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Supplier evaluation based on Nash bargaining game model

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ABSTRACT

Traditional DEA method is improper for supplier evaluation and selection, as it adopts varying weights in evaluation, and fails to consider competition among the suppliers. In order to solve these two problems, Nash bargaining game DEA model is applied to supplier evaluation in present paper. However, there is a non-uniqueness problem with Nash bargaining game efficiency of supplier in existing Nash bargaining game DEA model. The existing Nash bargaining game DEA model is improved in present paper on this issue, then the improved model is applied to the third party logistics service provider evaluation. The result of supplier evaluation based on the improved model is more persuasive compared with the existing research achievement, owing to adopting common weights in evaluation, and the game between suppliers being taken account.

1. Introduction

It is well known that a substantial proportion of the cost of a typical engineering product is accounted for in raw material, components and other supplies. On average, manufacturers' purchases of goods and services amount to 55% of revenue (Akarte, Surendra, Ravi, & Rangaraj, 2001). So, supplier selection based on supplier evaluation is one of the most important decision makings in business operation. De Boer, Labro, and Morlacchi (2001) considered that the supply chain partner selection process comprising three main stages, they respectively are "criteria formulation stage", "qualification stage" and "choice stage". According to statistical analysis of literature (Chong & Barnes, 2011), data envelopment analysis (DEA) is the most popular approach in qualification stage. No need for determining relationship of inputs and outputs, no need for being given weight, and equivalence of DEA efficiency and Pareto efficiency may be the cause of extensive using of DEA in this field. In the process of supplier evaluation based on DEA, how to use DEA model to reasonably provide efficiency for supplier, is the key for the success of decision making. Eventually research concentrates on how to creatively use DEA model or improve DEA model under different question setting.

Great majority of literatures for supplier evaluation and selection based on DEA have used traditional DEA method (CCR model (Charnes, Cooper, & Rhodes, 1978) and BCC model (Banker, Charnes, & Cooper, 1984) (Please see literature review (Chong & Barnes, 2011)). Since these two models adopt varying weights in evaluation, they can only distinguish supplier DEA efficient or inefficient, and are not suitable for ranking suppliers.

The literatures (Braglia & Petroni, 2000; Falagario, Sciancalepore, Costantino, & Pietroforte, 2012; Talluri & Baker, 2002; Talluri & Narasimhan, 2004; Talluri & Sarkis, 2002) based on cross-efficiency method (Doyle & Green, 1994; Sexton, Silkman, & Hogan, 1986) make progress on supplier evaluation relative to literatures based on traditional DEA model, for the advantage of cross-efficiency method over traditional DEA model: It use DEA in a peer evaluation, rather than a pure self-evaluation mode, thereby avoiding unrealistic DEA weighting schemes. However, the DEA optimal weights obtained from the original DEA are generally not unique, depending on which of the alternate optimal solutions to the DEA linear programs is used; thus, the cross-efficiency scores of supplier are also not unique, such evaluation result is still difficult to be accepted.

It is well known that, there is contention among suppliers who strive for order and the process is a game; however, there is no literature for supplier evaluation based on DEA with that in mind. Lack of corresponding DEA model for supplier evaluation may lead to this situation. Nash bargaining game DEA model based on cross-efficiency method proposed by Wu, Liang, Feng, and Hong (2009) satisfies this need. In the model, every decision making unit (DMU) is a game player, the ultimate solution (Nash bargaining efficiency) obtaining from bargaining process is a Pareto optimal solution, and all DMUs will have motivation to accept it. The remarkable thing of this DEA model is that all DMUs adopt common weights in evaluation. So, it is a good choice to use Nash bargaining game DEA model for supplier evaluation. However,

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there is a problem in the Nash bargaining game DEA model: for every DMU, the bargaining solution (Nash bargaining efficiency) between CCR efficiency and cross-efficiency can be obtained by using the existing Nash bargaining game model, but cross-efficiency of DMU is not unique. The non-uniqueness of cross-efficiency would lead to non-uniqueness of Nash bargaining efficiency for DMU. The non-uniqueness of Nash bargaining efficiency possibly reduces theoretical value and the usefulness of Nash bargaining game DEA model.

The critical point in making Nash bargaining game DEA model is to determine bargaining upper bound and lower bound of DMU, no explanation is made in literature (Wu et al., 2009), about why cross-efficiency of DMU is determined to be bargaining lower bound, and CCR efficiency of DMU is determined to be bargaining upper bound. The present paper thinks that the key to eliminate non-uniqueness of Nash bargaining efficiency is to make clear bargaining upper bound and lower bound of DMU, and make sure that the possible maximal efficiency of DMU is the bargaining upper bound, the possible minimal efficiency of DMU is the bargaining lower bound (the possible maximal and minimal efficiency of DMU are theoretically unique). Once the possible maximal and minimal efficiency of DMU can be computed, the non-uniqueness problem of Nash bargaining efficiency can be settled. For that the possible maximal efficiency of DMU is CCR efficiency of DMU is not controversy, a bargaining lower bound model which is made for the possible minimal efficiency of DMU will be made latter in the present paper. Thereby, Nash bargaining game DEA model can be improved. Then, the improved model is applied to the third party logistics service provider evaluation.

Briefly, traditional DEA method is improper for supplier evaluation. supplier evaluation based on cross-efficiency method make progress on supplier evaluation relative to literatures based on traditional DEA model, for the advantage of cross-efficiency method over traditional DEA model, but the cross-efficiency scores of supplier are not unique. Nash bargaining game DEA model based on cross-efficiency method is able to consider contention among suppliers who strive for order, and adopts common weights in evaluation, so the evaluation approach based on Nash bargaining game DEA model can evaluate and rank all suppliers justly. But the non-uniqueness of Nash bargaining efficiency possibly reduces theoretical value and the usefulness of Nash bargaining game DEA model. The present paper thinks that the key to eliminate non-uniqueness of Nash bargaining efficiency is to make clear bargaining upper bound and lower bound of DMU, and makes sure that the possible maximal efficiency of DMU is the bargaining upper bound, and the possible minimal efficiency of DMU is the bargaining lower bound. For that the possible maximal efficiency of DMU is CCR efficiency of DMU is not controversy, a bargaining lower bound model which is made for the possible minimal efficiency of DMU will be made latter in the present paper; the non-uniqueness problem of Nash bargaining efficiency is then settled in the improved model. The improved model is then applied to the third party logistics service provider evaluation.

The proposed model supplies a gap for the existing Nash bargaining game DEA model, non-uniqueness problem with Nash bargaining game efficiency of supplier in existing Nash bargaining game DEA model is solved. To the best of author's knowledge, there is no reference that discusses supplier evaluation based on DEA adopts common weights in evaluation, and considers contention among suppliers who strive for order.

The rest of this paper unfolds as follows. Section 2 introduces the CCR model and the cross-efficiency evaluation method. Section 3 presents the improved Nash bargaining game DEA model. In section 4, an illustrative example of the third party logistics service provider evaluation is illustrated, and finally concluding remarks are made in Section 5.

2. CCR model and cross-efficiency evaluation method

Nash bargaining game DEA model is based on cross-efficiency evaluation method, and still lies in the cross-efficiency method system; moreover, cross-efficiency method will be used for improving Nash bargaining game DEA model. So CCR model and cross-efficiency evaluation method will be concisely introduced.

Cross-efficiency evaluation method is proposed by Sexton et al. (1986), and developed by Doyle and Green (1994). It is improvement and perfection of CCR model. The main idea of this method is to use DEA in peer evaluation, rather than a pure self-evaluation mode, a effective ranking result to differentiate performance of all DMUs thus can be obtained. The method has been one of the main DMUs ranking methods.

Adopting the conventional nomenclature of DEA, assume that there are n DMUs that are to be evaluated in terms of m inputs and s outputs. We denote the ith input and rth output for DMU_j ($j = 1, 2,\dots, n$) as $x_{ij}(i = 1,\dots, m)$ and $y_{rj}(r = 1,\dots, s)$ respectively:

$$X_j = (x_{1j}, x_{2j}, \dots, x_{mj})^{\mathrm{T}} > 0, \quad j = 1, 2, \dots, n$$
$$Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})^{\mathrm{T}} > 0, \quad j = 1, 2, \dots, n,$$

The efficiency rating for any given DMU_d can be computed using the following CCR model (Charnes et al., 1978):

$$\begin{aligned} & Max \sum_{r=1}^{s} \mu_r y_{rd} = E_{dd} \\ & \text{s.t.} \sum_{i=1}^{m} \omega_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} \geqslant 0, \quad j = 1, 2, \dots, n \\ & \quad \sum_{i=1}^{m} \omega_i x_{id} = 1 \\ & \quad \omega_i \geqslant 0, \quad i = 1, 2, \dots, m \\ & \quad \mu_r \geqslant 0, \quad r = 1, 2, \dots, s \end{aligned} \tag{1}$$

Suppose that DMU_d is the DMU under evaluation, $\omega_1, \dots, \omega_m$, $\mu_1, \dots, \mu_s$ are associated input weights and output weights in model (1); changing each DMU_d ($d = 1, \dots, n$) under evaluation, a set of optimal weights $(\omega^*_{1d}, \dots, \omega^*_{md},\ \mu^*_{1d}, \dots, \mu^*_{sd})$ and CCR efficiency E^*_{dd} of every DMU_d can be obtained by using model (1).

Based on above optimal weights of CCR model, Sexton et al. defined the cross-efficiency for DMU_j relative to DMU_d (Using weights of DMU_d) as

$$E_{dj} = \frac{\sum_{r=1}^{s} \mu^*_{rd} y_{rj}}{\sum_{i=1}^{m} \omega^*_{id} x_{ij}}, d, \quad j = 1, 2, \dots, n \tag{2}$$

The element E_{dj} of cross-efficiency matrix is the efficiency of DMU_j based on weights of DMU_d, diagonal elements of cross-efficiency matrix are the self-evaluation efficiency of DMU_d ($d = 1, \dots, n$).

Summating and averaging all elements E_{dj} ($d = 1, 2, \dots, n$) of jth column of cross-efficiency matrix for DMU_j ($j = 1, 2, \dots, n$), namely

$$E_j^{cross} = \frac{1}{n} \sum_{d=1}^{n} E_{dj} \tag{3}$$

So E_j^{cross} $(j = 1, \dots, n)$ is the average cross-efficiency score of DMU_j. All DMUs can be evaluated and ranked according to E_j^{cross} $(j = 1, \dots, n)$.

3. Existing and the proposed Nash bargaining game DEA model

3.1. Existing Nash bargaining game DEA model

The advantage of existing Nash bargaining game DEA model (Wu et al., 2009) lies on the satisfaction of four properties which