. This is what allows an organization to achieve competitive advantages and gain more share from the market. Therefore, activities such as supply and demand planning, preparing materials, producing and planning products, controlling the stock, distributing, delivering and serving the customers are managed within the context of an integrated supply chain as opposed to just at a company level. Supply Chain Management (SCM) manages, controls and coordinates these activities so that the customers can receive reliable and fast services and quality products at a low cost. The activities of a supply chain begin with the customer's order and continue until he/she pays for the purchased good or received

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service. SCM must manage the flows between the various stages and within each single stage of the chain in order to maximize the total profit.

In classic Data Envelopment Analysis (DEA) the supply chain is represented as a black box where only the initial inputs and the final outputs are considered in order to measure the efficiency. That is, intermediate products are neglected. On the other hand, in SCM, all possible efficiency measures play an essential role in achieving the twofold goal of reducing the cost and enhancing the profit. In this regard, note that an independent decision maker in any component of the supply chain maximizes his/her own technical efficiency ignoring the other components and the whole chain. For this reason network models are useful to model the processes of the entire chain and hence represent the content of the black box. For supply chains consisting of a supplier, a manufacturer and a distributor, the supplier's outputs are the manufacturer's inputs and the manufacturer's outputs are, in turn, the distributor's inputs.

The DEA technique was first proposed to estimate the efficiency in nonparametric models where the efficiency values were determined for one input and one output [13]. Afterwards, Charnes et al. [3] presented the CCR model which could measure the efficiency with several inputs and outputs. Finally, the BCC model was proposed by Banker et al. [1]. Over the years, DEA has become a well-known method to deal with performance measurement problems (see among others, Emrouznejad et al. [11]; Cook et al. [9]; Kaviani and Abbasi [16]; Maghbouli et al. [21]; Matin and Azizi [22]).

Seiford and Zhu [26] proposed a standard two-stage DEA model consisting of 55 commercial banks that utilized the workforce and capital to gain profit and revenue and then produce market value, efficiency, and productivity of the stocks so that they could measure the efficiency at each stage. However, they did not assume any serial relationship between the two stages.

Kao and Hwang [15] introduced a two-stage process of DEA, i.e. profit making and premiums, for 24 non-life insurance companies in Taiwan. In the first stage, the customers interested in paying direct premiums and receiving premiums from other insurance companies were considered. In the second stage, the premiums were taken into account in the portfolio to gain investment profits. Kao and Hwang [15] modified the standard model of DEA so as to include the serial relationship between the processes of the two stages, and defined the efficiency of the whole process as a function of the efficiencies of the two separate stages.

In their two-stage DEA model, Kao and Hwang [15] assumed constant returns to scale (CRS) for the efficiency measures and proposed to evaluate the efficiency of a two-stage process as the product of the efficiencies of the two single stages. In order to also allow for variable returns to scale (VRS), Chen et al. [5] proposed to model the efficiency of a whole two-stage process as the mean weighted efficiency of the two separate stages. Finally, Wang and Chin [32], generalized the combined model of Chen et al. [5] introducing relative weights for the two separate stages.

A considerable amount of attention has been given to combining the fields of supply chain management and marketing. However, the use of DEA has been introduced in SCM only recently [31,30,6]. A supply chain is defined so as to include all the activities related to the process of converting the product from the initial input into the final product together with the analysis of all the information used in this process. SCM integrates these activities by improving the relations among the chain loops in order to achieve reliable and sustainable competitive advantages [14]. According to this definition, SCM is a set of actions that aims to integrate the chain components (i.e. suppliers, manufacturers, distributors, retailers and final customers) in order to reduce the system costs and increase the level of service provided for the customers. Other definitions of supply chain are available in Levi et al. [20] and Chopra and Meindl [8].

Two-stage DEA models can be used to analyze the inner relationships among the chain components of a supply chain, but they must be design in a suitable manner. Indeed, in many real-life examples, production processes (DMUs) comprise subunits that are connected to each other through a network: the output of a subunit may be the input of another subunit, and these interactions ultimately result in the final output production. Therefore, in many cases it may be necessary to examine the inefficiency that a DMU inherits from its subunits, which requires the use of suitable serial, parallel or network models. The basics of network modeling are illustrated by Fare et al. [12], identifying three models whose combination allows us to evaluate the efficiency of a production process by "looking inside the black box". The first model examines the distribution of different products among farms providing a general structure that can be utilized in allotting the budget or resources among all the units. The second model is an explicit one for evaluating the intermediate products, i.e. those products obtained within the technologies or industries forming the system. Finally, the third model proposes a network formulation of a dynamic DEA where some of the outputs at a period t become the inputs for the next period $t + 1$.

1.1. Contribution

A literature review on supply chains and SCM shows that so far most of the supply chain processes have been modeled using two-stage DEA models. Please, refer to Table 1 for an outline of the literature we refer to.

However, despite the fact that supply chains usually consist of more than two components, supply chains with three or more components, such as for example a supplier–manufacturer–distributor chain, have never been evaluated using a two-stage DEA. This evaluation should consist of determining whether or not the whole supply chain is managed by an integrated strategy that is profitable for all the components.

In two-stage DEA models, such as those reviewed above [5,32], the overall efficiency score is usually modeled first and, subsequently, used to calculate the first and/or second stage efficiency values. One of the two minor efficiencies is enough to obtain the other, giving place to the so-called