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Efficiency assessment of universities through data envelopment analysis

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Abstract

Assessing the efficiency of universities is vital for effective allocation and utilization of educational resources. In this paper, a data envelopment analysis (DEA) model for jointly evaluating the relative teaching and research efficiencies of universities was presented. The inputs and outputs for university performance measurement were first identified. They comprise a total of 16 measures which are believed to be essential. A variant of DEA called joint DEA maximization was used to model and evaluate these measures. The model was tested using a hypothetical example and its use and implications in university performance measurement were described. The application of DEA enables academics to identify deficient activities in their universities and take appropriate actions for improvement.

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Keywords: Higher education; Data envelopment analysis; Teaching efficiency; Research efficiency; Efficiency measurement.

1. Introduction

With ever-increasing enrolments of students into the public universities and limited funding, it is no longer an option for these institutes to operate at a higher degree of efficiency; it has become a necessity. In order to improve their efficiency, a performance measurement tool is required to measure the performance across the universities.

The rather special characteristics of universities cause difficulty in measuring their efficiency. Firstly, as with any other non-profit making organizations, naturally it is hard to assign monetary values to the inputs and outputs. Secondly, a university produces multiple outputs (e.g. graduates and publications) using multiple inputs (e.g. lecturers and facilities).

A variety of methods have been used to evaluate the performance of universities, while the most common methods are Stochastic Frontier Analysis (SFA) [1] and Data Envelopment Analysis (DEA) [2,3]. SFA is good in handling data with certain level of uncertainty; however it is not easy to be applied in a multiple inputs and outputs situation. On the other hand, DEA has become a popular performance measurement tool for non-profit institutions

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like schools, hospitals, and universities due to its capability of handling multiple inputs and outputs without a priori assumptions on the monetary values of the inputs and outputs.

The fundamentals of DEA methodology and a review of DEA applications in universities will be presented in Section 2. The mathematical model for this study is discussed in Section 3. A hypothetical example is used to illustrate the application and implication of the model in Section 4. Lastly, Section 5 concludes the paper with some future works.

2. Literature Review

2.1. DEA fundamentals

Data Envelopment Analysis (DEA) was first introduced by Charnes, Cooper, and Rhodes in 1978 [4]. It is a simple yet powerful method used to measure the relative efficiency of a group of homogenous firms or decision making units (DMUs). A DMU can be defined as an entity responsible for converting input(s) into output(s) and whose performances are to be evaluated. The popularity of DEA is due to its ability to measure relative efficiencies of multiple-input and multiple-output DMUs without prior weights on the inputs and outputs.

The most basic DEA model is known as CCR model, which was named after the three authors. Consider there are n DMUs: DMU_1, DMU_2, …, and DMU_n. Each DMU_j, (j = 1, 2, …, n) uses m inputs x_{ij} (i = 1, …, m) and generates s outputs y_{rj} (r = 1, …, s). Let the input weights v_i (i = 1, …, m) and the output weights u_r (r = 1, …, s) as variables. Let the DMU_j to be evaluated on any trial be designated as DMU_0 (0 = 1, 2, …, n). The efficiency of each DMU_0, e_0, is thus found by solving the linear programming below, which is known as the multiplier form in DEA.

$$e_0 = max \sum_r u_r y_{r0} \tag{1}$$

$$s.t. \quad \sum_i v_i x_{i0} = 1 \tag{2}$$

$$\sum_r u_r y_{ro} - \sum_i v_i x_{io} \leq 0 \tag{3}$$

$$u_r, v_i \geq 0 \tag{4}$$

The model is run n times in identifying the relative efficiency scores of all the DMUs. Each DMU selects a set of input weights v_i and output weights u_r that maximize its efficiency score. The efficiency scores would fall in between 0 and 1. Generally, a DMU is efficient if it obtains the maximum score of 1; else, it is inefficient. One advantage of DEA is, for every inefficient DMU, DEA identifies a set of corresponding efficient DMUs that can be utilized as benchmarks for improvement.

This paper is not intended to cover the immense topics of DEA. Readers who are interested in a thorough discussion on the various topics of DEA are advised to refer to the literature reviews done by Cook and Seiford [5] and Kuah et al. [6].

2.2. Application of DEA in universities

DEA has been applied to evaluate the relative efficiencies among universities and relative efficiencies among university departments or courses. Previous studies on DEA applications in the context of university departments or courses include Johnes and Johnes [7], Johnes [8], Beasley [9], and Stern et al. [10]. While some main studies that utilized DEA to evaluate the relative efficiencies among universities include Ahn et al. [11], Abbott and Doucouliagos [12], Avkiran [13], Johnes and Yu [2], Bougnol and Dulá [3], Johnes [14], Fandel [15], and Breu and

Raab [16].

There is no definitive standard to guide the inputs/outputs selection in university efficiency assessment. For examples, Ahn et al. [11] have selected faculty salaries, state research funds, administrative overheads, and total investment in physical plants as inputs and number of undergraduate enrolments, number of graduate enrolments, total semester credit hours, and federal and private research funds as outputs; while Johnes [14] has chosen the quantity and quality of undergraduates, number of postgraduates, number of teaching and research staffs, administration expenditures, library and computer facility expenditures, and value of interest payments and depreciations as inputs and quantity and quality of first degree graduates, number of higher degree graduates, and research grants as outputs. Generally, the agreed inputs for universities can be classified as human and physical capital, and the outputs should arise from teaching and research activities [17]. The inputs and outputs as well as the DEA model used in this study are presented in the next section.

3. Mathematical Model

The input/output mix is identified based on previous studies plus some measures that the authors think are essential to evaluate the efficiencies of universities. The reason for incorporating more measures than other DEA studies on universities is to reduce the risk of excluding any important measure which could eventually affect the performance of the model. The DEA variant applied in this study is called joint DEA maximization, which was introduced by Beasley [9]. Joint DEA maximization is useful in applications where there are different functions in DMUs and the relative efficiencies of these functions have to be determined. In addition, there are inputs/outputs which are shared across the functions and need to be apportioned. This section will further describe the teaching efficiency model, the research efficiency model, and the overall efficiency model.

3.1. Inputs and outputs for teaching efficiency

The argument in the teaching efficiency model is that universities employ academic staffs to educate the students enrolled to produce graduates with certain level of quality. Thus, teaching efficiency is referring to the teaching performance of universities in delivering knowledge to undergraduate and postgraduate taught course students. The quality of students is taken as an input based on a general assumption that better entry qualifications will produce better quality products, in this case, the graduates. The outputs of teaching activities are concentrated on graduates. Graduates' results and graduation rate of a university are associated with the academic quality of graduates; while graduates' employment rate is reflecting the employers' perception on the quality of graduates from a particular university. The input and output mix for teaching efficiency is shown in Table 1.

3.2. Inputs and outputs for research efficiency

The argument in the research efficiency model is that universities employ research staffs and enroll research students to produce research outputs, namely publications, awards, and intellectual properties. Average research staffs' qualification is calculated based on a proposed scoring system (professors and above = 4, associate professors = 3, Ph.D holders = 2, master degree holders and below = 1). Number of research student graduates is also considered as an output in this model. Some studies considered research grants as an output based on the argument that they are the outcomes of research performance. This means that if the research performance of a university is better, more funds will be attracted. In contrast, in this study, research grants are treated as a resource for research activities, thus they are considered as an input. The input and output mix for research efficiency is shown in Table 2.

It should be noted that university expenditure is a shared resource for both teaching and research activities, and therefore in evaluating teaching and research efficiencies, the proportion of the expenditures for both functions needs to be determined. However, it is normally hard, if not impossible, for a university to measure or determine the proportion of its expenditures for research and teaching activities. Thus, joint DEA maximization [9] has been used to apportion the expenditures between the two functions and determining the overall efficiency, teaching efficiency, and research efficiency. The model is presented in Section 3.3 as follows.

Table 1. Input and output mix of teaching efficiency

Inputs	Outputs
X_1: Number of academic staffs	Y_1: Number of graduates from taught courses
X_2: Number of taught course students	Y_2: Average graduates' results *(CGPA)*
X_3: Average students' qualifications *(CGPA)*	Y_3: Graduation rate *(%)*
X_4: University expenditures *(Million USD)*	Y_4: Graduates' employment rate *(%)*

Table 2. Input and output mix of research efficiency

Inputs	Outputs
X_4: University expenditures *(Million USD)*	Y_5: Number of graduates from research
X_5: Number of research staffs	Y_6: Number of publications
X_6: Average research staffs' qualifications	Y_7: Number of awards
X_7: Number of research students	Y_8: Number of intellectual properties
X_8: Research grants *(Million USD)*	

3.3. Model for university performance measurement

Consider there are n universities: DMU_1, DMU_2, …, and DMU_n. Each university j, DMU_j, (j = 1, 2, …, n) uses 4 inputs X_{ij} (i = 1, …, 4) to generate 4 outputs Y_{rj} (r = 1, …, 4) from its teaching activities; and 5 inputs X_{ij} (i = 4, …, 8) to generate 4 outputs Y_{rj} (r = 5, …, 8) from its research activities.

As explained earlier, one of the inputs, X_4 (University expenditures), is common to both activities and thus it needs to be apportioned in order to determine the teaching and research efficiencies. Since it is hard for a university to apportion the exact amount of expenditures, the allocation for each function is done with an objective of maximizing its overall relative efficiency. Let p be the proportion of expenditure on teaching activities, and (1 - p) be the proportion of expenditure on research activities.

Next, let the input weights v_i (i = 1, …, m) and the output weights u_r (r = 1, …, s) as variables. Let the DMU_j to be evaluated on any trial be designated as DMU_0 (0 = 1, 2, …, n). The teaching efficiency (T_0) and research efficiency (R_0) of DMU_0 are thus defined as:

$$T_0 = \frac{\sum_{r=1}^{4} u_r Y_{r0}}{\sum_{i=1}^{3} v_i X_{i0} + p(v_4 X_{40})} \tag{5}$$

$$R_0 = \frac{\sum_{r=5}^{8} u_r Y_{r0}}{(1-p)(v_4 X_{40}) + \sum_{i=5}^{8} v_i X_{i0}} \tag{6}$$

The DEA model to measure the overall efficiency (E_0) is modeled as follows:

$$max\ E_0 = \frac{\sum_{r=1}^{8} u_r Y_{r0}}{\sum_{i=1}^{8} v_i X_{i0}} \tag{7}$$

s.t.

$$\sum_{r=1}^{8} u_r Y_{rj} - \sum_{i=1}^{8} v_i X_{ij} \leq 0, \quad \forall j \tag{8}$$

$$\sum_{r=1}^{4} u_r Y_{rj} - \sum_{i=1}^{3} v_i X_{ij} - p(v_4 X_{4j}) \leq 0, \quad \forall j \tag{9}$$

$$\sum_{r=5}^{8} u_r Y_{rj} - (1-p)\big(v_4 X_{4j}\big) - \sum_{i=5}^{8} v_i X_{ij} \leq 0, \quad \forall j \tag{10}$$

$$0.3 \leq p \leq 0.7 \tag{11}$$

$$u_r, v_i \geq \varepsilon \tag{12}$$

Equation (7) is the objective function to find the optimum set of weights (v_i and u_r) that gives the maximum relative overall efficiency for DMU_j under evaluation, while subjected to the constraints (8) to (12). Constraints (8) to (10) are to limit the relative efficiencies (E_0, T_0, and R_0) of all DMUs to be within 1. In addition, constraint (11) is to prevent zero proportion of the expenditures on either function; and ε is a small non-Archimedean number, 0.01. The model is run n times in identifying the relative efficiency scores of all the DMUs. DMUs with efficiency scores of 1 are considered as efficient, while those with efficiency scores lower than 1 are considered as inefficient. With the optimum set of weights obtained for DMU_j, the teaching efficiency and research efficiency of DMU_j are determined using equations (5) and (6) respectively.

4. A Hypothetical Example

The application of the model will be illustrated using a hypothetical example of 30 universities. The data are generated randomly and shown in Table 3. After solving the problem using the constructed model, the relative efficiencies of universities are summarized in Table 4. 9 universities obtained E_0 of 1 which means they are overall efficient; 3 universities are efficient in their teaching activities (T_0 = 1); and 11 universities are efficient in their research activities. Out of these 30 universities, only 1 university - DMU_{29}, is efficient in all the three criteria. The model shows a strong discriminatory power between efficient and inefficient universities.

Table 3. Hypothetical data for 30 universities

	Inputs								Outputs							
DMU	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
1	2643	12086	2.67	196	684	3.18	728	127	11688	2.73	90.06	92.15	658	2649	320	163
2	3222	7522	2.52	147	504	3.16	584	43	3109	3.32	98.80	61.24	555	2780	260	24
3	3284	14683	3.23	136	890	3.10	1109	44	6843	3.40	87.49	90.02	705	2946	61	163
4	2150	10441	2.53	138	922	3.09	2216	44	3144	3.11	87.65	71.17	1821	1218	85	249
5	2065	7386	3.02	172	402	3.09	2064	113	5953	3.21	94.14	67.40	1730	2640	217	110
6	1973	11655	3.35	73	590	2.75	2260	102	6639	3.15	91.79	88.63	625	1357	49	110
7	1777	7379	2.77	181	930	3.17	2203	66	6031	2.93	86.23	92.02	1681	2775	243	82
8	1513	6931	3.36	172	1063	2.66	2931	114	6836	2.50	82.60	87.94	1437	947	410	290
9	2021	5932	2.74	180	925	2.58	2026	95	5318	2.58	76.41	97.52	807	2502	163	80
10	2888	8098	3.42	58	665	2.51	2665	109	7462	3.15	92.27	65.27	1491	310	381	142
11	2183	7563	3.22	158	693	3.22	1968	63	7045	3.15	88.03	65.13	901	666	122	71
12	1995	7678	2.62	182	430	2.85	1210	85	5371	3.32	81.84	91.03	815	2385	395	303
13	3346	13757	3.28	108	703	3.18	2146	89	8206	2.86	81.64	73.19	852	1143	377	237
14	2724	13315	2.53	144	1030	3.18	2648	86	10222	2.52	90.61	96.38	829	2531	288	98
15	2504	14374	2.58	77	997	3.27	1075	42	9578	3.14	77.51	97.05	876	2317	97	238
16	2006	5555	3.02	125	712	3.13	1550	64	4332	3.04	91.91	88.38	1216	2008	211	307
17	2146	9419	2.67	104	258	3.10	769	49	7200	3.15	96.88	83.97	198	2845	453	62
18	1890	10883	3.35	152	656	3.24	2853	58	7616	2.66	88.84	66.70	971	1292	300	131
19	2736	10763	2.79	186	235	3.24	1937	68	4360	2.64	94.24	89.87	863	2966	464	33
20	3248	11968	2.97	131	846	2.97	867	74	7857	2.79	85.43	77.80	398	1834	476	159
21	1679	6328	3.25	132	1013	3.15	1513	125	6228	3.40	80.40	76.92	753	314	112	114
22	1645	7059	3.35	145	780	3.15	775	54	6274	3.35	89.96	72.38	456	539	364	150
23	1391	6798	3.10	87	730	2.86	2746	76	4905	2.80	84.70	87.00	1606	1823	186	261
24	2894	5714	2.53	141	705	3.23	1119	103	5185	2.94	91.31	86.88	690	1463	93	39
25	2018	9375	3.34	54	776	2.54	783	109	3411	2.62	91.49	95.86	746	2488	364	263
26	3136	6450	3.38	63	530	2.60	1311	59	5552	2.97	83.33	92.17	613	596	232	248
27	2568	8381	3.17	84	1028	3.14	2428	100	4893	3.22	88.61	85.64	1719	1556	87	30
28	2451	9642	2.65	76	503	3.02	622	121	4973	2.72	87.85	82.52	588	1827	128	75
29	1930	5649	2.95	71	222	2.68	811	64	5021	3.18	87.96	99.77	641	2156	301	165
30	2429	12526	2.62	102	930	2.84	2343	65	6025	3.42	95.41	83.91	1199	1037	68	209

Table 4. Efficiency scores for the 30 universities

DMU	E_0	T_0	R_0
1	0.9805	0.9805	0.9460
2	1.0000	0.5902	1.0000
3	0.9513	0.6019	0.9513
4	0.9994	0.4854	1.0000
5	1.0000	0.8878	1.0000
6	0.9289	0.9695	0.5205
7	0.9758	0.8502	1.0000
8	1.0000	1.0000	0.6637
9	0.9821	0.9865	0.6118
10	0.9398	0.9432	0.7901
11	0.9442	0.9445	0.3960
12	1.0000	0.7697	1.0000
13	0.6754	0.7118	0.6190
14	0.8442	0.8680	0.5165
15	0.9935	0.9778	1.0000
16	0.9962	0.9987	0.9763
17	1.0000	0.9985	1.0000
18	0.8919	0.8919	0.6352
19	0.9959	0.4145	0.9959
20	0.9939	0.6381	0.9939
21	0.9979	0.9979	0.2513
22	1.0000	0.9786	1.0000
23	0.8869	1.0000	0.7917
24	0.9951	0.9952	0.4964
25	1.0000	0.6986	1.0000
26	0.8727	0.8727	0.9216
27	0.8673	0.7347	0.8943
28	1.0000	0.7161	1.0000
29	1.0000	1.0000	1.0000
30	0.6830	0.7125	0.6444

It should be noted that a university which is overall efficient does not necessarily mean that it is efficient in both teaching and research activities. It simply indicates that the university is efficient in producing outputs from its inputs. However, for a university that is both teaching and research efficient, it must be overall efficient. Some universities like DMU_2, are high in research efficiency but low in teaching efficiency. This could indicate that they focus more on research activities than teaching activities. In contrast, a few universities, for example DMU_{23}, have high teaching efficiency but low research efficiency. This could imply that they are more competent and productive in teaching but less capable in conducting research.

Another useful application of DEA is it can provide information on how much universities should improve in their performance. The objective is to move their performance towards becoming both teaching and research efficient. Take one of the universities which is inefficient in both teaching and research - DMU_{30}. It can improve its teaching outputs by 40% (calculated by $1/T_0 = 1/0.7125 = 1.4035$) and research outputs by 55% (calculated by $1/R_0 = 1/0.6444 = 1.5518$). For universities that are efficient particularly in one function but are inefficient in the other, improvement targets can be established using the same method.

5. Conclusions

The paper has presented a DEA model which consists of 16 inputs and outputs to measure the efficiencies of universities based on their teaching and research activities. This is the first attempt for a DEA study on university performance that includes this large amount of measures. Some new measures such as number of awards and patents are also introduced. Despite considering more measures, the model has demonstrated a strong discriminatory power in differentiating between efficient and inefficient universities even with a small sample size of 30.

Future studies should look into some particular issues in applying this DEA model to assess university performance. For example, a university's long and variable lead times between the inputs and outputs should be taken into consideration. In addition, there is a lack of studies on university performance measurement using DEA in the Asian region. Hence, it could be interesting to compare the performance of universities across a few Asian countries.

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