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Inno-Qual efficiency of higher education: Empirical testing using data envelopment analysis

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ABSTRACT

Since the overall quality of Taiwanese university education has been decreasing in recent years, and universities are losing their competitive advantage while facing foreign countries' education systems and the threat of closing, upgrading innovation performance and improving total quality performance (Inno-Qual performance) so as to enhance overall operational performance have become an urgent issue. Although relative measurement models are increasingly being used for conquering the above-mentioned difficulties, such as the Inno-Qual performance system (IQPS), which integrates the features of innovation and TQM, currently, no studies empirically evaluate the efficiency of such improvement, meaning that the costs of using the Inno-Qual performance system are increasing, particularly the human administrative cost for providing intellectual products, which is the nature of higher education. To overcome this problem, in this study, the IQPS is adopted by using data envelopment analysis (DEA) to evaluate the Inno-Qual efficiency of 99 Taiwanese universities divided into five types (research-intensive, teaching-intensive, profession-intensive, research & teaching-intensive, and education-in-practice-intensive). On the basis of the empirical results, we found that over half (73%) of the universities are highly inefficient in improving the Inno-Qual performance, and thus we conclude that improving the Inno-Qual efficiency based on our results will be helpful for reducing the majority of cost expenditures.

1. Introduction

In today's knowledge-based economic system, it is well known that higher education is the foundation of fostering high-tech talent, the key factor in raising national quality, and the main way to upgrade national competitive ability (Fairweather, 2000; Meek, 2000). The importance of higher education is especially emphasized in Taiwan; however, with the birth rate dropping, the number of universities increasing, and Taiwan joining the WTO, as compared to foreign countries, the overall quality of Taiwanese universities is decreasing, and universities are losing their competitive advantages (Chen and Chen, 2009a, 2009b, 2009c, submitted for publication; Taiwan Assessment and Evaluation Association, 2006). In this regard, regaining and increasing their competitive advantages has now become a critical problem for the Taiwanese government and for the universities (Department of Higher Education, 2004).

To overcome these problems, evaluating and improving the innovation performance and total quality management performance are needed (Chen & Chen, 2009a, 2009b, 2009c, submitted for publication), and, therefore, a growing body of research has proposed several related measurement models (Chen & Chen, 2008a, 2008b; Chin & Pu, 2006; Lin, Wang, Wang, & Yen, 2006; Tang, 2006); in addition, officially, visiting and standard procedure evaluation are some of the main performance evaluation methods for the Taiwanese Ministry of Education. Such evaluation methods, nevertheless, have numerous drawbacks and biases, such as measurement criteria proposed under the assumption of independence among each other, which is not the real-world situation; the function of each model can only measure the performance of TQM or innovation separately; and ignore the features of each type of university (e.g., research-intensive, teaching-intensive, and profession-intensive, proposed by Li (2007), and education-in-practice-intensive, proposed by Chen & Chen (2008a, 2008b)); and the methods largely focus on internal organizational improvement, which makes performance evaluation incomprehensive. Recently, a measurement model focusing on higher education proposed by Chen and Chen (2009a, 2009b, 2009c, submitted for publication) overcame the above-mentioned problems. It was called the Inno-Qual performance system (IQPS), and it is believed to be able to

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provide accurate results while evaluating and improving the overall quality of a university, as we argue.

Although the Inno-Qual performance system (IQPS) that can overcome the above-mentioned difficulties, currently, no studies empirically evaluate the Inno-Qual efficiency when universities using it, resulting in the Inno-Qual performance improving along with the costs increasing, particularly the human administrative costs due to one of nature of higher education, providing intellectual products. In this paper, we aim to overcome the above problems by adopting the IPQS and using data envelopment analysis (DEA). We believe that this study can not only indicate how to improve the Inno-Qual's efficiency so as to aid universities for improving future performance, but it can also enhance the validity of the IPQS for future use.

The rest of this paper is organized as follows. The overview of Inno-Qual in higher education is discussed in Section 2. Data envelopment analysis is introduced in Section 3. Empirical testing and discussions are conducted and presented in Section 4. Conclusions are in the last section.

2. The overview of Inno-Qual efficiency in higher education

The term innovation has received more attention than ever before for its ability to sustain competitive advantages (Daft, 2004; Krause, 2004). Therefore, its definition is not clear and will constantly change. Innovation performance has various criteria and indices along with different points of emphasis and concepts (Chen & Chen, 2009a, 2009b, 2009c, submitted for publication), ranging from an invisible concept or phenomenon to a visible product (Acs, Anselin, & Varga, 2001; Bosworth & Rogers, 2001; Chen & Chen, 2008a, 2008b; Dzinkowski, 2000; Gambardella & Torrisi, 2000; Guthrie & Petty, 2000; Hall & Bagchi-Sen, 2002; O'Sullivan, 2000; Ordaz, Lara, & Cabrera, 2005; Schoenecker & Swanson, 2002; Subramaniam & Youndt, 2005; Toivanen, Stoneman, & Bosworth, 2002; Van Buren, 2000).

In the field of higher education, innovation indices for universities to conduct innovation performance evaluation and improvement are numerous (Mei & Lee, 2006). Nevertheless, although the number of related measurement models is increasing, they face several biases, such as measurement criteria, which are proposed under the assumption of independence among each other, which is unsuitable for real-world situations, or ignorance of the features of the different types of universities. In this regard, among current measurement models, the innovation support system (ISS) and the pro-performance appraisal system (PPAS) are the latest systems developed not merely to enhance and measure innovation performance (Chen & Chen, 2008a, 2008b) for higher education but also to overcome the above-mentioned biases, as shown in Table 1 and Fig. 1.

The criteria include the extent of international academic interaction, the amount of financial support from the National Science Council (NSC), the number of journal articles accepted and published, the number of conferences and chaired professors, and the extent of a results-oriented organizational culture. Together, these criteria compose the ISS. Moreover, an innovation acceleration force involving transformational leadership is the latest ISS development to promote effective innovation performance across the three main types of universities (e.g., research-intensive, teaching-intensive, and profession-intensive) (Chen & Chen, 2008a, 2008b). Similarly, the criteria include employee turnover, the number of promotions, the number of articles published in international journals, the number of patents, winning student thesis, plans given by the NSC, and the level of satisfaction in industries. Together, these criteria compose the PPAS. Additionally, a support appraisal system to address financial support and budget planning is the newest PPAS development that ensures successful innovation.

Similar to innovation, the importance of the total quality management concept and related measurement models to assess its performance is increasing. Thus, the TQM criteria vary from one researcher to another (Chen & Chen, 2008a, 2008b, 2009a, 2009b, 2009c, submitted for publication; Dinh, Barbara, & Tritos, 2006; Escrig-Tena, 2004; Han, Chen, & Ebrahimpour, 2007; Ismail, 2006; Keng, Nooh, Veeri, Lorraine, & Loke, 2007; Kenneth & Cynthia, 2004; Nusrah, Ramayah, & Norizan, 2006; Ozden & Birsen, 2006; Wanger & Schaltegger, 2004).

Without the concept of total quality management for the ISS and the PPAS, Chen and Chen (2009a, 2009b, 2009c, submitted for publication) proposed an advanced innovation performance measurement system called the network hierarchical feedback system (NHFS) (Fig. 2). They integrated the characteristics and revised the drawbacks of the ISS and the PPAS and combined the concepts of the TQM. In Tables 2 and 3, detailed definitions of measurement criteria and indices for the NHFS and the types of universities are given.

Although the NHFS overcomes the majority of drawbacks and biases of the previous models and integrates the characteristics of innovation and total quality management, this system nonetheless has been criticized for its strong focus on internal organizational improvement and the lack of attention to external features, which does not fit the current overall trend for most Taiwanese universities. In view of this shortcoming, Chen and Chen improved the NHFS by providing the concept of external organizational improvement after a series of quantitative and qualitative studies to today's Inno-Qual performance system (IPQS) (Fig. 3). In Tables 2 and 3, detailed definitions of measurement criteria, indices and the types of universities evaluated under the IPQS are provided.

Due to overcoming drawbacks and biases that current measurement models face, we claim that the IPQS is the most appropriate model for precisely evaluating innovation, total quality management performance and efficiency (Inno-Qual efficiency). Currently, no studies that evaluate the Inno-Qual efficiency for universities in Taiwan exist, which makes today's universities that use the IPQS face high expenditures, particularly on human administrative costs owing to one of nature of higher education, providing intellectual products. In this regard, we aim to overcome the aforementioned dilemmas by adopting the IPQS with data envelopment analysis (DEA). We believe that this study can not only further indicate

Table 1
An innovation support system (ISS).

IS system	IS dimension	IS criteria	Optimal IS type
A novel innovation support system (ISS)	Academic research	International academic interaction Financial support of NSC Journals accepted and published	Research-intensive university (RU)
	External academic support	Number of conferences Number of chaired professors	
	Organizational culture	Results-oriented	
	Innovation acceleration force: transformational leadership		

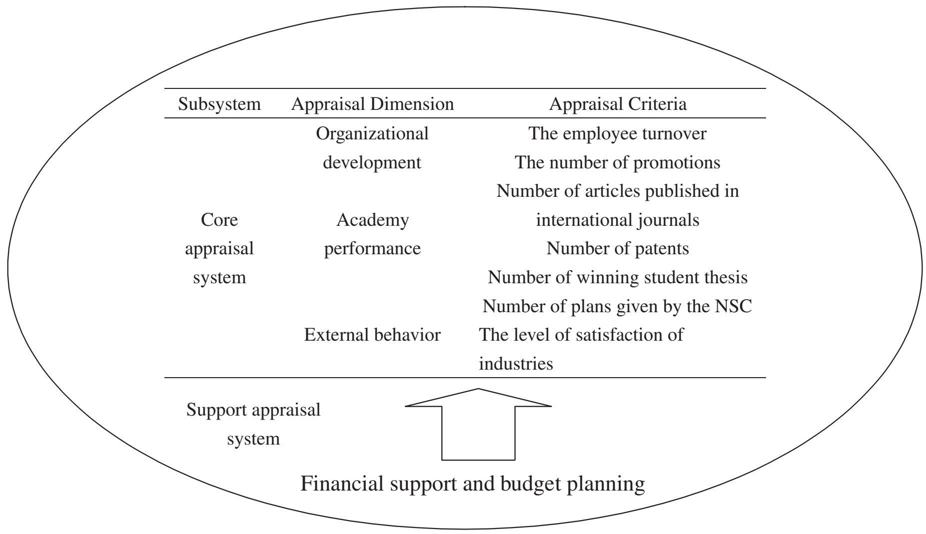

Fig. 1. A pro-performance appraisal system (PPAS).

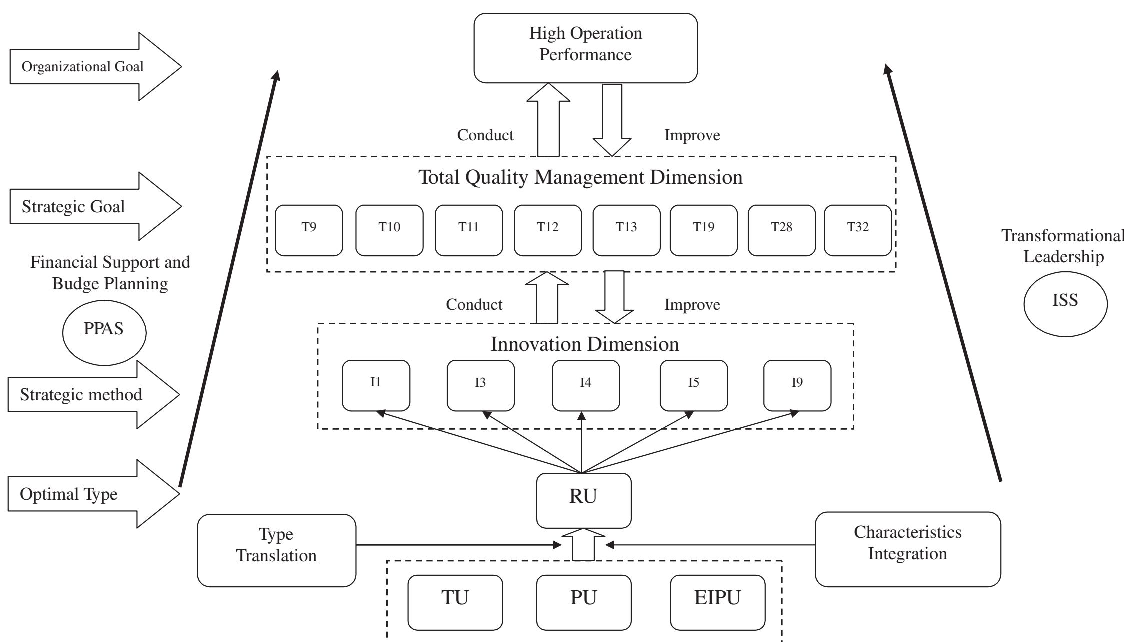

Fig. 2. A network hierarchical feedback system based on the integration of TQM and innovation (NHFS).

how to improve Inno-Qual's efficiency for improving the performance of universities, but it can also enhance the validity of the IPQS for future utilization.

3. Data envelopment analysis

The concept of data envelopment analysis (DEA) comes from the non-parametric frontier approach proposed by Farrel (1957). Charnes, Cooper, and Rhodes (1981) further advanced Farrel's approach by extending it from single-input–single-output technical efficiency measurements to multiple-input and multiple-output measurements. They also proposed the CCR model, making the scores model of the DEA transform into the linear programming model, and, they introduced duality theory in order to make calculation with greater ease. However, the CCR model does not consider the restrictions of convexity; that is, the CCR model works under the assumption of a constant return to scale (CRS), which is not fit for real practice. Hence, Banker, Charnes, and Cooper (1984) revised the CCR model and finally proposed the BCC model, adopting the assumption of variable return to scale (VRS).

The DEA aims to understand when a corporate, under a specific output, if an organization inputs too many resources or when, under a specific input level, if an organization outputs too little. Therefore, the application models of the DEA can be categorized into the input orientation model and the output orientation model. Under a certain quantity of outputs, using the minimization input level to compare the efficiency of the decision-making unit (DMU) is called input orientation. Similarly, under a certain input level, using the maximum quantity of output to compare the efficiency of decision-making unit (DMU) is called output orientation. Since higher education mainly provides invisible products (e.g., knowledge and skills) and the variable costs are relatively low, in this study, the output orientation model is adopted to evaluate

Table 2
Definition of measurement criteria and indices of the NHFS and IQPS.

Number	Definition of measurement criteria and indices	Weights	Number	Definition of measurement criteria and indices	Weights
Internal			*External*		
T9	Process redefinition of R&D and innovation (C)	0.136	T4	TQM Culture Construction (C)	0.087
T10	Input of R&D and innovation (C)	0.111	T10	Input of R&D and innovation (C)	0.109
T11	Evaluation of R&D and innovation results (C)	0.173	T11	Evaluation of R&D and innovation results (C)	0.115
T12	Market operation strategy development (C)	0.111	T13	Business relations management (C)	0.112
T13	Business relations management (C)	0.198	T14	Customer relationship management (C)	0.278
T19	Knowledge management (C)	0.086	T24	Supportive activity planning (C)	0.299
T28	Financial performance (C)	0.086	I6	The responsibility of the instructor (I)	0.187
T32	Unique competitive ability gaining performance (C)	0.099	I8	Promotion and job acquisition for previous students (I)	0.206
I1	Research patents (I)	0.197	I9	Appropriate use of multimedia (I)	0.228
I3	Financial support from national science council (I)	0.168	I10	The number of cooperating international universities (I)	0.170
I4	Journals accepted and published (I)	0.270	I15	Teaching that combines practice, attending courses and learning theory (I)	0.209
I5	Government tender planning (I)	0.195			
I9	Number of chaired professors (I)	0.170			

(C): measurement criteria and (I): measurement indices.

Inno-Qual efficiency. The CCR model is used to explore slack variables of input and output under a constant return to scale (CRS). The BCC model is used to evaluate pure technical efficiency (PTE) and scale efficiency (SE) of a single period.

Table 3
Definition of the types of universities for the NHFS and IQPS.

Number	Definition of types of universities
RU	Research-intensive university
TU	Teaching-intensive university
PU	Professional-intensive university
EIPU	Education-in-practice-intensive university

3.1. The CCR model

The DEA evaluates samples that are going to be evaluated for their efficiency as decision-making units (DMU). Assuming that there are n DMUs, each piece of DMU (DMU_i) utilizes m kinds of input x_{ij} ($j = 1,2,3,\ldots,m$), $x_{ij} \geqq 0$; and produces s kinds of output y_{ir} ($r = 1,2,3,\ldots,s$), $y_{ir} \geqq 0$. The CCR model transforms these multiple inputs and outputs into a single input and output by using virtual

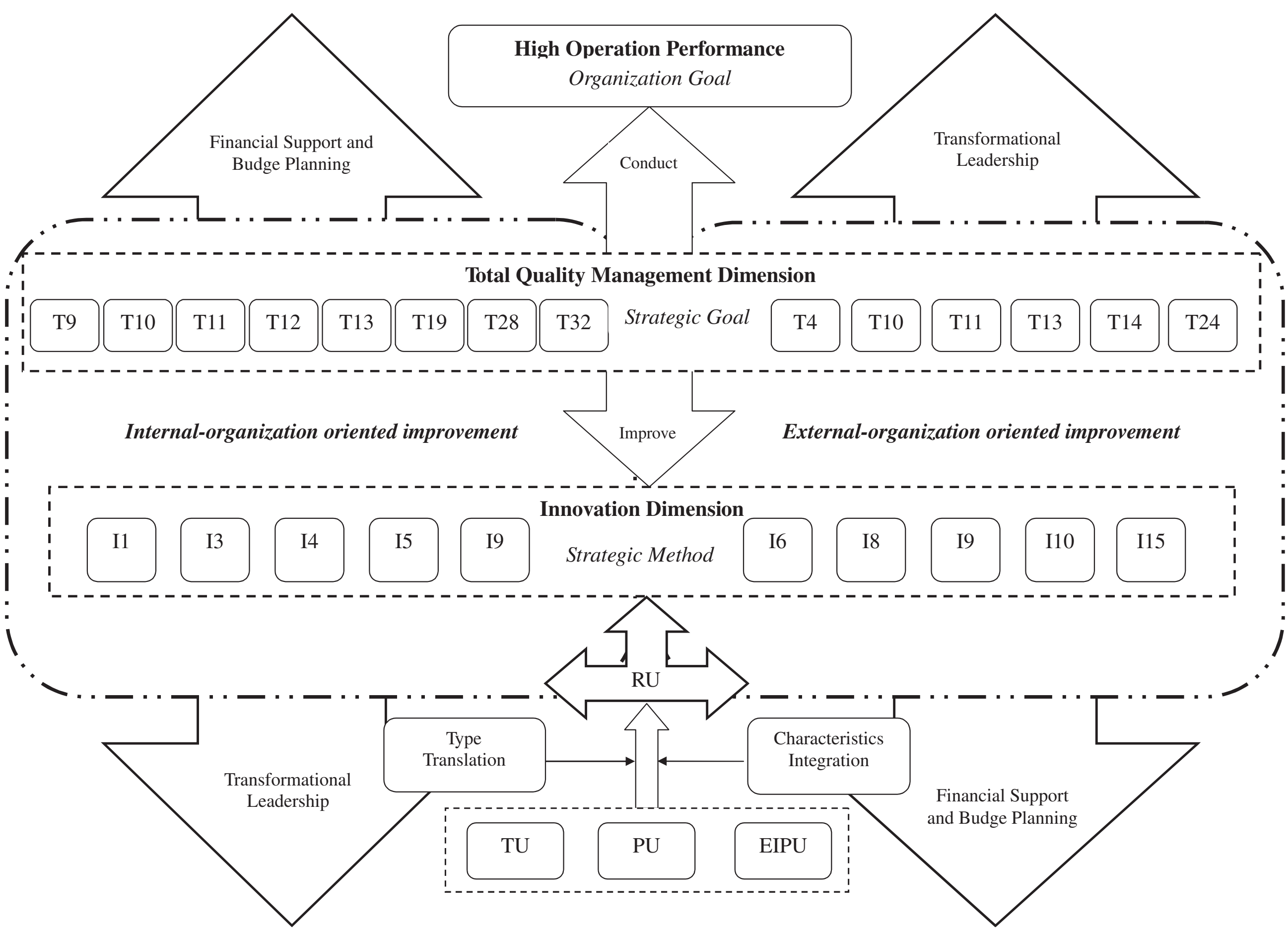

Fig. 3. A solid Inno-Qual performance system (IQPS).

Table 4
The input and output data of sample universities. Source: Higher Education Evaluation and Accreditation Council of Taiwan (2008, 2009), Department of Statistics (2008) and National Science Council (2009).

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journal articles accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research Patents ($N > 20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of International Members (2008)	No. of domestic full-time faculty (2008)
R	DMU_{R1}	7719	28384	722	205	66	33416	2516	1937
	DMU_{R2}	3565	10876	223	258	50	14184	608	698
	DMU_{R3}	2785	10963	333	158	41	11775	440	604
	DMU_{R4}	5608	16237	438	248	58	21972	1551	1207
	DMU_{R5}	3062	6741	172	143	35	11954	593	579
	DMU_{R6}	2617	6760	158	152	29	9348	739	475
	DMU_{R7}	892	7170	89	0	22	4296	176	383
T	DMU_{T1}	3278	2621	142	0	40	15514	3802	876
	DMU_{T2}	1603	0	19	0	6	7492	175	301
	DMU_{T3}	2068	0	49	0	3	8135	81	390
	DMU_{T4}	833	0	9	0	1	3704	29	178
	DMU_{T5}	1007	0	22	0	3	4632	36	179
	DMU_{T6}	896	0	12	0	4	4534	59	200
	DMU_{T7}	1027	0	11	0	2	4347	48	210
	DMU_{T8}	1429	0	14	0	1	5964	145	214
P	DMU_{P1}	1968	4224	91	93	27	8737	303	382
	DMU_{P2}	2063	1318	48	24	11	8487	264	335
	DMU_{P3}	2416	0	12	34	30	10609	117	365
	DMU_{P4}	2261	1478	49	46	21	8973	145	426
	DMU_{P5}	1437	0	23	23	7	6367	52	258
	DMU_{P6}	3522	0	11	47	6	9880	136	356
	DMU_{P7}	1338	0	9	0	4	6082	23	228
	DMU_{P8}	1173	0	5	36	2	7774	14	277
	DMU_{P9}	2839	704	18	0	9	13937	143	393
	DMU_{P10}	1562	4061	69	0	9	7049	320	510
	DMU_{P11}	3496	0	18	32	17	18184	346	587
	DMU_{P12}	2334	0	3	32	15	11730	64	452
	DMU_{P13}	3507	0	16	55	4	15687	14	509
	DMU_{P14}	2343	0	5	0	7	10955	89	284
	DMU_{P15}	1067	3068	51	0	5	5411	249	412
	DMU_{P16}	1614	2189	31	0	9	7584	229	465
	DMU_{P17}	1708	0	1	0	4	8949	9	261
	DMU_{P18}	2555	0	12	51	4	13360	55	456
	DMU_{P19}	1566	3091	34	0	9	7667	208	535
	DMU_{P20}	1896	0	9	0	8	10506	28	365
	DMU_{P21}	1634	0	6	0	7	10423	14	429
	DMU_{P22}	1919	0	2	0	3	10441	18	296
	DMU_{P23}	1216	0	4	0	3	6204	14	299
	DMU_{P24}	1470	0	0	54	3	6918	19	325
	DMU_{P25}	1033	0	1	0	6	6010	23	357
	DMU_{P26}	1681	0	3	0	4	7957	7	284
	DMU_{P27}	1587	0	2	0	4	7540	17	343
	DMU_{P28}	1007	0	3	577	3	5863	6	289
	DMU_{P29}	958	0	9	0	2	6028	6	270
	DMU_{P30}	1197	0	1	0	5	6732	26	286
	DMU_{P31}	855	0	2	0	3	5900	11	297
	DMU_{P32}	482	0	1	77	2	4109	6	244
	DMU_{P33}	1951	0	13	126	2	9525	10	331
	DMU_{P34}	630	0	2	0	1	3036	1	113
	DMU_{P35}	852	0	9	0	2	3698	9	442
	DMU_{P36}	1693	0	12	0	1	8692	6	336
	DMU_{P37}	1120	0	3	0	2	6841	5	255
	DMU_{P38}	1829	0	2	0	2	9143	7	364
	DMU_{P39}	1639	0	7	0	3	7186	6	330
	DMU_{P40}	799	0	6	0	1	6336	6	253
	DMU_{P41}	1143	0	6	0	0	5607	0	330
	DMU_{P42}	380	0	2	0	0	2488	0	172
R&T	$DMU_{R\&T1}$	3617	0	156	0	60	15588	1322	677
	$DMU_{R\&T2}$	3900	5861	148	136	37	17204	671	752
	$DMU_{R\&T3}$	2073	2654	43	0	21	8496	196	379
	$DMU_{R\&T4}$	2992	3358	126	27	12	12044	369	498
	$DMU_{R\&T5}$	2335	0	30	0	13	9928	413	326
	$DMU_{R\&T6}$	2592	0	31	0	11	12239	174	501
	$DMU_{R\&T7}$	1112	0	35	0	14	5234	162	196
	$DMU_{R\&T8}$	2328	0	65	0	8	10502	206	515
	$DMU_{R\&T9}$	1178	791	45	0	9	5260	348	240
	$DMU_{R\&T10}$	1232	0	11	0	3	4325	40	180

(*continued on next page*)

Table 4 (*continued*)

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journal articles accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research Patents ($N>20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of International Members (2008)	No. of domestic full-time faculty (2008)
	$DMU_{R\&T11}$	1346	193	16	0	4	7404	45	292
	$DMU_{R\&T12}$	1176	0	18	0	1	5127	20	234
	$DMU_{R\&T13}$	1309	0	26	0	12	6128	79	228
	$DMU_{R\&T14}$	3762	0	47	0	14	17604	591	524
	$DMU_{R\&T15}$	5891	1267	41	0	26	27534	1288	680
	$DMU_{R\&T16}$	3324	0	26	0	13	15934	344	443
	$DMU_{R\&T17}$	3617	2426	66	117	13	16476	218	486
	$DMU_{R\&T18}$	6502	2648	64	0	42	27729	1818	791
	$DMU_{R\&T19}$	5651	0	26	0	18	26924	1334	742
	$DMU_{R\&T20}$	4896	2171	47	52	31	20783	596	654
	$DMU_{R\&T21}$	2690	0	22	0	19	12357	569	371
	$DMU_{R\&T22}$	1614	5238	52	70	7	7380	108	594
	$DMU_{R\&T23}$	2185	1666	62	36	24	9398	147	320
	$DMU_{R\&T24}$	2162	0	10	0	23	8961	103	303
	$DMU_{R\&T25}$	2585	0	22	0	7	10583	41	352
	$DMU_{R\&T26}$	889	0	6	0	7	4383	29	140
	$DMU_{R\&T27}$	3279	1424	28	0	13	14695	107	549
	$DMU_{R\&T28}$	2364	0	11	0	11	10895	315	316
	$DMU_{R\&T29}$	4098	0	16	0	64	17969	1282	660
	$DMU_{R\&T30}$	3160	0	12	0	13	14733	271	387
	$DMU_{R\&T31}$	1546	0	4	0	15	6352	83	207
	$DMU_{R\&T32}$	2430	0	9	0	5	10732	62	370
	$DMU_{R\&T33}$	1152	992	8	27	2	5115	19	217
	$DMU_{R\&T34}$	679	700	14	0	8	3112	269	300
	$DMU_{R\&T35}$	1504	0	3	0	8	7004	27	176
	$DMU_{R\&T36}$	2153	0	8	0	10	11324	78	325
	$DMU_{R\&T37}$	1749	0	11	0	18	8870	280	294
	$DMU_{R\&T38}$	444	0	5	0	11	2578	113	133
	$DMU_{R\&T39}$	936	0	9	0	4	6668	29	233
	$DMU_{R\&T40}$	2220	0	13	0	7	10080	50	355
	$DMU_{R\&T41}$	1160	0	5	0	3	4922	13	178
EP	DMU_{EP1}	806	0	0	0	3	3071	5	120

R: research-intensive; T: teaching-intensive; P: professional-intensive; R&T: research & teaching-intensive; and EP: education-in-practice-intensive.

multipliers u_r and v_j and makes such a virtual output and input ratio DMU's efficiency value (h_i). The DEA adopts the maximum value for each efficiency of DMU and from the feasible solution sets of each DMU's virtual multipliers to explore the best weighted value for the DMU, making h_i a maximum. After considering its original unlimited scope and solutions, the CCR model (function one) thereby revises and provides the following:

$$\begin{aligned} \underset{u,y}{Max} \quad & h_i = \sum_{r=1}^{s} u_r y_{ir} \\ \text{s.t.} \quad & \sum_{j=1} v_j x_{ij} = 1 \\ & \sum_{r=1}^{s} u_r y_{ir} - \sum_{j=1}^{m} v_j x_{ij} \leqq 0 \end{aligned} \tag{1}$$

where u_r, $v_j \geqq 0$; $i = 1,2,3,\ldots,n$; $j = 1,2,3,\ldots,m$; $r = 1,2,3,\ldots,s$.

In 1984, Boyd and Fare found that when either u_r or v_j is zero in the CCR model, solutions will become degenerate, making the effi-

Table 5
Efficiency value and return to scale for research-intensive universities.

Sample university	CRSTE	VRSTE	SE	RS
DMU_{R1}	1.000	1.000	1.000	CRS
DMU_{R2}	1.000	1.000	1.000	CRS
DMU_{R3}	1.000	1.000	1.000	CRS
DMU_{R4}	0.865	0.966	0.895	DRS
DMU_{R5}	0.678	0.679	0.998	DRS
DMU_{R6}	1.000	1.000	1.000	CRS
DMU_{R7}	1.000	1.000	1.000	CRS

Table 6
The input and output slack for research-intensive universities.

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journals accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research patents ($N>20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of international members (2008)	No. of domestic full-time faculty (2008)
R	DMU_{R1}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{R2}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{R3}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{R4}	1.520	0.000	259.752	0.000	0.000	12.401	0.000	350.444
	DMU_{R5}	0.000	575.076	0.000	36.131	0.000	0.000	0.000	208.168
	DMU_{R6}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{R7}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

ciency value incorrect. Thus, they improved this problem by introducing the Archimedean quantity (ε), making u_r, and v_j into $\geqq \varepsilon$. To make the above model easily used, the dual problem of linear programming should be used to as to minimize the number of constraints. Thus, the relative efficiency value of the DMU can be acquired. Additionally, under constant return to scale (CRS), there is still room for the DMU to improve its input and output, and thus slack variables of input and output $\left(S_{ij}^-, S_{ir}^+\right)$ can be introduced.

The above model therefore can be revised as follows (function two). In the revised model, λ_i are the weights of each DMU, and θ_i is the relative efficiency of DMU_i. When $\theta_{i=1}$, this means that the DMU contains operational efficiency so that $S_{ij=}^- S_{ir=0}^+$. Otherwise, the DMU does not contain operational efficiency, and therefore slack variables of input and output, namely, S_{ij}^- and S_{ir}^+, can be calculated

$$\begin{aligned} Min \quad & h_i = \theta_i - \varepsilon\left[\sum_{j=1}^{m} S_{ij}^- + \sum_{r=1}^{s} S_{ir}^+\right] \\ \text{s.t.} \quad & \sum_{i=1}^{n} \lambda_i x_{ij} - \theta_i x_{ij} + S_{ij}^- = 0 \\ & \sum_{i=1}^{n} \lambda_i y_{ir} - S_{ir}^+ = y_{ir} \end{aligned} \tag{2}$$

where $\lambda_i \geqq 0$; $i = 1,2,3,\ldots,n$; $j = 1,2,3,\ldots,m$; $r = 1,2,3,\ldots,s$.

3.2. The BCC model

Since the CCR model contains the assumption of a constant return to scale (CRS), which does not fit well with the real-world situation, Banker et al. (1984) proposed the assumption of variable return to scale (VRS), using four axioms of the produce possible set (PPS) (e.g., convexity, inefficiency, ray unboundness, and minimum extrapolation) and the distance function of Shephard (1970) to derive pure technical efficiency (PTE) and scale efficiency (SE). After considering variable return to scale (VRS), the following linear programming model (function (3)) can be adopted:

$$\begin{aligned} \min_{\theta,\lambda} \quad & h_i \\ \text{s.t.} \quad & \sum_{i=1}^{n} \lambda_j x_{ij} \leqq h_i x_{ij} \\ & \sum_{i=1}^{n} \lambda_j y_{ir} \geqq y_{ir} \\ & \sum_{i=1}^{n} \lambda_j = 1 \end{aligned} \tag{3}$$

where $\lambda_i \geqq 0$; $i = 1,2,3,\ldots,n$; $j = 1,2,3,\ldots,m$; $r = 1,2,3,\ldots,s$.

Table 7
Efficiency value and return to scale for teaching-intensive universities.

Sample university	CRSTE	VRSTE	SE	RS
DMU_{T1}	0.396	0.402	0.987	IRS
DMU_{T2}	0.794	0.877	0.905	IRS
DMU_{T3}	1.000	1.000	1.000	CRS
DMU_{T4}	0.978	0.978	1.000	CRS
DMU_{T5}	0.565	1.000	0.565	IRS
DMU_{T6}	0.891	0.931	0.957	DRS
DMU_{T7}	0.386	1.000	0.386	IRS
DMU_{T8}	1.000	1.000	1.000	CRS

Table 9
Efficiency value and return to scale for profession-intensive universities.

Sample university	CRSTE	VRSTE	SE	RS
DMU_{P1}	1.000	1.000	1.000	CRS
DMU_{P2}	0.389	0.415	0.937	IRS
DMU_{P3}	0.385	0.416	0.924	DRS
DMU_{P4}	0.362	0.375	0.966	IRS
DMU_{P5}	0.689	0.825	0.835	IRS
DMU_{P6}	0.546	0.549	0.994	DRS
DMU_{P7}	0.626	0.964	0.649	IRS
DMU_{P8}	0.299	0.299	0.998	DRS
DMU_{P9}	0.602	0.800	0.753	DRS
DMU_{P10}	1.000	1.000	1.000	CRS
DMU_{P11}	0.338	0.453	0.746	DRS
DMU_{P12}	0.280	0.329	0.850	DRS
DMU_{P13}	0.405	0.474	0.855	DRS
DMU_{P14}	0.322	0.350	0.920	DRS
DMU_{P15}	1.000	1.000	1.000	CRS
DMU_{P16}	0.844	0.855	0.953	IRS
DMU_{P17}	0.828	0.850	0.974	IRS
DMU_{P18}	0.518	0.561	0.924	DRS
DMU_{P19}	0.824	0.842	0.979	IRS
DMU_{P20}	0.861	0.917	0.939	DRS
DMU_{P21}	0.627	0.653	0.960	DRS
DMU_{P22}	0.908	0.958	0.947	DRS
DMU_{P23}	0.370	0.463	0.801	IRS
DMU_{P24}	0.734	0.862	0.852	IRS
DMU_{P25}	0.078	1.000	0.078	IRS
DMU_{P26}	0.907	0.967	0.939	IRS
DMU_{P27}	0.783	0.861	0.909	IRS
DMU_{P28}	1.000	1.000	1.000	CRS
DMU_{P29}	1.000	1.000	1.000	CRS
DMU_{P30}	0.809	1.000	0.809	DRS
DMU_{P31}	0.678	0.753	0.901	DRS
DMU_{P32}	1.000	1.000	1.000	CRS
DMU_{P33}	1.000	1.000	1.000	CRS
DMU_{P34}	1.000	1.000	1.000	CRS
DMU_{P35}	1.000	1.000	1.000	CRS
DMU_{P36}	1.000	1.000	1.000	CRS
DMU_{P37}	0.198	0.219	0.904	IRS
DMU_{P38}	1.000	1.000	1.000	CRS
DMU_{P39}	0.954	1.000	0.954	IRS
DMU_{P40}	0.593	0.755	0.785	DRS
DMU_{P41}	1.000	1.000	1.000	CRS
DMU_{P42}	0.833	1.000	0.833	IRS

Table 8
The input and output slack for teaching-intensive universities.

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journals accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research patents ($N > 20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of international members (2008)	No. of domestic full-time faculty (2008)
T	DMU_{T1}	0.000	19.689	6580.519	0.000	129.137	0.000	0.000	0.000
	DMU_{T2}	0.000	0.000	618.242	2.060	73.937	0.000	0.000	0.000
	DMU_{T3}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{T4}	0.000	0.027	0.000	0.002	0.981	0.000	6.077	19.982
	DMU_{T5}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{T6}	0.000	951.442	5.043	0.000	0.000	0.000	0.000	0.323
	DMU_{T7}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{T8}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

When the efficiency value of the constant return to scale (CRS) calculated from Eq. (2) divided by Eq. (3), it provides the efficiency value of the variable return to scale (VRS), also called scale efficiency (SE). If scale efficiency (SE) equals one, it means that the DMU is achieving constant return to scale (CRS). On the contrary, if the scale efficiency (SE) is less than one, it means that the DMU is scale inefficient. However, in order to see whether the scale inefficiency is in increasing or decreasing scale, non-increasing return to scale conditions must be introduced so as to compare the scale efficiency under the variable return to scale (VRS). When considering the non-increasing return to scale conditions, the constraint $\sum_{i=1}^{n}\lambda_j = 1$ in Eq. (3) needs to be revised to $\sum_{i=1}^{n}\lambda_j \leqq 1$. The model can then be revised as follows (function (4))

$$\begin{aligned} \underset{\theta,\lambda}{Min} \quad & h_i \\ \text{s.t.} \quad & \sum_{i=1}^{n} \lambda_j x_{ij} \leqq h_i x_{ij} \\ & \sum_{i=1}^{n} \lambda_j y_{ir} \geqq y_{ir} \\ & \sum_{i=1}^{n} \lambda_j \leqq 1 \end{aligned} \tag{4}$$

where $\lambda_i \geqq 0$; $i = 1,2,3,\ldots,n$; $j = 1,2,3,\ldots,m$; $r = 1,2,3,\ldots,s$.

In the comparison with efficiency values calculated from Eqs. (4) and (3), if two efficiency values equal each other, it means that the DMU is an increasing return to scale (IRS); otherwise, the DMU is a decreasing return to scale (DRS).

4. Empirical testing and discussion

Since there are no studies on Inno-Qual efficiency for industries and because evaluating and improving innovation and total quality management performance are becoming critical issues for higher education in Taiwan, the aim of this study is to overcome the above-mentioned problems by adopting the IPQS using the DEA.

To provide comprehensive and precise results, sample universities were chosen originally based on four types of universities (i.e., research-intensive, teaching-intensive, professional-intensive, and education-in-practice-intensive). However, this categorization is overbroad for precise measurements because some universities today focus equally on teaching and research. Thus, we decided to create a new dimension, the research & teaching-intensive university. After discarding the universities that did not belong to the

Table 10
The input and output slack for profession-intensive universities.

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journals accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research patents ($N > 20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of international members (2008)	No. of domestic full-time faculty (2008)
P	DMU_{P1}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P2}	0.000	0.000	2144.407	0.000	0.000	0.000	0.000	19.545
	DMU_{P3}	0.329	0.000	3977.663	66.510	0.000	6.185	0.000	0.000
	DMU_{P4}	0.000	0.000	585.487	0.000	0.000	0.000	0.000	169.157
	DMU_{P5}	0.000	0.000	1000.667	0.000	2.845	0.000	0.000	0.000
	DMU_{P6}	0.000	0.000	672.825	5.319	34.530	0.000	0.000	323.621
	DMU_{P7}	0.000	0.000	0.000	1.598	0.000	0.000	0.000	0.000
	DMU_{P8}	0.000	0.000	97.057	0.000	0.000	0.000	0.000	57.638
	DMU_{P9}	1.784	0.000	299.255	12.059	115.249	0.000	0.000	358.096
	DMU_{P10}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P11}	16.846	0.000	2419.464	53.925	0.000	7.712	0.000	0.000
	DMU_{P12}	2.747	0.000	2194.295	44.280	10.760	0.000	0.000	97.972
	DMU_{P13}	11.740	0.000	716.986	0.000	0.000	0.000	0.000	212.421
	DMU_{P14}	0.000	0.000	843.047	14.224	118.854	0.000	0.000	389.709
	DMU_{P15}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P16}	0.000	0.000	0.000	6.280	55.799	0.000	0.000	0.000
	DMU_{P17}	0.000	0.000	376.421	19.001	94.233	0.000	0.000	304.849
	DMU_{P18}	8.505	0.000	656.959	11.141	0.000	0.000	0.000	0.000
	DMU_{P19}	0.000	0.000	0.000	8.268	66.516	0.000	0.000	108.441
	DMU_{P20}	2.596	0.000	1215.995	31.800	107.351	0.000	0.000	0.000
	DMU_{P21}	0.763	0.000	1269.050	40.209	97.449	0.000	0.000	0.000
	DMU_{P22}	2.234	0.000	334.376	21.110	104.257	0.000	0.000	0.000
	DMU_{P23}	0.000	0.000	0.011	0.597	0.002	0.000	0.000	0.000
	DMU_{P24}	0.000	0.000	274.568	18.204	0.000	0.000	0.000	62.337
	DMU_{P25}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P26}	0.000	0.000	418.223	18.094	62.825	0.000	0.000	202.320
	DMU_{P27}	0.000	0.000	311.515	15.989	71.700	0.000	0.000	0.000
	DMU_{P28}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P29}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P30}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P31}	0.000	0.048	3.234	0.020	0.000	0.000	295.390	4.787
	DMU_{P32}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P33}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P34}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P35}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P36}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P37}	0.000	0.000	114.968	2.021	29.682	0.000	0.000	0.000
	DMU_{P38}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P39}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P40}	0.000	0.027	0.000	0.027	0.252	0.388	0.000	0.000
	DMU_{P41}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	DMU_{P42}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

university but in higher education, such as colleges and institutes, all five types of universities (99 universities in total) were studied.

As for output data, according to the IPQS, the Inno-Qual indices include research patents, financial support from the National Science Council (NSC), journal articles accepted and published, government tender planning, the number of chaired professors, promotion and job acquisition for all previous students, appropriate use of multimedia, the number of cooperating international universities, and teaching that combines practice, attending courses and learning theory (Table 2). To precisely measure the Inno-Qual efficiency, after discussing with senior experts (11 from research-intensive universes, four from teaching-intensive universities, six from professional-intensive universities, 15 from research and teaching universities, and three from education-in-practice-intensive universities), five critical Inno-Qual indices were created. They were: Journal Articles Accepted and Published, Research Patents, Financial Support from the National Science Council, the Number of Cooperating International Universities, and Promotion and Job Acquisition for all Previous Students. These were extracted from external and internal organizational-oriented improvement dimensions (Table 4).

To fit the usage of the DEA and increase Inno-Qual efficiency visibility, we revised the indices while maintaining their characteristics. First, the journal articles accepted and published are restricted to those cited by essential science indicators (ESI) that have accumulated until 2009 (Higher Education Evaluation & Accreditation Council of Taiwan, 2009). Second, research patents include domestic and international ones. In this study, the total number of patents includes both types. Based on the latest calculation by the Higher Education Evaluation and Accreditation Council of Taiwan (2008), universities with more than 20 research patents for 2004–2007 were used in this study. Third, financial support from the National Science Council is calculated by the number of cases which accepted to be supported and is limited to 2009. Fourth, we calculated the number of cooperating international universities in accordance with their countries (Department of Statistics, 2008) and based on more than half of the senior experts' opinions that replacing the number of cooperating international universities by their countries will better identify the degree of diversification of a target university. Lastly, obtaining employment, advancing to graduate or professional school, and joining the military, under Taiwanese law, are the three main paths graduates can take. Hence, to acquire precise results on the last index, we revised it as the number of graduates and restricted it to 2008, according to the latest statistics available from the Department of Statistics in 2009.

As for the input data, since most of the output data are mainly from domestic students, foreign members, including faculty, students and domestic full-time faculty, and domestic and international human administrative costs for students and faculty. These do not currently have a specific standard. Thus, such costs are always a major part of the overall costs for a university. In this regard, the numbers of domestic students, foreign members, and domestic full-time faculty members calculated in 2009 for 2008 by the Department of Statistics were used as the input data. We believe that finding the efficiency input will help reduce unnecessary costs for Taiwanese universities.

According to the results for research-intensive universities presented in Table 5, the CRSTE, the VRSTE, and the SE of DMU_{R1}, DMU_{R2}, DMU_{R3}, DMU_{R6}, and DMU_{R7} are equal to one; five of them are already at the efficient frontier. Therefore, we suggest that universities should look to provide more profitable external development opportunities for students or internal development opportunities for high-prestige foreign members and to motivate faculty members to conduct more valuable R&D or submit papers to higher level journals listed by the ESI so as to acquire a higher level of Innovation and TQM performance for the same amount of input.

In addition, DMU_{R4} and DMU_{R5} are in the decreasing return to scale stage, meaning that both universities should especially decrease the scale of domestic full-time faculty members or increase the scale of research or student development support so as to increase Inno-Qual scale efficiency. More detailed indications regarding improving Inno-Qual efficiency for the each DMU are presented in Table 6.

Based on the results regarding teaching-intensive universities presented in Table 7, the CRSTE, VRSTE, and SE of DMU_{T3}, DMU_{T4}, and DMU_{T8} are equal to one. This implies that these three universities are at the efficient frontier and thus cannot increase scale efficiency by their original input scale. We suggest that these three universities emphasize the output more on quality than on quantity. Since the nature of the teaching-intensive university is to explore its area of research (Chen & Chen, 2008a, 2008b), the value of its field will grow higher if researchers provide more abstruse and detailed insight. Five of the universities are also encouraged to integrate the characteristics of the research-intensive university, such as adding more practical courses and making DMU_{R1}, DMU_{R2}, DMU_{R3}, DMU_{R6}, and DMU_{R7} their benchmarks for future innovation and TQM performance upgrades.

In addition, DMU_{T1}, DMU_{T2}, DMU_{T5}, and DMU_{T7} are in the increasing return to scale stage; that is, four of them need to increase the amount of research or increase the external and internal

Table 11
Efficiency value and return to scale for research & teaching-intensive universities.

Sample university	CRSTE	VRSTE	SE	RS
$DMU_{R\&T1}$	0.522	0.645	0.809	DRS
$DMU_{R\&T2}$	0.781	0.985	0.793	DRS
$DMU_{R\&T3}$	0.369	0.399	0.923	IRS
$DMU_{R\&T4}$	1.000	1.000	1.000	CRS
$DMU_{R\&T5}$	0.374	0.375	0.996	IRS
$DMU_{R\&T6}$	0.538	0.589	0.914	DRS
$DMU_{R\&T7}$	0.302	0.881	0.343	IRS
$DMU_{R\&T8}$	0.689	0.693	0.995	DRS
$DMU_{R\&T9}$	0.527	1.000	0.527	IRS
$DMU_{R\&T10}$	0.568	1.000	0.568	IRS
$DMU_{R\&T11}$	0.495	0.548	0.902	IRS
$DMU_{R\&T12}$	1.000	1.000	1.000	CRS
$DMU_{R\&T13}$	0.563	0.712	0.791	IRS
$DMU_{R\&T14}$	0.467	0.672	0.695	DRS
$DMU_{R\&T15}$	0.361	0.654	0.552	DRS
$DMU_{R\&T16}$	0.233	0.300	0.775	DRS
$DMU_{R\&T17}$	0.543	0.670	0.811	DRS
$DMU_{R\&T18}$	0.216	0.391	0.552	DRS
$DMU_{R\&T19}$	0.260	0.484	0.538	DRS
$DMU_{R\&T20}$	0.455	0.731	0.623	DRS
$DMU_{R\&T21}$	0.593	0.676	0.877	DRS
$DMU_{R\&T22}$	1.000	1.000	1.000	CRS
$DMU_{R\&T23}$	0.315	0.339	0.929	IRS
$DMU_{R\&T24}$	0.177	0.178	0.991	IRS
$DMU_{R\&T25}$	0.563	0.599	0.939	DRS
$DMU_{R\&T26}$	0.938	0.983	0.954	DRS
$DMU_{R\&T27}$	0.236	0.296	0.796	DRS
$DMU_{R\&T28}$	0.336	0.369	0.909	DRS
$DMU_{R\&T29}$	0.065	0.093	0.698	DRS
$DMU_{R\&T30}$	0.122	0.152	0.805	DRS
$DMU_{R\&T31}$	0.840	1.000	0.840	IRS
$DMU_{R\&T32}$	0.406	0.440	0.923	DRS
$DMU_{R\&T33}$	0.766	1.000	0.766	IRS
$DMU_{R\&T34}$	1.000	1.000	1.000	CRS
$DMU_{R\&T35}$	1.000	1.000	1.000	CRS
$DMU_{R\&T36}$	0.150	0.157	0.954	DRS
$DMU_{R\&T37}$	0.811	0.819	0.991	IRS
$DMU_{R\&T38}$	0.808	1.000	0.808	IRS
$DMU_{R\&T39}$	0.642	0.797	0.806	DRS
$DMU_{R\&T40}$	0.261	0.263	0.992	IRS
$DMU_{R\&T41}$	0.378	1.000	0.378	IRS

development opportunities for domestic students and potential foreign members in order to increase the Inno-Qual scale efficiency. Regarding DMU_{T6}, it is in the decreasing return to scale stage, and thus it should especially decrease the scale of domestic full-time faculty members or increase the number of publications it produces listed by the ESI and supported by the NSC. More detailed indications on improving Inno-Qual efficiency for teaching-intensive universities that are not at the efficient frontier are given in Table 8.

According to the results on profession-intensive universities presented in Table 9, the CRSTE, the VRSTE, and the SE of DMU_{P1}, DMU_{P10}, DMU_{P15}, DMU_{P28}, DMU_{P29}, DMU_{P32}, DMU_{P33}, DMU_{P34}, DMU_{P35}, DMU_{P36}, DMU_{P38}, and DMU_{P41} are at the efficient frontier and in a constant return to scale stage. Hence, they cannot increase Inno-Qual efficiency by adjusting their input. We suggest that these universities should increase interactions with government-owned or privately run corporations so as to increase advanced R&D opportunities. We also suggest that they upgrade to the research-intensive university or integrate characteristics from this type of university in order to enhance its ability to create invisible creation such as new thoughts or theories. By doing so, their competitive abilities will catch up to those of research-intensive universities; additionally, future enhancements to the Inno-Qual performance will be as smooth as those of research-intensive universities.

DMU_{P2}, DMU_{P4}, DMU_{P5}, DMU_{P7}, DMU_{P16}, DMU_{P17}, DMU_{P19}, DMU_{P23}, DMU_{P24}, DMU_{P25}, DMU_{P26}, DMU_{P27}, DMU_{P37}, DMU_{P39}, and DMU_{P42} are in the increasing return to scale stage. Thus, they need to increase the scale of their output so as to increase the Inno-Qual scale efficiency, especially the quantity of financial support from the NSC and research patents. Also, we suggest that they decrease the scale of their domestic full-time faculty.

Additionally, DMU_{P3}, DMU_{P6}, DMU_{P8}, DMU_{P9}, DMU_{P11}, DMU_{P12}, DMU_{P13}, DMU_{P14}, DMU_{P18}, DMU_{P20}, DMU_{P21}, DMU_{P22}, DMU_{P30}, DMU_{P31}, and DMU_{P40} are in the decreasing return to scale stage. Therefore, they need to decrease the amount of input in order to increase Inno-Qual scale efficiency, such as decreasing the number of domestic full-time faculty. More detailed indications on improving Inno-Qual efficiency for profession-intensive universities that are not at the efficient frontier are given in Table 10.

According to the results on research & teaching-intensive universities presented in Table 11, the CRSTE, the VRSTE, and the SE of $DMU_{R\&T4,\ DMUR\&T12}$, $DMU_{R\&T22}$, $DMU_{R\&T34}$, and $DMU_{R\&T35}$ are at the efficient frontier and in a constant return to scale stage. Therefore, these universities can either transform into research-intensive universities, improving Inno-Qual performance, or focus

Table 12
The input and output slack for research & teaching-intensive universities.

University type	Sample university	Output					Input		
		No. of graduates (2008)	Journals accepted and published (ESI) (2009)	Quantity of financial support from the NSC (2009)	Research patents ($N > 20$) (2004–07)	No. of cooperating foreign countries (2008)	No. of domestic students (2008)	No. of international members (2008)	No. of domestic full-time faculty (2008)
R&T	$DMU_{R\&T1}$	10.396	0.000	7986.772	0.000	115.075	28.545	0.000	0.000
	$DMU_{R\&T2}$	14.034	0.000	3.335	0.000	0.000	10.900	0.000	0.000
	$DMU_{R\&T3}$	0.000	420.932	0.000	25.233	87.827	0.000	0.000	0.000
	$DMU_{R\&T4}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T5}$	0.000	0.000	2583.163	0.000	117.485	0.000	0.000	300.138
	$DMU_{R\&T6}$	1.942	0.000	2583.516	40.549	58.986	0.000	0.000	0.000
	$DMU_{R\&T7}$	0.000	50.479	636.375	0.000	0.001	6.050	0.000	0.000
	$DMU_{R\&T8}$	0.000	0.000	2047.789	0.000	15.865	0.000	0.000	332.265
	$DMU_{R\&T9}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T10}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T11}$	0.000	0.000	821.192	0.000	48.850	0.000	0.000	0.000
	$DMU_{R\&T12}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T13}$	0.000	0.000	1873.968	0.000	0.002	3.815	0.000	0.000
	$DMU_{R\&T14}$	20.526	0.000	2428.154	0.000	86.515	0.000	0.000	125.107
	$DMU_{R\&T15}$	49.382	0.000	1818.419	31.103	72.567	4.074	0.000	0.000
	$DMU_{R\&T16}$	6.376	0.000	2661.637	0.000	68.274	0.000	0.000	595.588
	$DMU_{R\&T17}$	12.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T18}$	37.113	0.000	0.000	0.000	104.501	11.571	0.000	51.055
	$DMU_{R\&T19}$	45.427	0.000	2688.065	8.063	98.652	0.000	0.000	287.807
	$DMU_{R\&T20}$	32.650	0.000	1080.112	22.876	18.866	4.958	0.000	69.375
	$DMU_{R\&T21}$	4.238	0.000	3727.351	76.901	56.698	0.294	0.000	0.000
	$DMU_{R\&T22}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T23}$	0.000	79.700	2131.845	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T24}$	0.000	0.000	3556.286	22.566	85.528	0.000	0.000	223.454
	$DMU_{R\&T25}$	0.431	0.000	1010.868	0.000	110.518	0.000	0.000	73.267
	$DMU_{R\&T26}$	0.000	897.979	9.211	0.020	0.000	0.000	0.000	0.000
	$DMU_{R\&T27}$	0.000	0.000	0.000	37.838	44.335	0.000	0.000	556.211
	$DMU_{R\&T28}$	0.000	0.000	1519.317	11.179	113.615	0.000	0.000	295.530
	$DMU_{R\&T29}$	0.000	0.000	6396.000	0.000	112.615	0.000	0.000	247.201
	$DMU_{R\&T30}$	0.000	0.000	2504.261	0.000	75.735	0.000	0.000	344.804
	$DMU_{R\&T31}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T32}$	0.000	0.000	505.859	1.830	121.636	0.000	0.000	183.028
	$DMU_{R\&T33}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T34}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T35}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T36}$	0.000	0.000	2118.905	24.670	74.235	0.000	0.000	0.000
	$DMU_{R\&T37}$	0.000	0.000	2718.448	49.853	93.368	0.000	0.000	169.083
	$DMU_{R\&T38}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$DMU_{R\&T39}$	0.000	0.244	0.000	0.243	0.000	0.000	0.000	4.641
	$DMU_{R\&T40}$	0.000	0.000	1345.441	2.385	10.819	0.000	0.000	0.000
	$DMU_{R\&T41}$	0.000	72.000	0.000	6.000	0.000	0.000	0.000	597.000

Table 13
Efficiency value and return to scale for education-in-practice-intensive universities.

Sample university	CRSTE	VRSTE	SE	RS
DMU_{EP1}	1.000	1.000	1.000	CRS

more on the quality of their research by publishing papers in high-level journals listed by the ESI.

$DMU_{R\&T3}$, $DMU_{R\&T5}$, $DMU_{R\&T7}$, $DMU_{R\&T9}$, $DMU_{R\&T10}$, $DMU_{R\&T11}$, $DMU_{R\&T13}$, $DMU_{R\&T23}$, $DMU_{R\&T24}$, $DMU_{R\&T31}$, $DMU_{R\&T33}$, $DMU_{R\&T37}$, $DMU_{R\&T38}$, $DMU_{R\&T40}$, and $DMU_{R\&T41}$ are in the increasing return to scale stage. They should increase Inno-Qual efficiency by increasing their output, the amount of financial support from the NSC and the internal development opportunities for foreign members in particular. In addition, they should decrease the number of domestic full-time faculty members.

Except above, $DMU_{R\&T1}$, $DMU_{R\&T2}$, $DMU_{R\&T6}$, $DMU_{R\&T8}$, $DMU_{R\&T14}$, $DMU_{R\&T15}$, $DMU_{R\&T16}$, $DMU_{R\&T17}$, $DMU_{R\&T18}$, $DMU_{R\&T19}$, $DMU_{R\&T20}$, $DMU_{R\&T21}$, $DMU_{R\&T25}$, $DMU_{R\&T26}$, $DMU_{R\&T27}$, $DMU_{R\&T28}$, $DMU_{R\&T29}$, $DMU_{R\&T30}$, $DMU_{R\&T32}$, $DMU_{R\&T36}$, and $DMU_{R\&T39}$ are in the decreasing return to scale stage. Hence, they should decrease their amount of input, number of domestic full-time faculty, and number of domestic students in order to improve Inno-Qual scale efficiency. Also, they need to increase the quantity of financial support from the NSC and the number of student development opportunities in order to increase the Inno-Qual scale efficiency. More detailed indications on improving the Inno-Qual efficiency for research & teaching-intensive universities that are not at the efficient frontier are given in Table 12.

According to the results on education-in-practice-intensive universities presented in Table 13, the CRSTE, the VRSTE, and the SE of DMU_{EP1} are equal to one and thus at the efficient frontier as well as in the constant return to scale stage. However, since education-in-practice-intensive is the newest type of university, and based on the data in Table 4, we found that the amount of input and output of DMU_{EP1} is relatively low as compared with other types of universities. We assume that the Inno-Qual performance of DMU_{EP1} is not very good. We suggest that this university adopt translation or characteristics integration in order to become like a professional-intensive university on account of its similar characteristics and improve its Inno-Qual performance and competitive advantage in the Taiwanese academic community.

5. Conclusions

Since the birth rate in Taiwan is decreasing, the number of universities is increasing and Taiwan has joined the WTO, an increasing number of Taiwanese universities have recently tried to upgrade their innovation performance and improve their total quality performance (Inno-Qual performance) so as to enhance their overall operational performance. Although there are many relative measurement models, such as the Inno-Qual performance system (IQPS), which integrate the features of innovation and TQM, currently, no studies empirically evaluate the efficiency of such improvement, resulting in the Inno-Qual performance improving along with the cost increasing, particularly human administrative cost due to the nature of higher education, providing intellectual product. To overcome this problem, we adopted the IQPS using data envelopment analysis (DEA) to evaluate the Inno-Qual efficiency of five types of universities for a total of ninety-nine universities in Taiwan. Based on the empirical results, we found that over half (73%) of the universities are highly inefficient in improving the Inno-Qual performance, and we conclude that improving Inno-Qual efficiency in accordance with our results will help to reduce the majority of cost expenditures.

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