Measuring the efficiency of university departments: an empirical study using data envelopment analysis and cluster analysis

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Abstract

Universities continue to play a key role in the development of a country. As university income streams shift away from government and as the income from admissions decline under the sub-replacement fertility phenomenon, the efficiency of resource utilization has become an important issue for university administrators. This paper applies data envelopment analysis (DEA) and the concept of an assurance region to evaluate the relative efficiency (including aggregate, technical, and scale efficiencies) of academic departments at National Chung Cheng University in Taiwan. The input factors considered are personnel (expressed in the number of faculty-equivalent persons), operating expenses, and floor area, and the output factors are teaching (expressed in total credit hours), publications (expressed in the number of papers), and external grants. Notably, teaching quality is included by considering the classroom capacity in calculating credit hours, and publication quality is included by considering the author contribution to calculate the single-author-equivalent numbers of papers. In addition, a cluster analysis based on the efficiency decomposition to the contributions of the three outputs is applied to classify the departments into three groups. The results of this paper not only provide the department head with the relative efficiency and improvement directions for the department but also serve as a reference for resource allocation and future strategy development for the university administration.

Keywords Cluster analysis · Data envelopment analysis · Efficiency

Introduction

Universities continue to play a key role in the development of a country, and their main mission is to explore and transmit knowledge via research and teaching. Taiwan, which is located in East Asia, has the highest density of universities in the world. Taiwan covers an area of 35,887 km^2 and had a population of 23.33 million in 2020. With the advent of the era of the knowledge economy, many universities have been established in Taiwan in the

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past thirty years, and higher education has already become common in Taiwan. According to the Department of Statistics (DOS) of the Ministry of Education (MOE) (Department of Statistics of the Ministry of Education 2020), the number of universities and colleges in Taiwan has increased rapidly, from 50 in 1991 to the highest peak of 149 in 2007 and 2009, and then gradually decreased to 140 in 2020 due to factors such as a rapidly shrinking population under the sub-replacement fertility phenomenon. From 1991 to 2020, the number of universities in Taiwan almost tripled, which resulted in a reduction in the average government subsidy to each university. In fact, government subsidies account for only a portion of a university's budget, even if a national university faces financial pressures and must seek self-raised income. For example, National Chung Cheng University (CCU) in Taiwan receives only approximately 44.9% of its budget from the government. Thus, more efficient resource use is becoming an important issue for university administrators.

According to the National University Endowment Fund Establishment Act enacted in 1999 by the MOE of Taiwan (Laws & Regulations Database of Taiwan, 2015), universities are allowed to retain unused funds for future use. This strengthens the motivation for a national university to self-finance. In general, a university's self-raised income includes tuition fees, grants and contracts, private donations, profits from university investments, etc. (Kao & Hung, 2008), with income from tuition fees being relatively stable. However, according to the Department of Statistics of the MOE (the DOS of MOE 2018), the number of students in universities and colleges has decreased from a peak of 1.355 million in 2012 to 1.213 million in 2019, which is a cumulative decrease of 142,000 in the past eight years. Therefore, income from tuition fees has become more strained with the rapidly shrinking population of students and the controversy caused by increasing tuition fees. Thus, university administrators must be more careful in allocating limited and precious resources to academic departments. Every professor, each dollar and all other resources are expected to produce satisfactory outputs. Clearly, universities should conduct an efficiency analysis to investigate the resources used in producing outputs (Kao & Hung, 2008).

Although there are several popular international university ranking systems, such as the Academic Ranking of World Universities (ARWU), Times Higher Education (THE) World University Rankings, CWTS Leiden Ranking, and Quacquarelli Symonds (QS) World University Rankings (Olcay & Bulu, 2017), and some university evaluations (for example, the accreditation of schools of business provided by the Association to Advance Collegiate Schools of Business, AACSB), they are not aimed at measuring efficiency. Generally, these university ranking systems first select some indicators to represent the various aspects of excellence, assign weights to each indicator, which reflect their relative importance, and then adopt the weight-and-sum approach to calculate the overall scores for the participating universities that are thus ranked (Kaycheng, 2015); the objective of these university evaluations is to measure whether the establishment objectives and educational goals set by the department are achieved and how to improve the department if necessary. That is, these university ranking systems and university evaluations investigate the educational outputs produced by the university/department but not the relative efficiency of the university/department compared with other universities/departments. However, as mentioned above, when financial resources are limited, a university administrator must be more cautious in allocating precious resources to each department. Therefore, although some university ranking systems and university evaluations are provided by professional institutions, it is still necessary to investigate university/department efficiency.

Data envelopment analysis (DEA) has been demonstrated to be a preeminent methodology for measuring the relative efficiency of a university. In the literature, two types of efficiency evaluations at the university level have been extensively discussed (for example, Abbott &

Doucouliagos, 2003; Kao & Hung, 2008; Sellers-Rubio, Mas-Ruiz, & Casado-Díaz, 2010; Agasisti & Wolszczak-Derlacz, 2015). The first type compares the efficiency of different universities; for example, in the last five years, such studies have included Lee and Worthington (2016), Sagarra et al. (2017), Visbal-Cadavid et al. (2017), Guironnet and Peypoch (2018), Klumpp (2018), Quiroga-Martinez et al. (2018), Yang et al. (2018), Hou et al. (2019), Moreno-Gómez et al. (2019), Koçak et al. (2019), Shamohammadi and Oh (2019), Dumitrescu et al. (2020), Łącka and Brzezicki (2020), Moncayo-Martínez et al. (2020), Salas-Velasco (2020), Tran et al. (2020), and Zhang et al. (2020). The second type of efficiency evaluation compares the efficiency of different departments within a university, such as in the studies of Sinuany-Stern et al. (1994), Gander (1995), Kao and Hung (2008), Barra and Zotti (2016), Ding et al. (2020), and Ghasemi et al. (2020). There are also studies on the efficiency of Taiwan's universities, for example, Kao and Hung (2008), Kong and Fu (2012), and Lu (2012). The above studies show that using DEA to investigate university efficiency is necessary and appropriate.

This paper uses the BCC model (Banker et al. 1984) of DEA to analyze the efficiency of the academic departments at CCU, which was the first national university established after Taiwan's economic boom of the 1980s and is one of the main universities in Taiwan. In addition to measuring the aggregate efficiency of each department, technical efficiency and scale efficiency are also discussed. Furthermore, this study conducts a cluster analysis (Johnson & Wichern, 2002) based on the efficiency contributions of individual output factors decomposed from aggregate efficiency, classifies the departments into the three groups of *Teaching*, *Research*, and *General*, and further classifies them into subgroups with similar characteristics. The study results can provide the department head with the relative efficiency and necessary improvements for each department and offer university administrators not only a basis for allocating limited resources to departments but also references for future strategies. Although this paper follows the methodology of Kao and Hung (2008) to measure the efficiency of academic departments, there are several differences between this paper and Kao and Hung (2008). First, in this paper, teaching quality is included by considering the classroom capacity in calculating credit hours. Second, publication quality is included by considering the author contribution to calculate the single-author-equivalent numbers of papers. Third, this paper further classifies the departments of the *Research* group into two clusters, namely, the *Research-publications* and *Research-grants* subgroups. Fourth, this paper also classifies the departments of the *General* group into three clusters, specifically, the *General-publications*, *General-grants* and *General-inefficiency* subgroups. Fifth, the results of this paper are compared with the findings obtained in Kao and Hung (2008) and discussed.

The rest of this paper is organized as follows. Section 2 introduces the input and output factors adopted to measure the efficiency of the academic departments at CCU. Section 3 applies DEA to measure the relative efficiency of each department and make appropriate decompositions. A cluster analysis is conducted in Sect. 4 based on the efficiency measures and their decompositions to classify the departments into groups with similar characteristics. Finally, Sect. 5 concludes this paper.

Research design

This study focuses on measuring the relative efficiency of research and teaching in the academic departments at CCU. The first national university established after Taiwan's economic boom of the 1980s, CCU had a total of 11,205 students and 532 teachers from 2019–2020 (the DOS of MOE, 2020). It is a member of the Taiwan Comprehensive

University System (TCUS), a research-led university alliance in Taiwan, and is also a member of the AACSB (AACSB, 2020).

Selection of decision-making units (DMUs)

According to CCU's 2018 Annual Report (Academic Affairs Office of the National Chung Cheng University, 2020), it has 7 colleges and 29 departments, of which 68 offer Master's degrees and 30 offer doctoral degrees. Because a department offers different degrees, this paper selects DMUs according to the departments and individual graduate institutions but not individual programs. The Graduate Institute of Opto-Mechatronics is included in the Department of Mechanical Engineering because they have a very close relationship each other due to academic content and common resources such as faculty and space. Table 1 summarizes the 33 departments as DMUs selected in this paper.

Input–output factors

As is generally known, research and teaching have been considered to be the two major tasks of a university to achieve the missions of exploring and transmitting knowledge. However, evaluating the teaching and research efficiencies of university departments is very difficult. When DEA is used to evaluate the efficiency performance of university departments, it is necessary to determine the representative indicators that affect teaching and research performance. Several studies have discussed the selection of input–output factors to evaluate the efficiency of university departments by using DEA (for example, Abbott & Doucouliagos, 2003; Kao & Hung, 2008; Sinuany-Stern et al., 1994; Tomkins & Green, 1988). As noted by Kao and Hung (2008), at least two major difficulties arise when determining these input–output indicators, specifically, the availability of data and the measurement of research and teaching quality (Higgins, 1989; Kao & Hung, 2008).

To select representative input and output factors subject to the above difficulties, this paper uses as a basis the input and output factors selected in the study of Kao and Hung (2008) because the research object of Kao and Hung (2008) is the National Cheng Kung University (NCKU) in Taiwan, which is also a member of the TCUS with common characteristics to CCU. In addition, to consider the quality of teaching and research, this paper modifies the calculation of some input and output factors based on the regulations and current situation of CCU.

The three input factors used in this paper to measure department efficiency are personnel (expressed in the number of faculty-equivalent persons, X_1), operating expenses (in 1,000 new Taiwan dollars (NTD), 1,000 NTD $\cong$ 34.7 USD in November 2020, X_2), and floor area (in square meters, X_3). The first input factor (personnel) includes full-time academic faculty and administrative staff and does not include adjunct faculty, who are included in the second factor. Consistent with Kao and Hung (2008), each full-time faculty member is counted as 1, each staff member is counted as 0.5, and all persons in a department are added to yield the number of faculty-equivalent persons. These data are acquired from the public information platform of the MOE and the personnel changes announced by the Personnel Office of CCU.

The second input factor (operating expenses) is the administrative expenses allocated to each department by the university. Consistent with Kao and Hung (2008), these expenses include the equipment procurement and maintenance costs, the salaries paid to adjunct faculty and part-time workers, and all expenditures. The salaries paid to full-time faculty and

Table 1 The 33 decision-making units of CCU in this paper

College	Decision making units (Departments)
College of Humanities	1. Chinese Literature (including Master's, In-service Master's, and Ph.D. programs)
	2. Foreign Languages and Literature (including Master's, In-service Master's, and Ph.D. programs)
	3. History (including Master's and Ph.D. programs)
	4. Philosophy (including Master's and Ph.D. programs)
	5. Graduate Institute of Linguistics (including Master's and Ph.D. programs)
	6. Graduate Institute of Taiwan Literature and Creative Innovation (including Master's, and In-service Master's programs)
College of Science	7. Mathematics (including Master's, In-service Master's, and Ph.D. programs, Graduate Institutes of Applied Mathematics and Statistical Science)
	8. Earth and Environmental Sciences (including Master's and In-service Master's programs, and Graduate Institutes of Geophysics and Seismology)
	9. Physics (including Master's, In-service Master's, Ph.D. programs)
	10. Chemistry and Biochemistry (including Master's and Ph.D. programs)
	11. Biomedical Sciences (including Master's program and Graduate Institute of Molecular Biology)
College of Social Sciences	12. Social Welfare (including Master's, In-service Master's, and Ph.D. programs)
	13. Psychology (including Master's, In-service Master's, and Ph.D. programs)
	14. Labor Relations (including Master's and In-service Master's programs)
	15. Political Science (including Master's, In-service Master's, and Ph.D. programs)
	16. Communication (including Graduate Institute of Telecommunications)
	17. Graduate Institute of Strategic and International Affairs (including Master's and In-service Master's programs)
College of Engineering	18. Computer Science and Information Engineering (including Master's, In-service Master's, and Ph.D. programs)
	19. Electrical Engineering (including Master's, In-service Master's, and Ph.D. programs)
	20. Mechanical Engineering (including Master's, In-service Master's, and Ph.D. programs, and Graduate Institute of Opto-Mechatronics)
	21. Chemical Engineering (including Master's, In-service Master's, and Ph.D. programs)
	22. Communications Engineering (including Master's, In-service Master's, and Ph.D. programs)
College of Management	23. Economics (including Master's, In-service Master's, and Ph.D. programs)
	24. Finance (including Master's, and In-service Master's programs)
	25. Business Administration (including Master's, In-service Master's, and Ph.D. programs, Graduate Institute of Marketing Management)
	26. Accounting and Information Technology (including Master's, In-service Master's, and Ph.D. programs)
	27. Information Management (including Master's, In-service Master's, and Ph.D. programs)
College of Law	28. Law (including Master's, In-service Master's, and Ph.D. programs)
	29. Financial and Economic Law (including Master's and In-service Master's programs)
College of Education	30. Adult and Continuing Education (including Master's, In-service Master's, and Ph.D. programs, and Graduate Institute of Elder Education)
	31. Graduate Institute of Education (including Master's, In-service Master's, Ph.D. programs)
	32. Criminology (including Master's, In-service Master's, and Ph.D. programs)
	33. Athletic Sports and Leisure Education (including Master's program)

staff and expenses covered by grants are not counted. Unfortunately, operating expenses are difficult to obtain because they are not public. In this paper, these data are acquired from the Office of Institutional Research and the Accounting Office of CCU.

The third input factor (floor area) is the amount of space used by each department. A department with more usable space is expected to achieve more in terms of teaching and research. In recent years, because the new teaching building was completed at CCU, the spaces have been reallocated. For example, the Department of Accounting and Information Technology moved from the College of Management to the Innovation Building in 2016. These updated data are obtained from the college and department offices of CCU.

For the output factors, based on Kao and Hung (2008), this paper uses the total effective credit hours (Y_1), number of publications (expressed in single-author-equivalent numbers of papers, Y_2), and total external grants (expressed in 1,000 NTD, Y_3) to measure the achievement of a department in teaching and research. Notably, in contrast to Kao and Hung (2008), this paper modifies the calculation of the first two factors by considering the quality of teaching and research. The first output factor is total credit hours to represent achievement in teaching. The credit hours for a certain professional course are defined as the credits of the course multiplied by the number of students taking the course, and then, the total credit hours of a department are the sum of the credit hours of every professional course in this department. In addition, to make an undergraduate course and a graduate course comparable and form undergraduate-equivalent credits in the evaluation, the weight of graduate credits is assigned as twice the weight of undergraduate credits. Specifically, the number of students in some courses far exceeds the classroom capacity (that is, the upper limit of the number of students), which may undermine the quality of teaching and learning. Therefore, in this case, this paper modifies the number of students in calculating the credit hours to the effective number of students. That is, when the number of students taking a course exceeds the classroom capacity, the effective number of students is set as the classroom capacity. These related data are acquired from the System of Academic Affairs of CCU.

The second output factor is the number of publications, which represents achievement in research. Consistent with Kao and Hung (2008) and following the general consensus of the top administrators at CCU, the number of publications represents only the number of articles published in the journals included on the journal list of Science Citation Index Expanded (SCIE), the Social Science Citation Index (SSCI), and the Art and Humanities Citation Index (A&HCI). Notably, this measure has also been adopted by the MOE in determining the research capability of universities in Taiwan. These related data are acquired from the Web of Science (WOS) database with the article and review document types. The timespan of the data is from 2018 to 2019 to reduce errors caused by examining only one year, and then, the average of the numbers for 2018 and 2019 is used. Furthermore, in contrast to Kao and Hung (2008), for a co-authored paper, the weight for the author contribution is assigned to the department faculty to form the single-author-equivalent numbers of papers according to the regulation by the Office of Research and Development at CCU if the other authors of this paper are not with this department. The contribution weight of the first author is triple that of the other authors. For example, a weight of 0.5 ($=3/(3+1+1+1)$) is assigned to the first author of a four-author paper. If the first author is the only author in the department, then the number of publications of this department is counted as 0.5.

Consistent with Kao and Hung (2008), the third output factor of total external grants also represents achievement in research. A large amount of funding means that there may be more patents and can also promote the university's reputation to attract more

students to study, more faculty and staff to serve, and more research subsidies. The total external grants are also an important indicator used by the MOE to evaluate the research capabilities of universities. Unfortunately, however, the total external grants are difficult to acquire because some are not public. In this paper, these data are obtained from the Office of Institutional Research and the Office of Research and Development at CCU.

Accordingly, this study uses 33 DMUs, three inputs and three outputs, which conforms to the rules of thumb regarding the minimum number of DMUs suggested by authors such as Golany and Roll (1989), Bowlin (1998), and Dyson et al. (2001). Golany and Roll (1989) established a rule that the number of DMUs should be at least twice the number of inputs and outputs considered. Bowlin (1998) noted that three DMUs are required for each input and output variable used in the model to ensure a sufficient degree of freedom for a meaningful analysis. Dyson et al. (2001) recommended a total of two times the product of the number of input and output variables to achieve a reasonable level of discrimination. In this case, Golany and Roll (1989) suggested at least 12 DMUs, and both Bowlin (1998) and Dyson et al. (2001) recommended 18 DMUs. Table 2 lists the input and output measures of these departments, in which the department names are coded because some measures regarding operating expenses and external grants are not public.

Efficiency measurement

This paper applies DEA to measure the relative efficiency of university departments with multiple inputs and outputs; the paper adopts the BCC model to analyze the aggregate efficiency, technical efficiency, and scale efficiency of each department because this model allows variable returns to scale. Each department is permitted to select the weights of the inputs v_i ($i = 1, \ldots, m$) and outputs u_r ($r = 1, \ldots, s$) that are most favorable in calculating its relative efficiency subject to this set of weights such that all other departments' efficiencies do not exceed 1. However, it is possible that some departments will assign a weight of zero to unfavorable input or output factors. To eliminate this situation, the commonly used concept of an assurance region (AR) is adopted in this paper to restrict the flexibility of the departments in selecting the weights. This concept was proposed by Thompson et al. (1986) to restrict the ratios of different weights for the input and output factors incorporated into the a priori information provided by experts. Denote L_i^I and U_i^I as the lower and upper bounds of the ratio of v_i to v_1 ($i = 2, \ldots, m$), respectively, and L_r^O and U_r^O as the lower and upper bounds of the ratio of u_r to u_1 ($r = 2, \ldots, s$), respectively. The two sets of restrictions on weights are as follows: $L_i^I \leq v_i/v_1 \leq U_i^I$, $L_r^O \leq u_r/u_1 \leq U_r^O$, or equivalently, $v_1 L_i^I \leq v_i \leq v_1 U_i^I$, $u_1 L_r^O \leq u_r \leq u_1 U_r^O$. In particular, the units of the input and output measures in Table 2 are different. To make the above restrictions meaningful, the measures of each factor are divided by the average of this factor to obtain standardized input and output measures, which are dimensionless and comparable (Kao & Hung, 2008; Roll & Golany, 1993).

Let X_{ij} denote the standardized quantity of input i ($i = 1, \ldots, m$) employed by DMU j ($j = 1, \ldots, n$) and Y_{rj} denote the standardized quantity of output r ($r = 1, \ldots, s$) produced. Several formulations of the BCC model have been proposed (Kao, 2017); the input-based BCC-AR model used in this paper to determine v_i and u_r while maximizing E_k, the relative efficiency of DMU k, can be formulated as the following linear program:

Table 2 Input and output measures of the 33 CCU departments

DMU	Input			Output		
	Personnel	Expenses (1000)	Space (square meter)	Teaching (credit-hours)	Publications	External-grants (1000)
1	17.0	2228.58	1247.48	6767	0.50	9010.91
2	18.0	1788.54	2041.12	6360	1.43	4461.18
3	17.0	1765.28	1537.21	6018	0.00	1298.71
4	16.0	1372.15	1385.13	4066	2.00	22,957.38
5	7.5	787.73	553.72	880	1.50	3106.00
6	6.5	599.52	551.02	1902	0.00	1042.00
7	21.5	7754.84	2532.57	12,259	9.71	11,341.14
8	19.0	2660.93	4009.94	5398	10.34	53,931.92
9	24.5	5746.01	5915.69	10,737	9.84	38,181.62
10	20.0	4268.50	4310.00	10,921	10.52	48,422.14
11	17.5	3357.41	3406.27	5494	6.93	10,692.84
12	16.0	2124.87	2139.98	7639	0.91	5471.50
13	21.0	2694.03	2272.94	7612	5.73	18,915.68
14	11.0	1824.00	2961.45	8408	0.08	19,897.08
15	14.0	1211.30	2026.46	7029	1.23	1632.66
16	14.5	2909.94	1897.81	6653	1.29	12,883.16
17	6.5	1015.30	743.81	1872	0.57	750.56
18	29.5	8977.82	5654.28	21,556	15.21	67,965.99
19	23.0	7715.07	4802.52	14,292	19.51	77,772.43
20	25.5	7389.84	6925.63	15,888	31.06	160,350.73
21	15.0	4257.57	6174.39	8138	13.09	19,951.52
22	15.0	4238.14	3103.04	7054	6.70	28,812.00
23	18.0	3294.92	2587.05	14,791	7.29	9614.00
24	20.5	3349.37	2587.06	18,033	3.67	7651.00
25	23.5	3741.93	2836.54	17,772	5.60	4874.00
26	15.5	2833.27	2207.94	14,761	2.78	9416.00
27	15.5	2892.71	2614.59	10,020	13.92	6919.14
28	25.0	5210.92	2152.08	21,443	0.00	21,674.29
29	10.0	1955.42	842.98	12,683	0.00	5341.00
30	15.0	2580.42	2418.19	7525	2.48	18,425.16
31	10.0	2017.94	1640.01	2682	2.33	11,575.25
32	13.5	2141.80	2540.51	7135	2.58	6243.57
33	15.0	1937.33	1635.81	2982	0.12	8996.63
Average	16.9	3292.2	2735.0	9296.1	5.7	22,108.5

$$E_k = \max \cdot \sum_{r=1}^{s} u_r Y_{rk}$$

$$\text{s.t. } v_0 + \sum_{i=1}^{m} v_i X_{ik} = 1,$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \left(v_0 + \sum_{i=1}^{m} v_i X_{ij} \right) \leq 0, j = 1, \ldots, n, \tag{1}$$

$$v_1 L_i^I \leq v_i \leq v_1 U_i^I, u_1 L_r^O \leq u_r \leq u_1 U_r^O,$$

$$u_r, v_i \geq \varepsilon, r = 1, \ldots, s, i = 1, \ldots, m,$$

$$v_0 \text{ unrestricted in sign,}$$

where ε is a small positive number called a non-Archimedean number (Kao, 2017). The E_k derived from Model (1) is called the technical efficiency of DMU k, which can be used to measure the operation performance. If v_0 is set to 0, then the efficiency derived from Model (1) is called aggregate efficiency. The ratio of aggregate efficiency (AE) to technical efficiency (TE) is called scale efficiency (SE), which is expressed as SE = AE/TE and can be used to measure the inefficiency caused by an inappropriate scale (Kao & Hung, 2008). To discuss and compare the aggregate, technical, and scale efficiencies of every department, the commonly used BCC model is adopted in this paper. In addition, to eliminate the situation where a DMU can assign a weight of zero to unfavorable factors, in this paper, the commonly used concept of AR to incorporate the a priori information provided by experts is adopted. The benefits of the BCC-AR model used in this paper include that it incorporates experts' information such that the obtained results are meaningful and representative, and it provides further analysis to determine the possible reasons for the poor performance of these departments from the perspectives of technical efficiency and scale efficiency; this not only provides improvement directions for the department but also serves as a reference for resource allocation and future strategy development for the university administration (Kao & Hung, 2008).

Because both CCU and NCKU are members of the TCUS, this paper follows the work of Kao and Hung (2008) for the AR constraints. Let v_1, v_2, and v_3 denote the input weights of personnel, operating expenses, and floor area, respectively, and let u_1, u_2, and u_3 denote the output weights of teaching, publications, and external grants, respectively. The restrictions regarding the AR used in this paper are $1 \leq v_1/v_2 \leq 4$, $1 \leq v_1/v_3 \leq 4$, $0.5 \leq v_2/v_3 \leq 2$, $0.5 \leq u_1/u_2 \leq 2$, $1 \leq u_1/u_3 \leq 4$, and $1 \leq u_2/u_3 \leq 4$.

Model (1) is a linear program that can be solved by using many computer software programs, such as Excel Solver used in this paper. By substituting standardized measures into Model (1) and solving it 33 times, each time with v_0 excluded and included, one can obtain the aggregate efficiency, technical efficiency, and scale efficiency of each DMU as shown in Table 3. Because of the AR constraints, the average aggregate efficiency score is only 0.5503, and only Department 20's (Mechanical Engineering) aggregate efficiency is 1, which is found to be efficient. The next seven departments with favorable aggregate efficiency scores of more than 0.7 are Departments 29 (Financial and Economic Law), 27 (Information Management), 19 (Electrical Engineering), 23 (Economics), 26 (Accounting and Information Technology), 24 (Finance), and 18 (Computer Science and Information Engineering) in order. Somewhat surprisingly, Department 29 (Financial and Economic Law) has the second-best aggregate efficiency score, which indicates that the analysis method used in this paper does not disfavor any specific department with only one poor

Table 3 Efficiency scores and aggregate efficiency decomposition of the 33 departments

Department	Aggregate efficiency	Technical efficiency	Scale efficiency	Aggregate efficiency decomposition		
				Teaching	Publications	External-grants
1	0.4115	0.4214	0.9765	0.3430	0.0206	0.0480
2	0.3677	0.3794	0.9691	0.2928	0.0533	0.0216
3	0.3171	0.3249	0.9759	0.3100	0.0000	0.0070
4	0.4723	0.6150	0.7679	0.1826	0.0729	0.2168
5	0.3107	1.0000	0.3107	0.0751	0.2078	0.0278
6	0.2838	1.0000	0.2838	0.2684	0.0000	0.0155
7	0.5628	0.5652	0.9957	0.3234	0.2079	0.0315
8	0.6323	0.7181	0.8806	0.1358	0.2112	0.2853
9	0.4605	0.4647	0.9909	0.2174	0.1618	0.0813
10	0.6564	0.6693	0.9806	0.2920	0.2283	0.1361
11	0.4091	0.4426	0.9243	0.1258	0.2576	0.0257
12	0.4087	0.4249	0.9619	0.3488	0.0337	0.0263
13	0.5342	0.5553	0.9620	0.2853	0.1743	0.0745
14	0.5239	0.6334	0.8272	0.4169	0.0034	0.1037
15	0.4586	0.5181	0.8852	0.3933	0.0557	0.0096
16	0.4045	0.4110	0.9843	0.2972	0.0469	0.0605
17	0.2713	0.7562	0.3588	0.2103	0.0521	0.0089
18	0.7063	0.7082	0.9974	0.3709	0.2125	0.1229
19	0.7957	0.7990	0.9959	0.2968	0.3291	0.1698
20	1.0000	1.0000	1.0000	0.2741	0.4351	0.2908
21	0.5889	0.6477	0.9092	0.1522	0.3975	0.0392
22	0.5186	0.5453	0.9510	0.2357	0.1817	0.1012
23	0.7818	0.7922	0.9868	0.5324	0.2130	0.0364
24	0.7446	0.7535	0.9882	0.6155	0.1016	0.0275
25	0.6946	0.7011	0.9908	0.5406	0.1384	0.0156
26	0.7551	0.7684	0.9827	0.6191	0.0945	0.0415
27	0.9155	1.0000	0.9155	0.2751	0.6205	0.0200
28	0.6909	0.6930	0.9970	0.6245	0.0000	0.0664
29	0.9854	1.0000	0.9854	0.9436	0.0000	0.0418
30	0.4869	0.5067	0.9609	0.3193	0.0855	0.0822
31	0.3481	0.4526	0.7693	0.1612	0.1139	0.0731
32	0.4507	0.4929	0.9144	0.3253	0.0955	0.0299
33	0.2103	0.2366	0.8889	0.1559	0.0050	0.0494
Average	0.5503	0.6363	0.8869	0.3321	0.1458	0.0724

output measure, such as the number of publications. This may be because the evaluation is based on the utilization of resources and AR restrictions, and this department uses relatively few resources (personnel and floor area) and teaches courses that all students can take. The top six departments at CCU with a favorable performance are distributed among the three colleges of Engineering, Law, and Management. This is different from the results reported by Kao and Hung (2008) in which the departments with a favorable performance at NCKU are distributed between only two colleges, namely, Engineering and Liberal Arts.

According to Table 2, the reason may be that the departments in the College of Humanities at CCU use relatively more resources (personnel and expenses), and each department at CCU has to offer general education courses. Regarding the unsatisfactory departments, however, three departments (Departments 6, 17, and 33) have aggregate efficiency scores lower than 0.3, and two of these departments do not offer baccalaureate degrees. In addition to these three departments, 13 departments have aggregate efficiency scores of less than 0.5. These 16 departments are distributed across four colleges other than the Colleges of Engineering, Management, and Law. This is different from the results reported by Kao and Hung (2008). This paper conducts further analysis to find the possible reasons for the poor performance of these departments from the perspectives of technical efficiency and scale efficiency.

In terms of the college level, as shown in Table 4, College F (Law) is the highest with an average aggregate efficiency score of 0.8381, followed by Colleges E (Management) and D (Engineering) with average aggregate efficiency scores of 0.7783 and 0.7219, respectively. Eight departments with aggregate efficiency scores of more than 0.7 are distributed in these three colleges. It may be somewhat surprising that College F (Law) may coincidentally not produce any SCIE/SSCI/A&HCI papers during the study period. The reason for College F (Law) still having good performance is that the total credit hours are quite high and the number of faculty is relatively small. Thus, the BCC-AR model adopted in this paper does not favor the departments or colleges that are generally recognized to be research-oriented. In contrast, College A is the worst, with an average aggregate efficiency score of only 0.3605, and College G has the second-worst performance, with an average overall efficiency value of only 0.3740; both values are less than 0.4. The reason for these results is that each of these two colleges has relatively less floor area and lower operating expenses, but their teaching burden on professional courses is not heavy compared with Colleges D, E, and F (Engineering, Management, and Law). Because the academic structures of CCU and NCKU are significantly different, for example, CCU has a College of Law but NCKU does not have one, and NCKU has a College of Medicine but CCU does not have one, it seems to not be meaningful to compare the results in terms of the college level with the results reported by Kao and Hung (2008); however, both Colleges of Engineering at these two universities have good performance.

From the perspective of technical efficiency (referring to the third column of Table 3), five departments, specifically, 5 (Graduate Institute of Linguistics), 6 (Graduate Institute of Taiwan Literature and Creative Innovation), 20 (Mechanical Engineering), 27 (Information Management), and 29 (Financial and Economic Law), have perfect scores of 1, and

	College	Average aggregate efficiency	Average technical efficiency	Average scale efficiency
Table 4 Average efficiency scores of seven colleges at CCU	A	0.3605	0.6235	0.7140
	B	0.5442	0.5720	0.9544
	C	0.4335	0.5498	0.8299
	D	0.7219	0.7400	0.9707
	E	0.7783	0.8030	0.9728
	F	0.8381	0.8465	0.9912
	G	0.3740	0.4222	0.8834

another five departments (17, 19, 23, 24, and 26) have scores higher than 0.75. For the 16 departments with aggregate efficiency scores of less than 0.5, 13 departments (1–4, 9, 11, 12, 15, 16, 30–33) have technical efficiency scores less than the average of 0.6363, which indicates that their inefficiency is due to inefficient operation. From the perspective of scale efficiency (referring to the fourth column of Table 3), only Department 20 (Mechanical Engineering) has a perfect score of 1, and it is also the unique department with perfect aggregate and technical efficiency scores; therefore, Department 20 (Mechanical Engineering) is a real benchmark department at CCU. The scale efficiency scores of most other departments also reached 0.76 or higher. Only three departments (5, 6, and 17) have scale efficiency scores smaller than 0.4. These three departments do not offer baccalaureate degrees, and among the 33 departments, they have the smallest faculty size and floor area. In addition, the v_0 values show that these three departments lie in the region of increasing returns to scale. Accordingly, these departments can be appropriately merged with other homogeneous departments to increase the efficiency of resource utilization. In particular, Departments 5 and 6 have the lowest scale efficiency scores but have technical efficiency scores of 1, which indicates that their inefficiency is due to an inappropriate scale.

Moreover, consistent with Kao and Hung (2008), aggregate efficiency is the aggregation of the individual performance of teaching, publications, and grants, and it can be decomposed to individual performance to determine the contribution of the three outputs to the aggregate efficiency score. As shown in the last row of Table 3, in this case, the average total credit hours have the largest contribution, with an average score of 0.3321, which accounts for 60.4% of the average aggregate efficiency score. The average score of 0.1458 for publications has the second largest contribution, which accounts for 26.5% of the average aggregate efficiency score. External grants have the smallest contribution, at 0.0724, which accounts for only 13.1% of the aggregate efficiency score. Because both publications and external grants are a part of research, the efficiency contribution of research can be calculated as 0.2182 (=0.1458+0.0724) by summing the average scores for publications and external grants, which accounts for 39.6% of the average aggregate efficiency and is 20.8% smaller than that of teaching. Overall, the main contribution to the aggregate efficiency of CCU is from teaching, followed by publications and external grants in this order. Their relative proportions are approximately 4.6:2:1. The ratio of the contribution of teaching to the contribution of research at CCU is approximately 1.53 (=4.6/(2+1)). A possible reason is that research, whose main mission is to explore knowledge, which always requires innovation, foresight, and sagacity, is generally considered to be more difficult than teaching, especially for some research fields.

According to the decomposition of the aggregate efficiency scores shown in Table 3, each department can identify its weaknesses and make necessary improvements. For example, Department 25′s aggregate efficiency score is 0.6946, technical efficiency score is 0.7011, and scale efficiency score is 0.9908, which are better than the university's average scores (see Table 3). However, the department's aggregate and technical efficiency scores are lower than the average scores of College E, which are 0.7783 and 0.8030, respectively, and Department 25 ranks last in the college (see Table 4). Clearly, Department 25 needs to identify its weaknesses and make necessary improvements. Regarding the contributions of the three outputs to the efficiency score of this department, teaching (total credit hours) has the largest contribution, with an average score of 0.5406 (77.8%), followed by publications (0.1348, 20.0%) and external grants (0.0156, 2.2%). For College E, the contributions of teaching, publications and external grants are 0.5165 (66.37%), 0.2336 (30.01%), and 0.0282 (3.62%), respectively. The contributions of publications and external grants of Department 25 are clearly smaller than the averages for both the university and the college.

Therefore, research, particularly external grants, is the weakness of Department 25, and it is thus necessary to improve the quality and quantity of research in this department. As is generally known, teaching and research are the two most important tasks in universities and should be balanced and developed comprehensively because university teachers' time and energy are limited. Regarding the ratio of the contribution of teaching to the contribution of research, Department 25 has the largest ratio at approximately 3.50 (=77.8/(20+2.2)), followed by College E's average at approximately 1.97 (=66.37/(30.01+3.62)) and the university's average at approximately 1.53, as shown above. Department 25′s ratio of teaching to research is approximately 2.29 (=3.50/1.53) times the average for the university and is approximately 1.29 (=1.97/1.53) times the average for College E. This result indicates that Department 25 has devoted too many resources to teaching and neglected research. More importantly, giving many lectures to students regardless of the teaching quality may temporarily increase the efficiency score, but this violates the goal of university education. In fact, research helps teaching, and they are synergistic, not opposed (Sternberg, 2002). The department head should understand and address the real problems, change the direction of the department to better use resources to achieve the educational goals of the department, and encourage faculty research. In addition, the faculty of Department 25 should put more effort into research and give attention to the quality of teaching and the effectiveness of student learning.

Cluster analysis

As noted by Kao and Hung (2008), the weights obtained from the DEA model may not represent the real importance of the associated factor. Thus, following the work of Kao and Hung (2008), this paper applies a cluster analysis (Johnson and Wichern, 1998) to distinguish the dissimilarity among the 33 departments at the CCU concerning the efficiency contributions of teaching and research, where the research contribution is obtained by adding the contributions of publications and external grants as shown in Table 5.

This paper uses the statistical software SAS 9.4 to conduct the commonly used two-stage procedure in cluster analysis (Punj & Stewart, 1983). The first stage applies Ward's minimum variance method (Ward, 1963) to find the preliminary clusters. The number of clusters is determined based on the cut-off point of the hierarchical tree. The distance that increases sharply in the linkage distance of Ward's method, which denotes the sum of squares among clusters, at successive clustering steps is selected as the optimal cut-off point (Francis, 1995; Kao & Hung, 2008). Figure 1 shows the relationship between the sum of squares among the clusters and the clustering steps. The sum of squares among clusters increases sharply from 7.501 to 19.979 between steps 30 and 31, and according to the associated hierarchical tree depicted in Fig. 2, it is appropriate to categorize 33 departments into three clusters at the first stage.

The second stage is to adopt the K-means method (Johnson & Wichern, 2002) to divide the 33 departments into three clusters, namely, the *Teaching*, *Research*, and *General* groups, based on the teaching and research efficiency scores, as shown in Table 5. The results are listed in the rightmost column of Table 5 and shown in Fig. 3, where three convex polygons are drawn to enclose the departments in these three groups, and the three polygons are clearly separated without overlapping. In addition, for each group, Table 6 summarizes the average aggregate efficiency score, the average teaching and research scores, and the contributions of teaching and research to the average aggregate efficiency score.

Table 5 Teaching and research contributions to the efficiency scores and clustering of the 33 departments

Department	Teaching contribution to efficiency score	Research contribution to efficiency score	Group
1	0.3430	0.0686	3
2	0.2928	0.0749	3
3	0.3100	0.0070	3
4	0.1826	0.2897	3
5	0.0751	0.2356	3
6	0.2684	0.0155	3
7	0.3234	0.2394	3
8	0.1358	0.4965	2
9	0.2174	0.2431	3
10	0.2920	0.3644	3
11	0.1258	0.2834	3
12	0.3488	0.0599	3
13	0.2853	0.2488	3
14	0.4169	0.1071	3
15	0.3933	0.0653	3
16	0.2972	0.1073	3
17	0.2103	0.0610	3
18	0.3709	0.3354	3
19	0.2968	0.4989	2
20	0.2741	0.7259	2
21	0.1522	0.4367	2
22	0.2357	0.2829	3
23	0.5324	0.2493	1
24	0.6155	0.1291	1
25	0.5406	0.1540	1
26	0.6191	0.1360	1
27	0.2751	0.6404	2
28	0.6245	0.0664	1
29	0.9436	0.0418	1
30	0.3193	0.1676	3
31	0.1612	0.1870	3
32	0.3253	0.1254	3
33	0.1559	0.0544	3

As shown in Fig. 3, the *Teaching* group consists of six departments, specifically, 23–26 (Economics, Finance, Business Administration, and Accounting and Information Technology), 28 (Law), and 29 (Financial and Economic Law), which is similar to the results reported by Kao and Hung (2008), with Political Economy, Business Administration, Accountancy and Law at NCKU included in their Teaching Group. As noted by Kao and Hung (2008), these departments have a relatively high teaching responsibility. At CCU, the Department of Finance has the responsibility of teaching Finance Management, which is required by all departments in the College of Management. The average aggregate efficiency score of this group is 0.7754 of which 0.6460 is contributed by

Fig. 1 Linkage distance of Ward's minimum variance method in the clustering steps
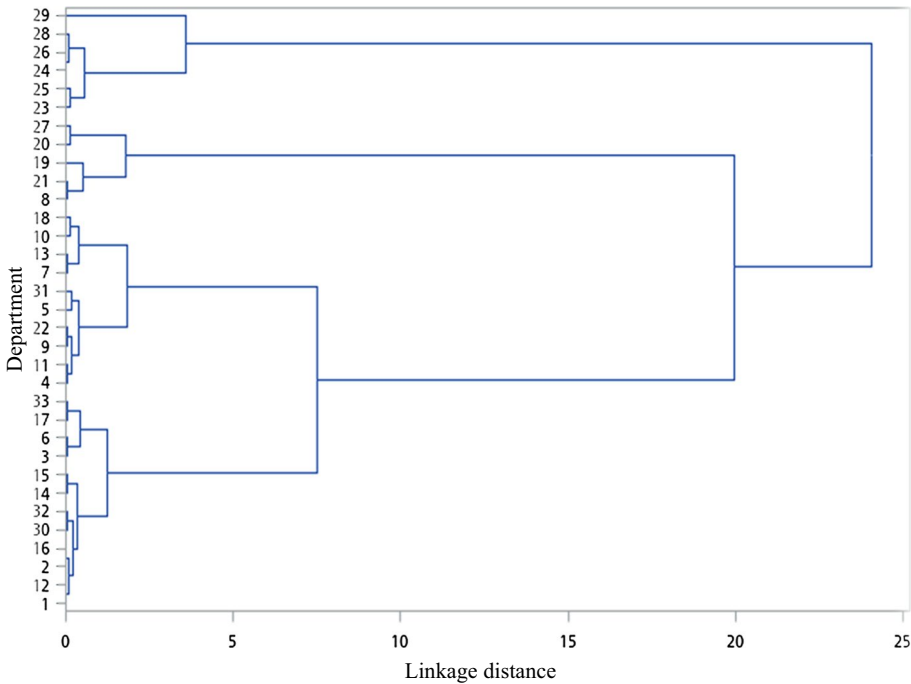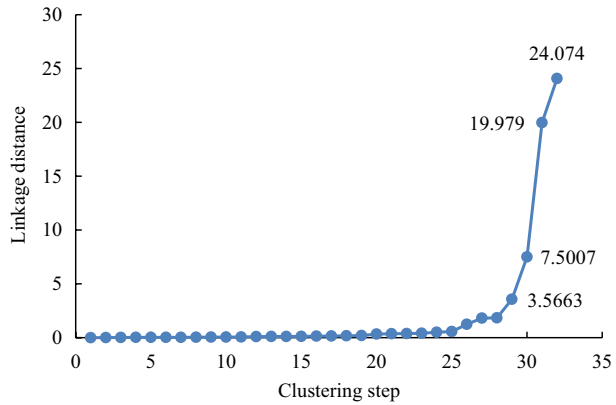

Fig. 2 Hierarchical tree of the linkage distance for the 33 CCU departments

teaching; this is a proportion of 83%, as shown in Table 6. In fact, this group has the highest average teaching score, 0.6460, among these three groups. The lowest teaching score in this group, which is 0.5324 from Department 23, is still larger than the highest score of the other two groups, which is 0.4169 from Department 14. Four of the six departments in this group are from College E, and the other two are from College F. Teaching has a large contribution for this group because these departments from
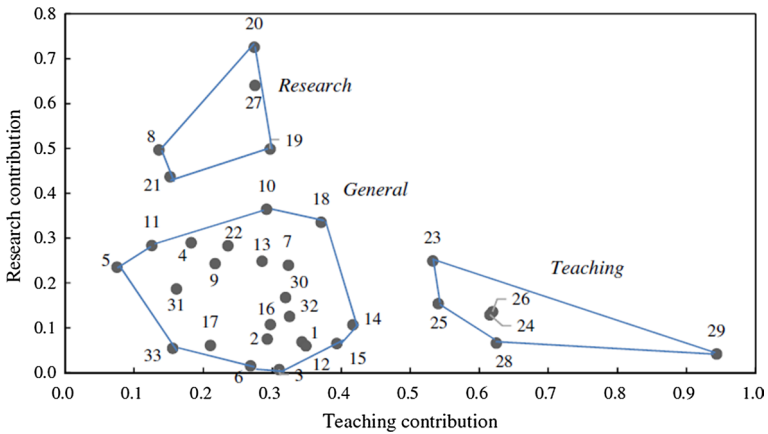
Fig. 3 Classification according to the teaching and research contributions to the efficiency scores for all 33 departments

Table 6 Average aggregate efficiency scores, average teaching and research contributions and percentages of three groups

Group	Average aggre-gate efficiency	Average teaching contribution	Average research effi-ciency	Percentage of teaching contribu-tion	Percentage of research contri-bution
Teaching	0.7754	0.6460	0.1294	83%	17%
Research	0.7865	0.2268	0.5597	29%	71%
General	0.4352	0.2705	0.1647	62%	38%

Colleges E and F have high teaching loads, and they provide courses that generally do not have prerequisite courses or knowledge so that all students can take them.

The *Research* group has five departments, that is, Departments 8 (Earth and Environmental Sciences), 19–21 (Electrical Engineering, Mechanical Engineering, and Chemical Engineering), and 27 (Information Management), in which only three of them are included in the results reported by Kao and Hung (2008) with Earth Sciences, Electrical Engineering, and Chemical Engineering at NCKU included in their Research Group. This group is characterized by a high efficiency score for research, including publications and external grants. In this group, Department 21 has the lowest efficiency score for research, 0.4367, which is larger than the scores for all the departments in the other two groups. This group covers only three colleges, Colleges B, D, and E (Science, Engineering, and Management), which generally meet CCU expectations. As shown in Table 6, the average aggregate efficiency score for this group is 0.7865 of which 0.5597 is contributed by research (71%). Notably, this group has the highest average aggregate efficiency score among all three groups.

The third group called *General* has 22 departments, which constitute two-thirds of the 33 departments. This group does not have a clear, specific characteristic and covers nearly all colleges, except for College E (four of the five departments belong to the *Teaching* group, and the remaining department belongs to the *Research* group). As shown in

Table 6, this group has the worst average aggregate efficiency score, 0.4352, among the three groups, with 0.2705 (62%) contributed by teaching and 0.1647 (38%) contributed by research. The value contributed by teaching is lower for this group (0.2705, 62%) than for the *Teaching* group (0.6460, 83%) but is larger than the teaching value of the *Research* group (0.2268, 29%). In contrast, the contribution of research is smaller for this group (0.1647, 38%) than for the *Research* group (0.5597, 71%) but is larger than the research contribution of the *Teaching* group (0.1294, 17%). Notably, all 16 departments with aggregate efficiency scores of less than 0.5 belong to this group.

Therefore, the 33 CCU departments could be categorized into the above three groups according to the following rules: (1) *Teaching*: teaching score greater than 0.5; (2) *Research*: research score greater than 0.4; and (3) *General*: teaching score less than 0.5 and research score less than 0.4. These rules are different from the four rules adopted in Kao and Hung (2008).

Notably, the following classifications of subgroups are different from those of Kao and Hung (2008) to characterize the features of the departments in the *General* group at CCU. Figure 3 shows that the teaching and research efficiency scores of the 22 departments in the *General* group are different. For example, the difference between Departments 18 (Computer Science and Information Engineering) and 33 (Athletic Sports and Leisure Education) is quite significant. Therefore, it is necessary to further classify them. One way is to connect the lower-left corner point of the *Teaching* group with the lower-left corner point of the *Research* group by a line segment. Two departments, 10 (Chemistry and Biochemistry) and 18, lie above this line segment; they are located at the relatively central position of Fig. 3 and have higher efficiency scores for teaching and research among these 22 departments in the *General* group. In addition, the aggregate efficiency scores of Departments 10 and 18 are above 0.65 (refer to Table 3), and the efficiency scores for teaching and research for each department are close (refer to Table 4). Thus, this subgroup can be named the *General-comprehensive* subgroup.

Because the above-mentioned research efficiency score is the sum of the efficiency scores for publications and external grants, to explore the within-group differences, the *Research* group can be further classified into subgroups according to publications and external grants. After reusing the K-means method and setting two and three clusters, the classifications for the *Research* and *General* groups are shown in Figs. 4 and 5, respectively, where the efficiency scores for publications and external grants are used as the horizontal axis and vertical axis, respectively. Figure 4 shows that Departments 21 (Chemical Engineering) and 27 (Information Management) are further identified as the *Research-publications* subgroup because their publications that contribute to research are relatively large in the *Research* group, while Departments 8 (Earth and Environmental Sciences), 19 (Electrical Engineering), and 20 (Mechanical Engineering) are further classified as the *Research-grants* subgroup, with relatively larger contributions of external grants to research in the *Research* group. These two subgroups can be separated by a line of $3P - 4G = 0.6$, where P and G represent the efficiency scores for publications and grants, respectively. Figure 5 shows the three subgroups obtained according to publications and external grants for the 22 departments in the *General* group. The first subgroup, named *General-grants,* contains only Department 4 (Philosophy) with an external grant score greater than 0.2. The second subgroup, named *General-publications*, has the eight departments of 5 (Graduate Institute of Linguistics), 7 (Mathematics), 9–11 (Physics, Chemistry and Biochemistry, and Biomedical Sciences), 13 (Psychology), 18 (Computer Science and Information Engineering), and 22 (Communications Engineering). Their efficiency scores for publications are larger than 0.2. The third subgroup contains the remaining 13 departments of the *General* group. Because their efficiency scores for both publications and external grants
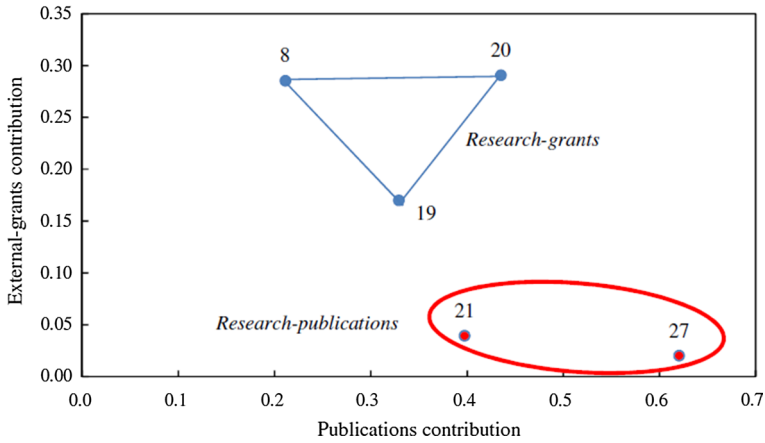
Fig. 4 Classification according to the teaching and research contributions to the efficiency scores for five departments in the *Research* group
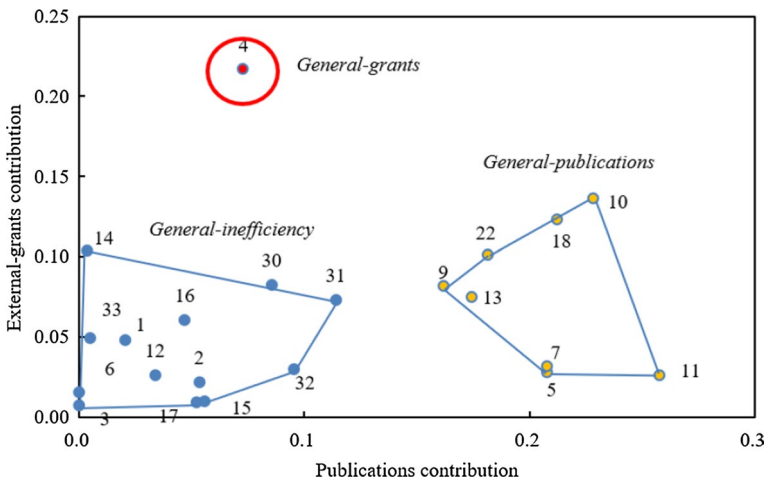

Fig. 5 Classification according to the teaching and research contributions to the efficiency scores for 22 departments in the *General* group

are smaller than 0.15, they are categorized as the *General-inefficient* subgroup. These 13 departments should be the focus of attention for CCU. In the future, these departments should identify their key areas of development to improve their efficiency scores.

Conclusion

Currently, universities play an important role in the development of a country. However, government subsidies account for only a small part of the income sources of universities in Taiwan. Even national universities in Taiwan face financial pressures, particularly under

the sub-replacement fertility phenomenon, and the controversy that arises from tuition has increased in Taiwan. Universities have to utilize resources more efficiently to achieve their mission. Therefore, a university should investigate not only the outputs produced by each department but also the resources utilized in producing these outputs. Therefore, it is necessary to further evaluate whether departments efficiently use their limited resources to achieve their goals.

This paper applies the BCC-AR model of DEA to measure the relative efficiency of 33 departments at CCU in Taiwan. The inputs considered are personnel, operating expenses, and floor area, and the outputs considered are total credit hours, publications, and external grants. Specifically, the quality of teaching and research is considered. The results show that among 33 departments, only Department 20 (Mechanical Engineering) is efficient, with aggregate efficiency, technical efficiency, and scale efficiency scores of 1, and this indicates that it is the most outstanding department and can be regarded as the benchmark department at CCU. To the contrary, Department 33 has the lowest aggregate efficiency score. At the college level, College F (Law) is the most efficient college with the highest average aggregate efficiency score, followed by Colleges E (Management) and D (Engineering), and College A has the lowest average efficiency score. Except for Colleges E, F, and D, 19 departments that have aggregate efficiency scores below the average aggregate efficiency score for CCU are distributed among the remaining four colleges. In addition, from the technical and score efficiency scores obtained in this paper, the departments with unsatisfactory aggregate efficiency can identify their inefficiency as being due to inefficient operation or an inappropriate scale. For a department with inefficient operation (e.g., Departments 2, 3, and 33), the basic principle for increasing efficiency is either increasing outputs or decreasing inputs. As Kao and Hung (2008) noted, if the ideal amount of a certain output of a department of this type is not achievable, then another output could be strengthened to a higher level than its ideal amount for substitution (Charnes et al., 1978). Departments with inefficiency caused by an inappropriate scale (e.g., Departments 5, 6, and 17) can be appropriately merged with other homogeneous departments to increase the efficiency of resource utilization.

Furthermore, aggregate efficiency is decomposed into the contributions of teaching, publications, and external grants, and a cluster analysis is applied to categorize the 33 departments into three groups of similar characteristics, namely, *Teaching* (six departments), *Research* (five departments), and *General* (22 departments). Except for the *Teaching* group, each group is further divided into two subgroups according to publications and external grants to identify more information. The *Research* group is divided into the *Research-publications* and *Research-grants* subgroups, and the *General* group is divided into the three subgroups of *General-publications* (8 departments), *General-grants* (1 department), and *Inefficiency* (13 departments). These 13 departments in the *Inefficiency* subgroup are the departments to which university administrators should give more attention.

According to the efficiency scores obtained via DEA and the results obtained via efficiency decompositions and a cluster analysis, university administrators can realize the utilization of resources and the characteristics of each department, identify the inefficiency among departments and their causes, and suitably reallocate resources to improve the overall efficiency of the university. In addition, each department head can identify the strengths and weaknesses of his/her department, which serves as a direction for continuous development or improvement to maximize efficiency.

Notably, this paper has considered the quality of teaching and research in calculating the output measures. To consider teaching quality, this paper uses classroom capacity as

the upper limit of the number of students in calculating credit hours because some departments provide courses without regard to teaching quality and student learning effectiveness. Because subjectivity is usually involved, it is a challenging task to design other more suitable measures for the output performance of students and student evaluation of teachers to represent achievements in teaching; this is therefore a direction for future research. In addition, the difficulty of publishing papers differs among various fields or journals, and journal quality also involves subjectivity. Such a task is also challenging because there is no common basis for comparing the quality of different research works. To assess research quality, this paper calculates the single-author-equivalent numbers of publications by assigning a weight to the author contribution for each co-authored paper by considering the number of authors and the order of authors, but this paper does not assign different weights to distinguish the quality or difficulty of the publications included in SCIE, SSCI and A&HCI. The commonly used weighting method is based on the number of journals included in SCIE, SSCI and A&HCI (that is, 9200, 3400, and 1800, respectively) as the difficulty of publication. However, this is not meant for individual researchers because the numbers of research categories covered by SCIE, SSCI and A&HCI are distinctive. For example, SCIE contains over 9200 journals across 178 science disciplines, SSCI contains approximately 3400 journals across 58 areas of social sciences, and A&HCI contains 1800 journals across 28 areas of the humanities and arts. It may be more meaningful that the relative weights are assigned based on the average number of journals per research category, that is, approximately 51.7 ($=9200/178$), 58.6 ($=3400/58$), and 64.3 ($=1800/28$) for SCIE, SSCI and A&HCI, respectively. In addition, the number of articles published annually in each journal can be used to represent the quality of research; this also provides a direction for future research.

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