Expert Systems with Applications 41 (2014) 4181–4185

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Supplier evaluation based on Nash bargaining game model

Meiqiang Wang [a,*], Yongjun Li [b]

[a] School of Management, Gui Zhou University, Gui Yang 550025, PR China
[b] School of Management, University of Science and Technology of China, He Fei, An Hui Province 230026, PR China

ARTICLE INFO

Keywords:
Supplier evaluation
DEA cross-efficiency
Nash bargaining game

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,

* Corresponding author. Tel.: +86 8516926767.
E-mail addresses: wangmq@mail.ustc.edu.cn (M. Wang), lionli@mail.ustc.edu.cn (Y. Li).

0957-4174/$ - see front matter
http://dx.doi.org/10.1016/j.eswa.2013.12.044

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

Nash considered a reasonable solution should satisfy. The four properties including Pareto efficiency, symmetry, invariance with respect to affine transformation, and independence of irrelevant alternatives. Furthermore, this model adopts common weights in evaluation, so the evaluation approach based on Nash bargaining game DEA model can evaluate and rank all DMUs justly. For the ultimate solution is a result of bargaining and a Pareto one, all the DMUs will have motivation to accept it.

According to literature (Nash J F., 1950), denotes the set of all individuals by $N = \{1, 2, \ldots, n\}$, a payoff vector is an element of the payoff space R^N, a feasible set S is a subset of the payoff space, and a breakdown point $\bar{b}$ is an element of the payoff space. A bargaining problem is then specified as the triple $(N, S, \bar{b})$. The solution is a function that is associated with each bargaining problem $(N, S, \bar{b})$, expressed as $F(N, S, \bar{b})$. If the feasible set is compact, convex, and contains some payoff vector such that each individual's payoff is greater than the individual's breakdown payoff, the solution satisfies Nash four properties is unique, and can be obtained by solving following maximization problem:

$$\underset{\vec{u}\in S,\, \vec{u}\geqslant \vec{b}}{Max} \prod_{i=1}^{n} (u_i - b_i) \tag{4}$$

where $\vec{u}$ is the payment vector of individuals, and u_i is the ith element of $\vec{u}$, b_i is the ith element of $\vec{b}$.

Literature (Wu et al., 2009) generalized the above results to solving Nash bargaining game efficiency of DMUs. Denotes average cross-efficiency of DMU_j as E_j^{CROSS}, CCR efficiency as E_j^{CCR}, $j = 1, \ldots, n$, then Nash bargaining game efficiency score of DMU_j which will be surely between the CCR efficiency score and the cross-efficiency score, can be solved by following programming:

$$Max \prod_{j=1}^{n} \left(\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} - E_j^{CROSS} \right) \left(E_j^{CCR} - \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \right) \tag{5}$$

$$j \neq l,\ l \in ES$$

$$\text{s.t.}\ \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leqslant E_j^{CCR}$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \geqslant E_j^{CROSS} \quad j = 1, \ldots, n;\ j \neq l$$

$$u_r \geqslant 0, \quad r = 1, \ldots, s; \quad v_i \geqslant 0,\ i = 1, \ldots, m$$

where ES is the set of DMUs that their cross-efficiencies are equal to the corresponding CCR efficiencies, DMU_l ($l \in S$) will not participate in the bargaining;

$$E_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$$

is the efficiency of DMU_j which is obtained after bargaining.

According to mathematical proof of literature (Wu et al., 2009), there is unique solution $(E_j^*)_{j\neq l, l\in ES}$ satisfied above four properties in Nash bargaining game $\langle S, (E_j^{CROSS}, E_j^{CCR})_{j\neq l, l\in ES} \rangle$. The ultimate efficiencies of all DMUs are $E_j^* (j \neq l, l \in ES,\ j = 1, \ldots, n)$, E_l^{CROSS} or E_l^{CCR} $(l \in ES)$.

3.2. The improved Nash bargaining game DEA model

There are two problems with the existing Nash bargaining game DEA model. The first, no account for why cross-efficiency is bargaining lower bound of DMU, and CCR efficiency is bargaining upper bound of DMU; the second, 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, and would make decision maker think the result is unacceptable. Furthermore, there is a problem would puzzle decision maker in general applied research: there are three kinds of frequently-used cross-efficiencies, they are arbitrary, aggressive, and benevolent cross-efficiency, which cross-efficiency of supplier should be substituted to model (5)? Since different cross-efficiency would lead to different Nash bargaining efficiency of supplier, the decision maker has to give up this approach.

What needs to be stressed is that: non-uniqueness of Nash bargaining efficiency of DMU is leaded only by non-uniqueness of cross-efficiency of DMU. Once E_j^{CROSS} of DMU_j in model (5) is given, Nash bargaining efficiency of DMU_j obtained from model (5) is unique, according to lemma of literature (Wu et al., 2009).

In CCR model, the maximum of relative ratio of weighted sum of outputs to that of inputs is regarded as the efficiency (satisfying constraint of less than or equal to 1), but the question is that why the efficiency is the maximum of relative ratio? It is obvious that object maximizing is the need of making program model; in fact, all possible relative ratio of weighted sum of outputs to that of inputs, satisfying constraint of less than or equal to 1, may be possible efficiency of DMU evaluated. Possible efficiency of DMU lies in an interval. In view of the above, no difficult to understand why cross-efficiency of DMU is determined to be bargaining lower bound, and CCR efficiency of DMU to be bargaining upper bound in model (5). We conclude that, the authors may think that the maximum of DMU is CCR efficiency, the minimum of DMU is cross-efficiency, and the bargaining among DMUs based on cross-efficiency approach should process between the maximum efficiency and the minimum efficiency of DMU. However, bargaining upper bound in model (5) is right, bargaining lower bound in model (5) is not right; possible minimum of DMU is unique, but cross-efficiency of DMU is not unique.

The approach solving possible minimum efficiency of DMU_j will be modeled follow, then the obtained possible minimum efficiency of DMU_j is substituted to Nash bargaining game DEA model (5) to solve Nash bargaining game efficiency of DMU_j. It is important to note that the obtained possible minimum efficiency of DMU_j is a cross-efficiency also (see following model (6)), but it is minimum efficiency of all possible cross-efficiency of DMU_j. Concrete steps are:

Step 1: Solving possible minimum efficiency of DMU_j, denoted by $E_{j_0}^{\min}$, by using model (6) and formula (7).

Considering DMU_j and DMU_d, under condition that efficiency of DMU_d stay E_{dd}^* unchanged, possible minimum cross-efficiency of DMU_j can be obtained by solving following model (6):

$$MinE_{dj} = \mu_d^j Y_j$$

$$\begin{aligned} \text{s.t.}\quad & \mu_d^j Y_l - \omega_d^j X_l \leqslant 0 \quad l = 1, \ldots, n \\ & \omega_d^j X_j = 1 \\ & \mu_d^j Y_d - E_{dd}^* \times \omega_d^j X_d^j = 0 \\ & \omega_d^j \geqslant 0, \mu_d^j \geqslant 0 \end{aligned} \tag{6}$$

Possible minimum cross-efficiency of DMU_j is E_{dj}^* in model (6). For DMU_j evaluated, under condition that efficiency of every DMU_d stay E_{dd}^* $(d \neq j_0)$ unchanged, all possible minimum cross-efficiencies of

DMU_j evaluated can be obtained by solving model (6), then possible minimum efficiency of DMU_j evaluated is

$$E_{j_0}^{\min} = \frac{1}{n-1}\sum_{\substack{d=1\\ d\neq j_0}}^{n} E_{dj_0}^{*}. \quad (7)$$

.The idea of this model is: Minimizing cross-efficiency of DMU_j evaluated, under condition that optimal efficiency E_{dd}^{*} $(d \neq j_0)$ of certain DMU_d stays unchanged. This model eliminates the problem that cross-efficiency is non-unique, by means of selecting a set of optimal weights from multiple sets of optimal weights.

Step 2: Substituting E_j^{CROSS} for $E_j^{\min}$, for every DMU_j in model (5); obtaining following improved Nash bargaining game DEA model (8), then Nash bargaining game efficiency of DMU_j can be solved.

$$Max\prod_{j=1}^{n}\left(\frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}} - E_j^{\min}\right)\left(E_j^{CCR} - \frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}}\right) \quad (8)$$

$$j \neq l, l \in ES$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}} \leqslant E_j^{CCR}$$

$$\frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}} \geqslant E_j^{\min} \quad j = 1,\ldots,n; j\neq l$$

$$u_r \geqslant 0,\ r = 1,\ldots,s;\ v_i \geqslant 0, \quad i = 1,\ldots,m$$

where ES is the set of DMUs that possible minimum efficiency are equal to possible maximum efficiency, DMU_l ($l \in ES$) will not participate in the bargaining;

$$E_j = \frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}}$$

is the efficiency of DMU_j which is obtained after bargaining.

As what mentioned before: non-uniqueness of Nash bargaining efficiency of DMU is leaded only by non-uniqueness of cross-efficiency of DMU. Once E_j^{CROSS} of DMU_j model (5) is given, Nash bargaining efficiency of DMU_j obtained from model (5) is unique, according to lemma of literature (Wu et al., 2009).We have make clear that the bargaining among DMUs based on cross-efficiency approach should process between the maximum efficiency and the minimum efficiency of DMU. Maximum efficiency of DMU i.e. E_j^{CCR} undoubtedly is unique; minimum efficiency of DMU i.e. $E_j^{\min}$ obtained from model (6) and formula (7) is unique also. Because possible minimum efficiency of DMU $E_j^{\min}$ is cross-efficiency also (the minimum of all possible cross-efficiency of this DMU), similar mathematical proof as literature (Wu et al., 2009) can be made and similar conclusion can be drawn: there is a unique solution $(E_j^{*})_{j\neq l, l\in ES}$ in Nash bargaining game $\langle S, (E_j^{\min},\ E_j^{CCR})_{j\neq l, l\in ES}\rangle$. The ultimate efficiencies of all DMUs are $E_j^{*}(j\neq l,\ l\in ES,\ j = 1,\ldots,n)$, $E_l^{\min}$ or E_l^{CCR} $(l \in ES)$.

Thus, the bargaining upper bound and lower bound of DMU are explicit; furthermore, the uniqueness of possible minimum efficiency and possible maximum efficiency of DMU certainly lead to uniqueness of bargaining efficiency of DMU. These improvements will tremendously enhance theoretical value and the usefulness of Nash bargaining game DEA model.

4. The third party logistics service provider evaluation

The data set is partially taken from (Talluri and Baker, 2002). There are 18 suppliers – the third party logistics service providers.

Table 1
Related attributes for 18 suppliers.

DMU	Inputs		Outputs			
	TC	NS	NB	NOT	EXP	CRE
1	253	197	90	187	240	90
2	268	198	130	194	210	80
3	259	229	200	220	270	70
4	180	169	100	160	200	70
5	257	212	173	204	160	70
6	248	197	170	192	230	80
7	272	209	60	194	200	90
8	330	203	145	195	170	60
9	327	208	150	200	180	70
10	330	203	90	171	170	60
11	321	207	100	174	200	80
12	329	234	200	209	210	100
13	281	173	163	165	300	90
14	309	203	170	199	250	80
15	291	193	185	188	250	90
16	334	177	85	168	240	80
17	249	185	130	177	210	70
18	216	176	160	167	200	80

Table 2
Possible maximum and minimum efficiency scores; bargaining game efficiency scores; rank based on bargaining game efficiency scores of suppliers.

DMU	$E_j^{\min}$	E_j^{CCR}	Nash	Rank based on Nash
1	0.84197	0.99687	0.97152	9
2	0.89393	1	0.99246	4
3	0.91271	1	0.97686	6
4	0.89793	1	0.97202	8
5	0.87113	0.99249	0.96809	11
6	0.94821	1	0.99463	2
7	0.76872	0.96592	0.94150	15
8	0.82025	0.97990	0.95341	14
9	0.83849	0.98087	0.95982	12
10	0.71081	0.85930	0.83973	18
11	0.73958	0.86150	0.85059	17
12	0.84086	0.92549	0.90906	16
13	0.92859	1	0.98765	5
14	0.91111	1	0.99286	3
15	0.93954	1	0.99593	1
16	0.79626	0.97787	0.95807	13
17	0.88921	0.97908	0.97077	10
18	0.94365	1	0.97480	7

The inputs considered are total cost of shipments (TC) and number of shipments (NS); the outputs considered are number of bills received from the supplier without errors (NB), number of shipments to arrive on time (NOT), ratings for service-quality experience (EXP), and ratings for service-quality credence (CRE). Table 1 depicts the supplier's attributes.

Possible maximum efficiency scores (CCR efficiency scores) of every suppliers are obtained by using model (1), they are presented in the 3rd column of Table 2. We can read that supplier 2, 3, 4, 6, 13, 14, 15, and 18 are DEA efficient; needed discrimination is not presented, not to mention total ordering. Two reasons lead to this result. The first, the number of supplier inputs and outputs is too much relative to the number of suppliers; the second, the imperfection of CCR model – the unrestricted weight flexibility problem in CCR model being involved in an unreasonable self-rated scheme.

Possible minimum cross-efficiency solving model (6) is a quadratic programming, based on the idea "Minimizing cross-efficiency of DMU_j evaluated, under condition that optimal efficiency E_{dd}^{*} $(d \neq j_0)$ of certain DMU_d stays unchanged". The model has two advantages. The first, it eliminates the problem that cross-efficiency is non-unique, by means of selecting a set of optimal weights from multiple sets of optimal weights; the second, this quadratic programming is close to the actual situation that contention lies between suppliers, better discrimination of efficiency is presented, and total ordering can be obtained. The corresponding result of suppliers is presented in second column of Table 2 by using model (6) and formula (7).

The Nash bargaining game DEA model (8), which eliminates non-uniqueness of Nash bargaining efficiency in model(5), makes great progress, compared with the model solving supplier possible minimum efficiency. The bargaining efficiency scores obtained from this model satisfies the properties which Nash proposed, and adopts common weights in supplier evaluation, so the evaluation approach based on this model can evaluate and rank all suppliers justly. Nash bargaining efficiency of supplier which is obtained by using model (6), (8) and formula (7) is recorded in 4th column of Table 2, and total ordering of all suppliers is recorded in 5th column of Table 2. The result is authoritative.

5. Concluding remark

A good supplier selection makes a great distinction to a company's future to reduce operational costs and improve the quality of its end products. A full and impartial rank of all suppliers is needed in practical supplier evaluation, and direct or indirect competitive relation between suppliers striving for order should also be considered in supplier evaluation. The existing Nash bargaining game DEA model satisfies these two needs, but non-uniqueness of Nash bargaining efficiency in the existing Nash bargaining game DEA model make the model defective in theory, and puzzling in practice.

The present paper thinks that all possible relative ratio of weighted sum of outputs to that of inputs, satisfying constraint of less than or equal to 1, may be possible efficiency of DMU evaluated; so possible efficiency of DMU lie in an interval. On the basis of this point, the present paper considers that bargaining between DMUs based on cross-efficiency method, should process between possible maximum and possible minimum efficiency of DMU, then the improved Nash bargaining game DEA model is proposed, and non-uniqueness of Nash bargaining efficiency is eliminated, thus the basis for model popularizing in practice is founded.

The approach presented in this paper has some distinctive features: (1) 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; (2) the proposed model adopts common weights in evaluation, so the evaluation approach based on Nash bargaining game DEA model can evaluate and rank all suppliers justly; (3) for the ultimate solution is a result of bargaining and a Pareto one, all the suppliers will have motivation to accept it.

The problem considered in this study is at the initial stage of investigation and provides a great deal of fruitful scope for future research. This approach can be extended to supplier evaluation under variable returns to scale situation, and a new Nash bargaining game DEA model can be developed for supplier evaluation in the presence of undesirable outputs. Finally, the proposed model has been used for supplier evaluation in this study, but it seems that more fields (e.g. R&D project proposal evaluation) can be applied.

Acknowledgements

The authors thank the two anonymous reviewers for their valuable suggestions and comments.

This research was supported by the project on the National Natural Science Foundation of China (NSFC) under the Grant No: 71261003 and 71271196, and Natural Science Foundation of Gui Zhou Province under the Grant No: [2011]2101.

References

Akarte, M. M., Surendra, N. V., Ravi, B., & Rangaraj, N. (2001). Web based casting supplier evaluation using analytical hierarchy process. *Journal of the Operational Research Society, 52*(5), 511–522.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science, 30*(9), 1078–1092.

Braglia, M., & Petroni, A. (2000). A quality assurance-oriented methodology for handing trade-offs in supplier selection. *International Journal of Physical Distribution and Logistics Management, 30*(2), 96–111.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*, 429–444.

Chong, Wu, & Barnes, David (2011). A literature review of decision-making models and approaches for partner selection in agile supply chains. *Journal of Purchasing & Supply Management, 17*, 256–274.

De Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. *European Journal of Purchasing and Supply Management, 7*, 75–89.

Doyle, J. R., & Green, R. H. (1994). Efficiency and cross efficiency in DEA: Derivations, meanings and uses. *Journal of the Operational Research Society, 45*(5), 567–578.

Sexton, T. R., Silkman, R. H., & Hogan, A. J. (1986). Data envelopment analysis: Critique and extensions. In R. H. Silkman (Ed.), *Measuring efficiency: An assessment of data envelopment analysis*. San Francisco: Jossey-Bass.

Talluri, Srinivas, & Narasimhan, Ram (2004). A methodology for strategic sourcing. *European Journal of Operational Research, 154*, 236–250.

Talluri, Srinivas, & Baker, R. C. (2002). A multi-phase mathematical programming approach for effective supply chain design. *European Journal of Operational Research, 141*, 544–558.

Talluri, R., & Sarkis, J. (2002). A model for performance monitoring of suppliers. *International Journal of Production Research, 40*(16), 4257–4269.

Falagario, Marco, Sciancalepore, Fabio, Costantino, Nicola, & Pietroforte, Roberto (2012). Using a DEA-cross efficiency approach in public procurement tenders [J]. *European Journal of Operational Research, 218*(2), 523–529.

Nash, J. F. (1950). The bargaining problem. *Economica, 5*, 155–162. 4357–4362.

Wu, Jie, Liang, Liang, Feng, Yang, & Hong, Yan (2009). Bargaining game model in the evaluation of decision making units. *Expert Systems with Applications, 36*(3), 4357–4362.