ARTICLE IN PRESS

Omega ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Omega

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

Target intermediate products setting in a two-stage system with fairness concern ☆

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ARTICLE INFO

Article history:
Received 23 May 2016
Accepted 4 December 2016

Keywords:
Data envelopment analysis
Efficiency analysis
Intermediate products
Fairness concern
Nash bargaining game

ABSTRACT

In a two-stage system with two divisions connected in series, fairly setting the target outputs for the first stage or equivalently the target inputs for the second stage is critical, in order to ensure that the two stages have incentives to collaborate with each other to achieve the best performance of the whole system. Data envelopment analysis (DEA) as a non-parametric approach for efficiency evaluation of multi-input, multi-output systems has drawn a lot of attention. Recently, many two-stage DEA models were developed for studying the internal structures of two-stage systems. However, there was no work studying fair setting of the target intermediate products (or intermediate measures) although unreasonable setting will result in unfairness to the two stages because setting higher (fewer) intermediate measures means that the first (second) stage must make more efforts to achieve the overall production plan. In this paper, a new DEA model taking account of fairness in the setting of the intermediate products is proposed, where the fairness is interpreted based on Nash bargaining game model, in which the two stages negotiate their target efficiencies in the two-stage system based on their individual efficiencies. This approach is illustrated by an empirical application to insurance companies.

1. Introduction

In a two-stage system such as an enterprise with a production division and a distribution division, the collaboration and coordination between the two divisions is critical for the enterprise to achieve its highest efficiency. Normally, they are managed as two separate business units or two profit centers, whose profits or losses are calculated separately, and their performances are evaluated individually. In such a system, since the interaction between the two divisions (stages) is realized through intermediate products, i.e., the outputs for the first stage or equivalently the inputs for the second stage, the enterprise may set a target (goal) for the intermediate products. For a system to achieve target outputs with the available resources, setting higher (fewer) intermediate products means that the first (second) stage must make more efforts to achieve the overall production plan. Then, the first (second) stage may think the intermediate products set is unfair to it, this will affect its morale in cooperation with the other stage to achieve the target outputs. Since the setting of target intermediate products has an important management implication as it provides a direction (benchmark) for the two stages to achieve, thus, fairly setting intermediate products is an important issue for the two-stage system.

It is clear that the setting of the intermediate products will directly affect the target efficiency of each stage (division) in the system. When a two-stage system uses the available inputs to produce the target outputs, higher intermediate products set for the first stage means higher target efficiency for this stage to achieve whereas higher intermediate products for the second stage means lower target efficiency for this stage to achieve. That is, setting higher target efficiency for the first stage means that this stage should produce more intermediate products with the available inputs and setting higher target efficiency for the second stage means that this stage should consume few intermediate products to produce the target outputs. Thus, the fair intermediate products can be determined by setting appropriate target efficiencies for two stages. When does a stage feel unfair? Taking as an example a non-life insurance company with a weak premium acquisition ability in the first stage but a strong profit generation ability in the second stage, setting higher intermediate products, direct written premiums and reinsurance premiums, is unfair to the first stage, and is also unfavorable for the company to realize its target outputs. Therefore, the setting of an appropriate target

☆This manuscript was processed by Associate Editor Lim.

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http://dx.doi.org/10.1016/j.omega.2016.12.005

for the intermediate products of the system should consider the production abilities' difference of its two divisions. In other words, the setting of the expected (target) efficiency for each stage should consider its individual ability, i.e., the performance of the stage compared with its homogenous divisions (stages) in other similar two-stage systems.

Data Envelopment Analysis (DEA) is a non-parametric mathematical programming approach for evaluating the relative efficiency of a set of homogeneous decision making units (DMUs) with multiple inputs and multiple outputs [1,2]. It has been extensively developed and applied in the performance evaluation of multi-input multi-output complex systems [3]. The conventional DEA model can well deal with single-stage systems, but it cannot be used to evaluate more complex systems, such as two-stage systems, because the traditional DEA model considers the internal structure of a system as a black-box. Recently, two-stage DEA approaches were used to evaluate two-stage network structures in which the outputs of the first stage becomes the whole or part of the inputs of the second stage [4–7]. Following the review made by Cook et al. [8], we classify the previous studies on two-stage DEA approaches into four categories: standard DEA approaches, efficiency decomposition approaches, game-theoretic approaches, and network DEA approaches. In the standard approaches, the conventional DEA methodology is applied separately to the first and second stage without considering possible conflicts between the two stages [9,10]. The first efficiency decomposition approach consider the multiplicative or additive relationship between two stages by assuming the weights of the output products of the first stage are identical to the weights of the input products of the second stage, such as Chen et al. [11] with additive efficiency decomposition and Kao and Hwang [12] with multiplicative efficiency decomposition. More recent works see Kao and Hwang [13], Wang et al. [14] and Despotis et al. [15]. Game-theoretic approaches model the performance evaluation of a two-stage system as a non-cooperative or cooperative game. Among them, Liang et al. [16] proposed a cooperative game DEA model to calculate the efficiency of a two stage system, where the two stages have the same bargaining power and cooperate each other to jointly maximize their total efficiency. Other works in this category include Liang et al. [4]; Du et al. [17] and Li et al. [18]. Network DEA approaches are related to the network DEA concept narrowly defined in Cook et al. [8] for two-stage systems. One important work in this category is that of Färe and Grosskopf [19] who investigated DMUs with two-stage structure as a network DEA. A number of studies have been reported following this work, such as Lewis and Sexton [20]; Matthews [21]; Tone and Tsutsui [5], Liu et al. [22]. These studies considered the two stages of a system respectively when building its two-stage model, and established the relationships between the two stages through intermediate products.

In general, all these previous works on two-stage DEA models focus on the overall efficiency of a two-stage system or the efficiency of each stage in the system. Few works studied the frontier projection of a two-stage system except Chen et al. [23], Chen et al. [24] and Lim and Zhu [25]. Chen et al. [23] is the first one to use an envelopment DEA model to produce the frontier projection through determining the optimal values for the intermediate measures. Later, Chen et al. [24] stated that multiple and envelopment DEA models are dual models under the standard DEA, but there is a pitfall that these two types of models should be used respectively in deriving information for divisional efficiency and frontier projections (i.e., projected points on the production frontier). Lim and Zhu [25] used a linear program to calculate the overall and divisional efficiencies, and frontier projections simultaneously. However, they pointed out "*possible multiple optimal solutions exist. Therefore, the frontier projections and divisional efficiency scores are not necessarily unique. In fact, we show that a range of projections for the intermediate measures can be obtained for the frontier projections*". That is, there are usually a large range of frontier projections for the intermediate measures that the DMU has to choose as its production targets. As we have explained above, setting higher (fewer) intermediate measures as the projection means that the first (second) stage must make more efforts than the second (first) stage to achieve the overall production plan. It is very necessary to consider the fairness between the two stages in the setting of target intermediate products. In this paper, by constructing a Nash bargaining game, we build a new DEA model with fairness concern to address this issue. The two stages are considered as two players in our model who bargain (negotiate) their target efficiencies in the two-stage system. Based on this model and its Nash bargaining solution, we not only fairly set the target efficiencies of the two stages, but also obtain fair target intermediate products of the two-stage system. Moreover, the production frontier point of each stage in the system can be obtained. With the fair setting of target intermediate products, the corresponding frontier projections are more easily accepted by the two stages because they are treated equally in the system.

The rest of this paper is organized as follows. Section 2 briefly reviews some DEA models for two-stage systems. In Section 3, we present our approach for fairly setting the target intermediate products and determining frontier points through a Nash bargaining model. An application of the approach to 24 Taiwanese non-life insurance companies is given in Section 4. Some remarks for future research are given in the conclusion section.

2. Two-stage DEA models for two-stage systems

Assume that there are n DMUs to be evaluated, where each DMU as shown in Fig. 1 contains s different outputs, t intermediate products and m different inputs. Denote the ith input, dth intermediate product and rth output for DMUj ($j = 1, 2, ..., n$) as $x_{ij}(i = 1, 2, ..., m)$, z_{dj} $(d = 1, ..., t)$ and $y_{rj}(r = 1, 2, ..., m)$ respectively. $x_{ij} \geq 0$, $y_{rj} \geq 0 z_{dj} \geq 0$ and each DMU must have at least one positive input, one positive intermediate product, and one positive output value. In the first stage of the system, X_j $(x_{1j}, ..., x_{mj})$ are used as inputs to produce the intermediate products (outputs for the first stage) Z_j $(z_{1j}, ..., z_{tj})$. In the second stage, intermediate products Z_j $(z_{1j}, ..., z_{tj})$ are used as "inputs" to produce the outputs Y_j $(y_{1j}, ..., y_{sj})$. We denote the DMU being evaluated as DMU0 hereafter.

Färe and Grosskopf [19] proposed an equivalent network-DEA model for measuring the efficiency of the same system.

min ϕ
subject to

$$\sum_{j=1}^{n} \gamma_j x_{ij} \leq \phi x_{i0}, i = 1, ..., m, \tag{1a}$$

$$\sum_{j=1}^{n} \gamma_j z_{dj} \geq \tilde{z}_{d0}, d = 1, ..., t, \tag{1b}$$

$$\gamma_j \geq 0, j = 1, ..., n, \tag{1c}$$

$$\sum_{j=1}^{n} \pi_j z_{dj} \leq \tilde{z}_{d0}, d = 1, ..., t, \tag{1d}$$

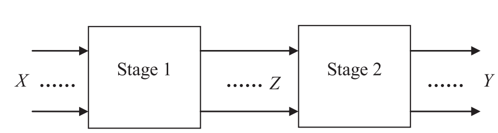

Fig. 1. Two-stage system.

Please cite this article as: An Q, et al. Target intermediate products setting in a two-stage system with fairness concern. Omega (2016), http://dx.doi.org/10.1016/j.omega.2016.12.005