African Journal of Business Management Vol. 6(4), pp. 1263-1269, 1 February, 2012
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM11.203
ISSN 1993-8233 ©2012 Academic Journals

Full Length Research Paper

Equitable allocation of fixed costs and its effect on technical and cost efficiency: Case study in universities

Mohammad Mahallati Rayeni[1]* and Faranak Hosseinzadeh Saljooghi[2]

[1]Department of Management, Institute of Technology of Bahonar, Zahedan, Iran.
[2]Department of Mathematics, University of Sistan and Baluchestan, Zahedan, Iran.

Accepted 10 August, 2011

This study proposes a methodology for the allocation and management of university financial resources by consideration efficiency as its objective, and then investigates effect of this allocation of fixed resources or costs on types of efficiencies. In available methods, the fixed cost is regarded as a new input in the evaluation of efficiency, but if inputs are different kinds of costs, then it is obvious that the fixed cost is a complement of other inputs rather than an extra independent input. Therefore, it is suitable to combine the allocated cost with other cost measures in cost allocation problem. Based on it, the study develops a data envelop analysis (DEA)-based approach to allocate the fixed cost among various decision making units (DMUs). The proportion of each input in the individual DMUs is determined uniquely, and the technical and scale efficiency of each DMU became equal before and after allocation. But cost efficiency of universities has changed, despite increase in inputs of all DMUs while overall average of cost efficiency improved.

Key words: Data envelopment analysis (DEA), fixed cost, allocation cost, resource management, technical efficiency, scale efficiency, cost efficiency.

INTRODUCTION

Organizations of any complexity typically consist of a number of individually identified units. In allocating resources, such as money and manpower to individual units, the total amount of resource that the organization can allocate, will be limited, also, the organization will have fixed costs that it has to pay and these will need to be covered by the individual units (Alam, 2009).

The allocation of fixed resources or costs, across a set of competing entities in an equitable manner has considerable importance, both from a practical organizational viewpoint and from costs research perspectives (Alam et al., 2010; Alam and Khakifa, 2009).

In the past three decades, parametric and nonparametric frontier approaches have been developed and increasingly used in applied economics and management science to evaluate the cost and profit efficiency of various types of decision making units (DMUs), including for profit and non-profit organizations. Data envelopment analysis (DEA) is a methodology that has been used to evaluate the efficiency of entities which are responsible for utilizing resources to obtain outputs of interest. DEA technique has allocated to itself a wide variety of research in operations research field (Tone and Sahoo, 2005; Lu et al., 2010; Chen et al., 2010; Mahallati and Saljooghi, 2010). In fact, DEA has become increasingly popular for efficiency analysis in the practical projects in field of management, economy, education, sport, etc.

One of the applications of this technique is allocation of a shared cost to all decision making units (DMUs). Clearly, the cost that is imposed on a DMU constitutes an additional input, which may alter the absolute efficiency rating of the DMU. The objective of management is to allocate those costs in such a way that the relative efficiency of all DMUs be not changed or be improved. Hence, any allocation that does not alter the relative efficiency measure is equitable. It should be emphasized that DMU has no control on this cost.

One of the most important problems in resource management is the problem of characterizing an equitable

*Corresponding author. E-mail: m_mohallati@yahoo.com.

allocation of fixed costs among all DMUs (Jahanshaloo et al., 2004; Li et al., 2009). Cook and Kress (1999) made the first attempt of solving cost allocation problem using DEA approach. In their approach, they treated the allocated fixed cost as an additional input measure in performance evaluation. Based on two principles of efficiency invariance and Pareto-minimality – invariance is defined as the relative efficiency of each DMU before and after allocation that is not changed; a cost allocation is input Pareto-minimality if no cost can be transferred from one DMU to another without violating the invariance principle - Beasly (2003) proposed a DEA-based model which maximizes the average DMU efficiency. By this assumption that the allocated cost is a new input, he provided a nonlinear DEA-based cost allocation approach which considered the effect caused by the feasible allocation plans on the average efficiency across all DMUs, and added some additional constraints to obtain a unique cost allocation.

If input is ever regarded as a cost, then it is obvious that the fixed cost is a complement of other inputs rather than an extra independent input. Therefore, it is necessary to combine the allocated cost with other cost measures in cost allocation problem. Based on it, we investigate the effect of allocated cost on the technical, scale and cost efficiency score and develop a DEA-based approach to allocate the fixed cost among various DMUs, such as that efficiency of DMUs remains without change or the average efficiencies is improved.

DEA can measure the different kind of efficiency. The basic DEA models can be divided into CCR and BCC types. The CCR model is introduced by Charnes et al. (1987), while Banker et al. (1984) proposed the BCC model. The efficiency value calculated in CCR is the ‘‘overall technical efficiency”, whereas the efficiency value computed by BCC is ‘‘pure technical efficiency”. Cost efficiency is also one kind of efficiencies. Cost efficiency (CE) evaluates the ability of a decision making unit (DMU) to produce the current outputs at minimal cost, given its input prices. The concept of CE can be traced back to Farrell (1957), who originated many of the ideas underlying efficiency assessments. The Farrell’s concept was developed by Fare et al. (1985), who formulated a linear programming (LP) model for CE assessment. This LP model requires input and output quantity data as well as input prices at each decision making unit. There are some DEA models that deal with cost efficiency analysis when the data are known exactly. A firm is said to have realized cost efficiency, if it is operating with the optimal combination of inputs, given input prices. The traditional approaches to measuring cost efficiency require input prices. Recently, more attempts to measure cost efficiency have been advanced. For example, given incomplete input price data information, Kuosmanen and Post (2001) put forward a methodology to derive the upper and lower bounds of overall efficiency. The authors consider the whole price domain instead of separate single input price vectors. Camanho and Dyson (2008) and later Mostafaee and Saljooghi (2010) have developed ways to measure upper and lower bounds for cost efficiency when information of input prices is imprecise.

In this research, the study considers the university as a decision making unit (DMU), an organization with research and teaching activities. The DMUs receive research grants, equipment grants, fees and funding council income. These inputs yield to some outputs such as research students, undergraduate students and research quality rating. The study will exhibit a method for equitable allocation of fixed costs based on scale efficiency.

The proposed methodology serves as a guiding mechanism for the allocation and management of university financial resources taking efficiency as its objective.

Amongst the DEA applications to financial research, some studies deserving special mention, amongst others, Yeh (1996) was one of the pioneers to combine DEA with financial ratio analysis. She utilized DEA to evaluate bank performance. Her study empirically demonstrated that DEA, in conjunction with financial ratio analysis, can effectively aggregate and reclassify perplexing ratios into meaningful financial dimensions, which enable analysts to gain an insight into the operating strategies of banks. Emel et al. (2003) proposed a credit scoring methodology based on DEA. Arcelus and Coleman (1997), analyzed the efficiency of 32 departments of the University of New Brunswick (Canada), on the basis of which the budget is distributed. Li et al. (2009) studied a car manufacturer with 17 city dealers in Anhui Province, China.

The study briefly describes the DEA framework for measuring efficiency, then presents and discusses the empirical results of the non-parametric efficiency analysis for allocation of fixed cost between universities.

EFFICIENCY AND DATA ENVELOPMENT ANALYSIS

Measuring of efficiency is an important subject for organizations which performance improvement is one of their interests. Sherman (1998) defines efficiency as “the ability to produce the outputs or services with a minimum resource level required".

Data envelopment analysis is a non-parametric approach for measuring relative efficiency that produces a single aggregate measure of relative efficiency among comparable units. In the simplest case where a process or unit has a single input and a single output, efficiency is defined as the ratio of output to input, but in the state of multi inputs and multi outputs, DEA defines relative efficiency as the ratio of the sum of weighted outputs to the sum of weighted inputs. The optimum coefficients for each of the DMUs are separately calculated so that the most efficiency for the viewed DMU is obtained. In this model, the maximum amount in relation to virtual output to virtual input is assessed for each DMU, so that no

DMUs efficiency should be more than a '100% efficient' while all the variables multipliers should be positive.

Technical efficiency

Technical efficiency depicts the capability of production units to transform inputs into outputs. Consider that *n* decision making units (DMUs) consume *m* type of inputs for producing *s* outputs. For DMU_j, an input–output bundle ($x_j = (x_{1j}, \dots, x_{mj}) \in \Re^m$, $y_j = (y_{1j}, \dots, y_{sj}) \in \Re^s$) is considered feasible when the output bundle y_j can be produced from the input bundle x_j. Inputs are transformed into outputs using a technology that can be described by the production possibility set: T = {(x, y)| y can be produced from x}. So, relative efficiency model is formulated thus:

$$\text{Maximize} \quad \theta_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

$$\text{subject to} \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \qquad j = 1,2,\dots,n$$

$$u_r \ge 0 \quad r = 1,\dots,s$$
$$v_i \ge 0 \quad i = 1,\dots,m \qquad (1)$$

The model (1) is simply linearlized; its duality is model (2). In this model, in measuring input-oriented technical efficiency, all inputs are treated equally and the objective is to reduce all inputs by the same proportion to the extent possible. By this, technical efficiency can be calculated from model (2):

$$TE_o = \text{Minimize} \quad \theta_o$$
$$\text{Subject to} \quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_o x_{io} \qquad i = 1, \dots, m$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro} \qquad r = 1, \dots, s$$
$$\lambda_j \ge 0 \qquad j = 1,\dots,n \qquad (2)$$
$$\theta \text{ free}$$

This is called CCR model. The CCR assumes "constant returns to scale (CRS)", that is, the increase of investment by one unit generating output by one unit. The CRS assumption is appropriate when all DMUs are operating at an optimal scale. However, government regulations, constraints on finance and so on, may cause a DMU not to be operating at optimal scale. The use of the CRS specification when not all DMUs are operating at the optimal scale, results in measures of technical efficiency (TE) that are confounded by scale efficiencies. In another model of DEA, the BCC model assumes "variable returns to scale", that is, the scale of output is varying. The use of the VRS specification permits the calculation of TE devoid of these scale efficiency effects. The CRS can be easily modified to account for VRS by adding the convexity constraint: $\sum_{j=1}^{n} \lambda_j = 1$.

The efficiency value calculated in CCR is the "overall technical efficiency", whereas the efficiency value computed by BCC is "pure technical efficiency" (PTE). The former divided by the latter is "scale efficiency" (SE). The comparison of scale efficiency value and pure technical value sheds light to the main source of inefficiency of DMU, may it be the technical problems associated with the quantity and combination of input and output factors or the whole operational scale. It must be noted that TE and PTE are greater than zero and less or equal to one.

Cost efficiency

Cost efficiency is defined as the effective choice of inputs vis a vis prices with the objective to minimize production costs, whereas technical efficiency investigates how well the production process converts inputs into outputs. It should be noted that DEA can also be used to measure cost efficiency. When input prices are available, reducing the more costly input assumes a greater priority than reducing the less costly ones. In this case, efficiency lies in producing the target output bundle y_o at the minimum cost. Again, consider *n* decision making units (DMUs) with *m* inputs (inputs such as equipment cost, salary, material and so on) for producing *s* outputs. For DMU_j, an input–output bundle ($x_j = (x_{1j}, \dots, x_{mj}) \in \Re^m$, $y_j = (y_{1j}, \dots, y_{sj}) \in \Re^s$), which the inputs have prices $c_j = (c_{1j}, \dots, c_{mj}) \in \Re^m$.

In the input cost space, $x_j = (x_{1j}, \dots, x_{mj}) \in \Re^m$, and $c_{ij} = p_{ij}.x_{ij}$, where p_{ij} is the price of input i at DMU j. In order to obtain a measure of cost efficiency, when the input and output data are known and the prices differ from DMU to DMU, minimal cost model was proposed by Tone (2005) as follows:

$$\sum_{i=1}^{m} c_{ik}^{*} = \text{Min} \quad \sum_{i=1}^{m} c'_{ik}$$
$$\text{s.t.} \quad \sum_{j=1}^{n} c_{ij} \lambda_j \le c'_{ik} \qquad i = 1, \dots, m$$
$$\sum_{j=1}^{n} y_{rj} \lambda_j \ge y_{rk} \qquad r = 1, \dots, s$$
$$c'_{ik} \ge 0, \ \lambda_j \ge 0, \quad i = 1, \dots, m, \quad j = 1, \dots, n \qquad (3)$$

The CE measure is given by the ratio of the minimal cost value obtained from (3) to the current cost at DMU_k as following:

$$\text{Cost Efficiency} = CE_k = \frac{\sum_{i=1}^{m} c_{ik}^{*}}{\sum_{i=1}^{m} c_{ik}}$$

The variables of model (3) are c'_{ik} and λ_j;

also $\lambda_j = 0$ for $j \neq k$ and $\lambda_k = 1, c'_{ik} = c_{ik}$ is a feasible solution for model 3 which implies that this model is feasible and bounded, and $CE_k \in (0,1]$.

ALLOCATION OF FIXED COST

Suppose that a cost R is to be distributed among the n DMUs. That is, each DMU is to be allocated a cost r_{ij} such that $\sum_{j=1}^{n}\sum_{i=1}^{m} r_{ij} = R$.

The allocated cost of DMU_j must be divided among its inputs. So, the study chooses the cost allocation input i in DMU_j (r_{ij}) as follows:

$$r_{ij} = \frac{w_i.R}{\sum_{i=1}^{m} w_i} \cdot \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}} \qquad (4)$$

where w_i is weight or preference input i, which is determined due to manager's opinion. The traditional DEA approaches allocate the fixed cost among a group of decision making units (DMUs), and treat the allocated cost as an extra input of each DMU. Now, consider auxiliary model (5) as follows:

$$\sum_{i=1}^{m} \tilde{c}_{ik}^{*} = \text{Min} \quad \sum_{i=1}^{m} c'_{ik}$$
$$\text{s.t.} \quad \sum_{j=1}^{n} c_{ij}\lambda_j \leq c'_{ik} \qquad i = 1, \dots, m$$
$$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{rk} \qquad r = 1, \dots, s$$
$$\sum_{j=1}^{n} r_{ij}\lambda_j \leq r_{ik} \qquad i = 1, \dots, m$$
$$c'_{ik} \geq 0, \ \lambda_j \geq 0, \quad i = 1, \dots, m, \quad j = 1, \dots, n \qquad (5)$$

For fixed cost allocation, extra constraints are added to the DEA model of cost efficiency. But, the new constraints are redundant; if $\sum_{j=1}^{n} c_{ij}\lambda_j \leq c_{ik}$, then $\frac{w_i.R}{\sum_{i=1}^{m} w_i} \cdot \frac{\sum_{j=1}^{n} c_{ij}\lambda_j}{\sum_{j=1}^{n} c_{ij}} \leq \frac{w_i.R}{\sum_{i=1}^{m} w_i} \cdot \frac{c_{ik}}{\sum_{j=1}^{n} c_{ij}}$, and according to (4): $r_{ij} = \frac{w_i.R}{\sum_{i=1}^{m} w_i} \cdot \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}}$, so inequalities may be written as follows: $\sum_{j=1}^{n} r_{ij}\lambda_j \leq r_{ik}$.

Therefore by choosing r_{ij} as statement (4), the optimal values of models (3) and (5) are identical. If fixed cost is considered as a complement of other inputs rather than an extra independent input, we can use $\hat{c}_{ij} = c_{ij} + r_{ij}$ in the model 3 which results to model (6):

$$\sum_{i=1}^{m} \hat{c}_{ik}^{*} = \text{Min} \quad \sum_{i=1}^{m} \hat{c}'_{ik}$$
$$\text{s.t.} \quad \sum_{j=1}^{n} \hat{c}_{ij}\lambda_j \leq \hat{c}'_{ik} \qquad i = 1, \dots, m$$
$$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{rk} \qquad r = 1, \dots, s$$
$$c_{ik} \geq 0, \ \lambda_j \geq 0, \quad i = 1, \dots, m, \quad j = 1, \dots, n \qquad (6)$$

The CE measure with fixed cost is given by the ratio of the optimal cost value obtained from (6) to the current cost at DMU_k as follows:

$$\text{Cost Efficiency with fixed cost} = CE_k^R = \frac{\sum_{i=1}^{m} \hat{c}_{ik}^{*}}{\sum_{i=1}^{m} \hat{c}_{ik}}$$

CASE STUDY

Allocated cost in the universities

Here, the allocative cost which is discussed in this paper with the analysis of universities activity is illustrated. The empirical results reported correspond to the analysis of 30 universities of Iran. The study use two inputs, general expenditure and equipment expenditure that are of two kinds of cost; and four outputs consisting of three types of students (number of under graduate students, post graduate teaching and post graduate research) and the research score. Table 1 indicates data of universities.

Table 2 shows different kinds of efficiency (technical, pure technical, scale and cost efficiency) for each university. The models are implemented in an MS-Excel worksheet and are solved by using the DEA Solver software and LINDO software. The value of fixed cost is R=5000, which must be divided among DMUs. We want to allocate costs between two types of inputs equally; on the other hand, we consider $w_1 = w_2 = 1$. The columns 6 and 7 in Table 2 indicated the proportion of share cost for each of the inputs of DMUs, according to statement (4).

The technical, pure technical and scale efficiencies of the DMUs remain unchanged after the allocated costs are added as a complement of other inputs to the various DMUs. Also, cost efficiency is calculated with fixed cost. The results in Table 2 show that the determined efficiencies after allocation cost, notwithstanding increasing in inputs, changed slightly and were improved.

According to the results of Table 2, the DMUs which are cost efficient, after allocation cost in the previously mentioned way, remain efficient. The average cost efficiency, before allocation cost is 0.83277 and after allocation cost is 0.83694, which indicates an overall improvement, but efficiency of all DMUs were not improved. For better comparison of results of the cost efficiency before and after allocation of fixed cost, Figure 1 is plotted.

Conclusion

The problem of allocating a fixed cost such as annual overhead is important in many managerial decision problems. This paper observes a fact in the fixed cost allocation problem that, in some cases, the fixed cost is a

Table 1. Inputs and outputs of universities.

DMU	General expenditure	Equipment expenditure	Under graduate students	Post graduate teaching	Post graduate research	Research score
1	310	24	48	3	4	49
2	499	95	97	9	24	110
3	2642	756	345	5	152	2674
4	991	129	210	0	37	782
5	520	31	62	3	15	35
6	922	155	185	0	18	287
7	505	113	110	0	21	220
8	918	117	130	8	28	386
9	1250	121	162	0	28	538
10	895	119	129	0	28	930
11	997	88	31	38	58	618
12	1459	227	201	0	61	797
13	1021	85	163	8	32	752
14	1123	459	154	5	36	353
15	2060	115	215	3	51	2957
16	446	79	120	0	10	765
17	3891	840	351	25	62	2322
18	841	86	137	3	42	702
19	1192	173	259	2	41	881
20	4632	629	550	0	222	4849
21	833	64	133	19	29	299
22	910	137	177	10	55	965
23	1259	65	199	15	46	569
24	734	95	156	4	26	301
25	312	31	62	0	8	160
26	520	71	80	9	25	312
27	574	27	76	22	12	139
28	2014	151	410	3	54	1527
29	1043	84	159	15	50	519
30	210	5	19	0	7	77

Table 2. Cost efficiency in model (1) and fixed cost.

DMU	TE	PTE	SE	CE	r1	r2	CE^R
1	0.815311	0.997538	0.817323	0.738364	21.8169	11.6032	0.750437
2	1	1	1	0.990854	35.1181	45.9292	0.973398
3	0.953173	1	0.953173	0.852723	185.9359	365.4999	0.824923
4	0.974967	0.98853	0.98628	0.93824	69.7436	62.3670	0.947193
5	0.744921	0.809277	0.920478	0.624461	36.5960	14.9874	0.64212
6	0.77329	0.862092	0.896992	0.767755	64.8875	74.9372	0.769149
7	0.956365	1	0.956365	0.908415	35.5403	54.6316	0.89429
8	0.713782	0.718671	0.993197	0.702187	64.6060	56.5655	0.704852
9	0.637936	0.650404	0.98083	0.588594	87.9712	58.4993	0.600247
10	0.774194	0.785132	0.986068	0.77125	62.9875	57.5324	0.773593
11	1	1	1	1	70.16581	42.545	1
12	0.702028	0.744698	0.942702	0.699344	102.68	109.7467	0.698491
13	0.90041	0.901272	0.999043	0.792165	71.8549	41.0946	0.807426
14	0.63891	0.639937	0.998396	0.525072	79.0333	221.9107	0.497026

Table 2. Contd.

15	1	1	1	0.984862	144.9765	55.5985	1
16	1	1	1	1	31.3881	38.1938	1
17	0.470058	1	0.470058	0.441417	273.8367	406.111	0.432909
18	1	1	1	0.870038	59.1870	41.5780	0.882468
19	0.948418	1	0.948418	0.926476	83.8893	83.6395	0.931896
20	0.908397	1	0.908397	0.906202	325.986	304.0998	0.907443
21	1	1	1	0.96523	58.624	30.9418	0.972176
22	1	1	1	1	64.0430	66.2348	1
23	1	1	1	0.87298	88.6046	31.4252	0.895736
24	0.976767	0.980238	0.996459	0.939879	51.6567	45.9292	0.948374
25	0.920275	1	0.920275	0.846767	21.9576	14.9874	0.864171
26	0.914385	0.99169	0.922047	0.908288	36.5960	34.3261	0.905102
27	1	1	1	1	40.3963	13.0536	1
28	1	1	1	0.890571	141.7392	73.0033	0.915833
29	1	1	1	0.913238	73.4032	40.6111	0.927774
30	1	1	1	0.617774	14.7792	2.4173	0.641023

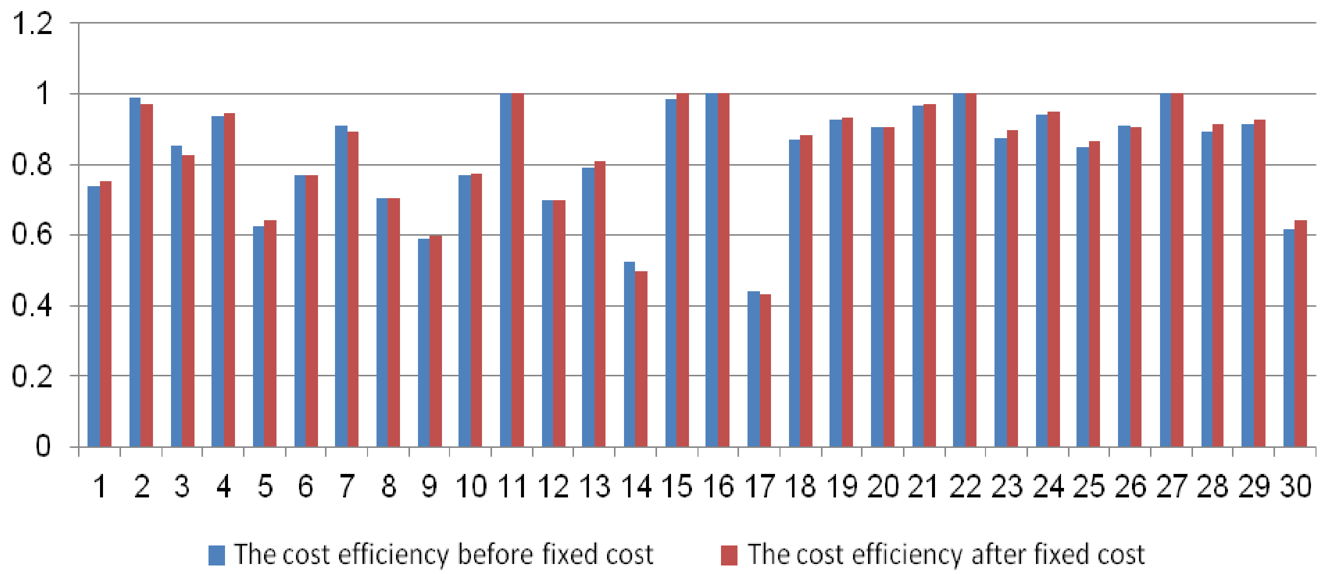

Figure 1. The cost efficiency scores of the universities, before and after allocation fixed cost.

factor. This fact was ignored by the previous researches. In the case when the allocated fixed cost is a complement of other cost input, this paper presents a reasonable DEA-based approach, which can give an equitable and unique allocation plan, which is a function of total cost R and the inputs that are used; also, allocated cost is independent of outputs values. We have illustrated the proposed approach for allocation fixed cost on data aggregation of universities. The allocation of fixed cost to universities inputs was carried out based on their scale; therefore, their scale efficiency does not change. This causes their technical efficiency to remain constant and improves the overall average of their cost efficiency.

REFERENCES

Alam GM (2009). Can governance and regulatory control ensure private higher education as business or public goods in Bangladesh? Afr. J. Bus. Manage., 3 (12): 890-906.

Alam GM, Khalifa MTB (2009). The impact of introducing a business marketing approach to education: a study on private HE in Bangladesh. Afr. J. Bus. Manage., 3(9): 463-474.

Alam, GM, Hoque KE, Oloruntegbe KO (2010). Quest for a better operation system in Education: Privatization, Teacher Educationalization

or Voucherilization: glimpsing from consumer and product perspectives. Afr. J. Bus. Manage., 4(6): 1202-1214.
Arcelus FJ, Coleman DF (1997). An efficiency review of university departments. Int. J. Syst. Sci., 28(7): 721–729.
Banker RD, Charnes A, Cooper WW (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Manage. Sci., 30(9): 1078-1092
Beasly JE (2003). Allocating fixed costs and resources via data envelopment analysis. Eur. J. Oper. Res., 147: 197–216.
Camanho AS, Dyson RG (2008). A generalisation of the Farrell cost efficiency measure applicable to non-fully competitive settings. Omega, 36: 147 – 162.
Charnes A, Cooper WW, Rhodes E (1978). Measuring the efficiency of decision making units. Eur. J. Oper. Res., 2 (6): 429–444.
Chen YC, Chiu YH, Huang CW (2010). Measuring super-efficiency of financial and nonfinancial holding companies in Taiwan: An application of DEA models. Afr. J. Bus. Manage., 4(13): 3122-3133.
Cook WD, Kress M (1999). Characterizing an equitable allocation of shared costs: a DEA approach. Eur. J. Oper. Res., 119: 652–661.
Emel A B, Oral M, Reisman A, Yolalan R (2003). A credit scoring approach for the commercial banking sector. Socio-Econ. Plan. Sci., 37: 103–123.
Färe R, Grosskopf S, Lovell CAK (1985). The measurement of efficiency of production. Kluwer Academic Publishers.
Farrell MJ (1957). The measurement of productive efficiency. J. Royal Stat. Society: Series A, 120: 253–381.
Jahanshahloo GR, Hosseinzadeh Lotfi F, Shoja N, Sanei M (2004). An alternative approach for equitable allocation of shared costs by using DEA. Appl. Math. Comput., 153: 267–274.
Kuosmanen T, Post T (2001). Measuring economic efficiency with incomplete price information: With an application to European commercial banks. Eur. J. Oper. Res., 134: 43–58.
Li Y, Yang F, Liang L, Hua Z (2009). Allocating the fixed cost as a complement of other cost inputs: A DEA approach. Eur. J. Oper. Res., 197: 389–401
Lu YH, Shen CC, Ting CT, Wang CH (2010). Research and development in productivity measurement: An empirical investigation of the high technology industry. Afr. J. Bus. Manage., 4(13): 2871-2884.
Mahallati Rayeni M, Hosseinzadeh Saljooghi F (2010). Benchmarking in the Academic Departments using Data Envelopment Analysis. Am. J. Appl. Sci., 7(11): 1464-1469.
Mostafaee A, H Saljooghi F (2010). Cost efficiency measures in data envelopment analysis with data uncertainty. Eur. J. Oper. Res., 202: 595–603.
Sherman HD (1988). Service organization productivity management. The Society of Management Accountants of Canada, Hamilton, Ontario.
Tone K, Sahoo BK (2005). Evaluating Cost Efficiency and Returns to Scale in the Life Insurance Corporation of India Using Data Envelopment Analysis. Socio-Econ. Plann. Sci., 39: 261-285.
Yeh QJ (1996). The application of data envelopment analysis in conjunction with financial ratios for bank performance evaluation. J. Oper. Res. Society, 47(8): 980–988.