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Abstract: In this era of global competition, higher education institutions (HEIs) are important institutions for social development and economic sustainability of a country. Thus, the efficiency of HEIs should always be evaluated to maintain their quality and improve their performance through various strategic planning. Such efficiency evaluation can be performed using data envelopment analysis (DEA). One of the prominent models of DEA is a super efficiency slacks-based measure (SE-SBM) model that can simultaneously deal with input and output slacks. However, the model has not much been used to evaluate the efficiency of HEIs. To address this gap, this paper utilises SBM and SE-SBM models to assess the efficiency of 41 research and teaching universities in Taiwan. The results showed that 25 universities achieved the super efficiency status, with the top ranked are the best DMUs consuming their educational inputs to produce their educational outputs.

Keywords: data envelopment analysis; higher education institutions; super efficiency slacks-based measure; Taiwanese universities.

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1 Introduction

HEIs are organisations providing tertiary education and awarding professional certificates or academic degrees. HEIs can include public or private universities, vocational and technical colleges, polytechnics, community colleges and other collegiate-level institutions (Taleb et al., 2019b). These institutions strive to provide society with competent human resources in various fields of knowledge and skills. These human resources are expectantly equipped with sufficient exposure to new research and technology, creative and independent ideas, and leadership and teambuilding skills, which are important in this extremely competitive job market. In spite of these benefits, HEIs have now been facing some challenges. The challenges include decreased student enrolment, financial difficulties and decreased government funding, which could put pressure on them to sustain in this current challenging world.

HEIs are non-profit organisations since the prices of their inputs and outputs are absent (Kao and Hung, 2008). The inputs can be human in terms of resources and physical capital, while the outputs can be teaching and research activities and services offered to the community (Avkiran, 2001; Hussain, 2017). All these inputs and outputs are to be considered to ensure that HEIs produce high quality graduates having essential knowledge and competent skills, who can face global competition for future political, social and economic sustainability. Such quality graduates are important for national development and economic growth of a country. In order to analyse the ability of HEIs to achieve their goals, their efficiency has to be evaluated. To evaluate the efficiency of non-profit organisations, a powerful approach called DEA is commonly used (Johnes, 2006).

DEA is a non-parametric technique utilising mathematical programming was proposed by Charnes et al. (1978). Its primary purpose is to assess the relative efficiency of a peer set of homogenous decision making units (DMUs) consuming multiple inputs to produce multiple outputs (Hussain et al., 2015). The main DEA models utilised in a wide range of real-world applications are radial and non-radial. The radial model consists of two types of efficiency measures are CCR model, proposed by Charnes et al. (1978), and BCC model; proposed by Banker et al. (1984). The CCR model assumes that returns to scale of evaluated DMUs is constant (CRS). In contrast, the BCC model assumes that returns to scale is variable (VRS) due to the fact that a convexity constraint is imposed into the model (Taleb et al., 2019a). However, the radial model ignores the input and output slacks in efficiency scores since it assumes the proportional augmentation of decreasing outputs (output-oriented) or the proportional reduction of increasing inputs (input-oriented) (Taleb et al., 2022; Yang et al., 2014). This limitation may mislead efficiency measures (Chiu et al., 2011; Cooper et al., 1999).

To address the issue of the radial model, several efficiency measures of non-radial models have been proposed (e.g., Cooper et al., 1999; Fare and Knoxx Lovell, 1978; Pastor et al., 1999). The models can deal with the slacks of inputs and outputs disproportionally by reducing inputs and increasing outputs simultaneously. In other words, the outputs and/or inputs are tolerable to increase and/or decrease disproportionally. This fully independent reduction in inputs and augmentation in outputs is the salient advantage of non-radial models over radial models. Fundamentally, non-radial models are suitable for applications aiming input reduction and output extension simultaneously (Cook et al., 2014; Taleb et al., 2019b). Both input reduction and/or output augmentation guarantee that an evaluated DMU is Pareto-efficient[1], which can be deemed as a prominent feature of non-radial models. In the same context, a novel non-radial slacks-based measure (SBM) model was proposed by Tone (2001). The model effectively discriminates efficient and inefficient DMUs since it directly deals with the slacks of input excesses (*how much inputs should be decreased*) and output shortfalls (*how much outputs should be increased*). However, the SBM model cannot rank high performing DMUs.

To discriminate high performing efficient DMUs, Tone (2002) proposed a super efficiency of a non-radial slacks-based measure (SE-SBM) model. The primary concept of the model relies on that of the radial super efficiency model proposed by Andersen and Petersen (1993). Both super efficiency models exclude each efficient DMU from its efficient frontier, formed by efficient DMUs, to calculate its super efficiency score. In the SE-SBM model, the excluded efficient DMU_o from the reference set of the SBM model measures a non-radial distance. This distance significantly affects the calculation of the super efficiency score. Thus, the SE-SBM model increases inputs and decrease outputs simultaneously. This feature has made the model more applicable in dealing with many settings of real life. In spite of this fact, the model has rarely been utilised to evaluate the efficiency of HEIs. Thus, the objective of this paper is to use the SBM model of Tone (2001) and SE-SBM model of Tone (2002) to measure the efficiency of 41 research and teaching universities in Taiwan. The models discriminate and ranks efficient and inefficient universities. The discriminating process was achieved by calculating their input savings (*maximum allowable increase in inputs*) and their output surpluses (*maximum allowable decrease in outputs*) (Kasim et al., 2019).

This paper is organised as follows. Section 2 considers a brief literature review related to efficiency studies in HEIs. The methodology for evaluating the efficiency of 41 research and teaching universities in Taiwan using the SBM and SE-SBM models is explained in Section 3. Section 4 reports and discusses the efficiency results of the evaluated universities, while Section 5 provides concluding remarks of this paper.

2 Literature review

HEIs are the backbone of a country's economy and society. However, their functionality has now been impeded by many factors, such as shrinking public funds and investments, increasing tuition fees and limited human resources. Thus, how HEIs utilise these limited inputs to produce the targeted outputs – termed as efficiency – should continually be tracked. Such operational efficiency measurement can help HEIs maintain their quality and assist policy makers to get insight into the educational processes which can eventually enhance the HEI systems. Scientific approaches which quantitatively measure the efficiency and recommend empirical and practical actions are thus important.

Many scholars and researchers have assessed the efficiency of HEIs using DEA. These include Bessent et al. (1983), Cardoso et al. (2021), Chen and Chen (2011), Johnes (1996, 2006), Kuah and Wong (2011), Taleb et al. (2019b), and Tyagi et al. (2009). However, all these studies were conducted based on radial models under the CRS or VRS technology. The radial model is an oriented model: input-oriented or output-oriented. The input-oriented concentrates on the proportional changes of a DMU's inputs to reduce the level of inputs, while maintaining the current level of outputs. In contrast, the output-oriented concentrates on the proportional changes of a DMU's outputs to increase the level of outputs, while maintaining the current level of inputs (Cooper et al., 1999). Thus, by reducing inputs or increasing outputs, an inefficient DMU can improve its performance. The reduction of inputs and/or expansion of outputs of an inefficient DMU can be identified via its input excesses and/or output shortfalls. Using this information, the inefficient DMU can then be projected onto the efficient frontier (Kasim et al., 2019). However, the value of the objective function of the radial model does not reflect all inefficiency, since it ignores the slacks of inputs and outputs.

To simultaneously deal with input and output slacks, Charnes et al. (1985) proposed a non-oriented additive model. However, the model cannot measure efficiency in-depth as the oriented model, since its objective function is a non-commensurate (i.e., it depends on the measurement units of inputs and outputs) (Du et al., 2010; Hussain, 2017). To rectify this issue, Tone (2001) proposed an SBM model whose objective function does not depend on the measurement units of inputs and outputs. Thus, its efficiency scores are restricted between zero and one. The SBM model considers the reduction of inputs and the augmentation of outputs concurrently by increasing input and output slacks. Since then, the SBM model has been used by many studies to assess the efficiency of HEIs (e.g., Abdullah et al., 2018; Johnes and Tone, 2017). However, these studies did not consider ranking of efficient DMUs, since the model cannot discriminate among efficient DMUs.

To discriminate and rank high performing DMUs, the radial super efficiency model proposed by Andersen and Petersen (1993) has been used by some efficiency studies in HEIs, such as Gnewuch and Wohlrabe (2018), Liu et al. (2018) and Ramzi and Ayadi (2016). Due to the infeasibility issue of the radial model that may occur under some cases of VRS, Tone (2002) proposed a novel non-radial SE-SBM model. The model offers some salient features:

1 the input savings and output surpluses of efficient DMUs can simultaneously be identified rectifying the infeasibility issue of the radial super efficiency model

2 its objective function is invariant

3 its scalar measure immediately deals with the excesses of inputs and the shortfalls of outputs.

To the best of authors' knowledge, there are several studies introduced by Hussain et al. (2016), Ken et al. (2009), Taleb et al. (2018) and Taleb et al. (2019a, 2019b) considered the efficiency analysis of HEIs based on Tone's (2002) model. However, there has been no efficiency study considering the model of Tone (2002) to assess the efficiency of research and teaching universities in Taiwan.

3 Data and methodology

This paper utilises the dataset of 41 research and teaching (R&T) universities in Taiwan for year 2009. The dataset was retrieved from the efficiency study introduced by Chen and Chen (2011). Each university was represented as an independent DMU. Three inputs and five outputs were considered. The inputs were the number of domestic full time-academic staff (x_1), the number of international academic staff (x_2) and the number of domestic students (x_3). The outputs were the number of graduates (y_1), the number of accepted and published articles in journals (y_2), the amount of financial support received from National Science Council of Taiwan (y_3), the number of research patents (y_4) and the number of cooperating foreign countries (y_5). The descriptive statistics of the inputs and outputs is reported in Table 1.

Table 1 Descriptive statistics of inputs and outputs

Variable	*Input index*		
	x_1	x_2	x_3
Mean	393,122	347.0488	11,233.51
Std. dev.	185.7297	442.4921	6,438.909
Minimum	133	13	2,578
Maximum	791	1,818	27,729

Variable	*Output index*				
	y_1	y_2	y_3	y_4	y_5
Mean	2,483.707	765.5854	34.07317	11.34146	15.63415
Std. dev.	1,446.539	1,433.816	36.32794	30.52426	13.92975
Minimum	444	0	3	0	1
Maximum	6502	5,861	156	136	64

To evaluate and analyse the efficiency of the universities, this paper relies on the SBM model of Tone (2001) and the SE-SBM model of Tone (2002). The inputs and outputs of the universities are denoted as matrices, which can be identified as follows:

$$X = \left[x_{ij}\right] = \left[x_{11}, \ldots, x_{mn}\right] \in \Re_{+}^{m \times n},\; Y = \left[y_{rj}\right] = \left[y_{11}, \ldots, y_{sn}\right] \in \Re_{+}^{s \times n}$$

The values of X and Y are positive. The production possibility set (PPS) which is the set of all feasible production plans of the SBM model can be defined as follows:

$$P=\left\{(X,Y)\left|X\geq\sum_{j=1}^{n}X_j\lambda_j,\ Y\leq\sum_{j=1}^{n}Y_j\lambda_j,\ \sum_{j=1}^{n}\lambda_j=1,\ \lambda_j\geq 0\right.\right\} \quad (1)$$

Suppose that there are n DMUs. Each DMU represents an independent university. DMUj (j =1, …, n) consumes m educational inputs x_{ij}(i = 1, …, m) to produce s educational outputs y_{rj} (r = 1, …, s). A non-negative multiplier vector for constructing linear programming of the universities is denoted by $\lambda = (\lambda_1, \ldots, \lambda_n$ Hence, the formula of the SBM model under the VRS assumption to evaluate efficiency of DMU$_o$ ($o \in \{1, \ldots, n\}$ is presented as follows:

$$\min\ \tau=\frac{1-\frac{1}{m}\left(\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}\right)}{1+\frac{1}{s}\left(\sum_{r=1}^{s}\frac{s_r^+}{y_{ro}}\right)} \quad (2)$$

s.t.

$$\sum_{i=1}^{m}x_{ij}\lambda_j=x_{io}-s_i^- \qquad i=1,\ldots,m,$$

$$\sum_{r=1}^{s}y_{rj}\lambda_j=y_{ro}+s_r^+ \qquad r=1,\ldots,s,$$

$$\sum_{j=1}^{n}\lambda_j=1\lambda_j\geq 0, s_i^-\geq 0,\ s_r^+\geq 0, \qquad j=1,\ldots,n$$

The difference between the current amount of inputs and outputs and their reference sets is represented by the slacks of input excesses $\left(s_{io}^-\right)$ and output shortfalls (s_{ro}^+). The resulted efficiency score of model (2) supports the property of unit invariant, considered in Section 2. It is denoted by τ^*_o, where $0 < \tau^*_o \leq 1$. The aim of input excesses and output shortfalls is to decrease inputs and increase outputs in order to achieve the optimum level of inputs and outputs of DMUs being evaluated. The optimal solution to model (2) can be utilised for projection process of inefficient DMUs and setting of their targets to improve performance by formulas in equation (3).

$$\begin{aligned}\hat{x}_{io}&=x_{io}-s_i^-\\ \hat{y}_{ro}&=y_{ro}+s_r^+\end{aligned} \quad (3)$$

Definition 1: A DMU$_o$ is said to be fully-efficient in model (2) if its resulted efficiency score is equal to one ($\tau^*_o = 1$) This result can be achieved if and only if all of the input and output slacks are zero $\left(s_i^-=s_r^+=0\right)$. Otherwise, DMU$_o$ is inefficient.

It is possible that multiple DMUs in SBM model (2) achieve the fully efficient status (Definition 1). To discriminate among efficient DMUs and rank them, the SE-SBM model of Tone (2002) is used. The PPS of the model of Tone (2002) spanning by (x, y) which exclude DMU$_o$ (x_o, y_o) from its reference set is defined as follows:

$$p\left(x_o, y_o\right) = \left\{ (\bar{x}, \bar{y}) \middle| \bar{x} \geq \sum_{j=1, j\neq o}^{n} x_j \lambda_j, \bar{y} \leq \sum_{j=1, j\neq o}^{n} y_j \lambda_j, \sum_{j=1, j\neq o}^{n} \lambda_j = 1, \bar{y} \geq 0, \lambda_j \geq 0 \right\} \tag{4}$$

Further, $\bar{p}(x_o, y_o)$ is a subset of $p(x_o, y_o)$ which is defined as

$$\bar{p}\left(x_o, y_o\right) = p\left(x_o, y_o\right) \cap \left\{\bar{x} \geq x_o \text{ and } \bar{y} \leq y_o\right\} \tag{5}$$

The values of inputs and outputs are assumed to be positive (i.e., $x > 0$, $y > 0$) and $\bar{p}(x_o, y_o)$ is not empty (see Tone, 2002).

According to formula (4), the status of super-efficient DMU$_o$ is defined by excluding the efficient DMU$_o$ from its reference set of SBM model (2). Thus, the efficiency score of the efficient DMU$_o$ is identified by measuring the distance between the efficient frontier and the excluded efficient DMU$_o$. The weighted non-radial distance l_i from (x_o, y_o) to $p\left(\bar{x}_o, \bar{y}_o\right) \in \bar{p}\left(x_o, y_o\right)$ is calculated by the index δ as presented in the following equation.

$$\min \ \delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\left(\frac{\bar{x}_i}{x_{io}}\right)}{\frac{1}{s}\sum_{r=1}^{s}\left(\frac{\bar{y}_r}{y_{ro}}\right)} \tag{6}$$

Super efficiency measures of the efficient DMU$_o$ (x_o, y_o) are calculated by the following formula:

$$\min \ \delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\left(\frac{\bar{x}}{x_{io}}\right)}{\frac{1}{s}\sum_{r=1}^{s}\left(\frac{\bar{y}}{y_{ro}}\right)} \tag{7}$$

s.t.

$$\sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j \leq \bar{x} \qquad i = 1, \ldots, m, \tag{7.1}$$

$$\sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j \geq \bar{y} \qquad r = 1, \ldots, s, \tag{7.2}$$

$$\bar{x} \geq x_{io} \text{ and } \bar{y} \leq y_{ro}, \quad \bar{y} > 0, \tag{7.3}$$

$$\sum_{j=1, j\neq o}^{n} \lambda_j = 1 \tag{7.4}$$

$$\lambda_j \geq 0 \qquad j = 1, \ldots, n, \ j \neq o \tag{7.5}$$

By replacing $\bar{x}$ with $x_{io} + z_i^-$ and $\bar{y}$ with $y_{ro} - z_r^+$, model (7) can be represented as follows

$$\min \ \delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\left(\frac{x_{io} + z_i^-}{x_{io}}\right)}{\frac{1}{s}\sum_{r=1}^{s}\left(\frac{y_{ro} - z_r^+}{y_{ro}}\right)} \tag{8}$$

s.t.

$$\sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j \le x_{io} + z_i^- \qquad i = 1, \ldots, m,$$

$$\sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j \ge y_{ro} - z_r^+ \qquad r = 1, \ldots, s,$$

$$x_{io} + z_i^- \ge x_{io}, \ y_{ro} - z_r^+ \le y_{ro}$$

$$z_i^-, z_r^+ \ge 0,$$

constraints (7.4) and (7.5).

Definition 2: The status of an efficient DMU$_o$ resulted from model (2) is super-efficient if the resulted super efficiency score in model (8) is greater than one, $\delta^* > 1$. This is equivalent to $x_{io} + z_{io}^- \ge x_{io}$ and $y - z \le y$.

4 Empirical results and discussions

The two-stage SE-SBM approach was used to calculate the efficiency scores of 41 research and teaching universities in Taiwan. In the first stage, SBM model (2) was run to discriminate between efficient and inefficient universities. The results of model (2) may contain efficient DMUs. In the second stage, the efficient DMUs was then ranked using SE-SBM model (8). The efficiency scores of inefficient and super-efficient universities are tabulated in Table 2.

Based on the three considered inputs and five outputs, there are 25 technical efficient universities out of the total 41 evaluated universities are as reported in Table 2. The technical efficiency score for each technical inefficient university is less than one, while that for each technical efficient university is equal to one, as presented in the 'efficiency score' column–columns 2, 6 and 10 (see Definition 1). The efficient universities were discriminated by calculating their super efficiency scores obtained by SE-SBM model (8), as shown in the 'Super efficiency score' column – columns 3, 7 and 11. The ranking of efficient and inefficient universities is presented in the 'rank' column – columns 4, 8 and 12. DMU# 33 is ranked first among the other efficient DMUs. This indicates that DMU#33 has the highest performance in consuming its educational inputs to produce its educational outputs. In other words, the top ranked DMU has the ability to keep its efficiency status better than other efficient DMUs. Additionally, the super efficiency score reflects that the efficient DMU can increase its inputs and/or decrease its outputs simultaneously. In contrast, the inefficient DMU# 11 is ranked the lowest compared to the other evaluated DMUs since it has the smallest efficiency score. Each inefficient DMU can improve its efficiency by decreasing inputs and/or increasing outputs using the projection formula proposed by Tone (2001) [see equation (3)].

Model (2) rates 25 efficient universities (DMUs # 1, #2, #3, #4, #7, #9, #10, #12, #15, #17, #18, #20, #22, #23, #24, #25, #26, #27, #29, #31, #33, #34, #35, #38, and #4). The other DMUs are considered inefficient. In addition, the SBM model can identify benchmarking for the inefficient universities to improve their performance. Their benchmarks are tabulated in Table 3. For example, efficient DMU# 4 is a benchmark for inefficient DMU# 8. The benchmark is based on an intensity value (i.e., λ_j^*). The value of 0 ($\lambda_j^* = 0$) reflects that an efficient university '*j*' cannot be a benchmark for an inefficient university. For example, efficient DMU# 1 cannot be a benchmark for any inefficient DMU. In contrast, the positive intensity value ($\lambda_j^* > 0$) reflects that an efficient university '*j*' can be a benchmark for an inefficient university. For example, efficient DMU# 7 is a benchmark for inefficient DMUs #8 and #37. The last row of Table 3 presents the number of times that each efficient university is benchmarked. For example, DMUs #1, #2, #3, #9, #24, # 27, #29, #31 and #34 are not benchmarked by any inefficient universities. DMUs #4, #7, #10, #17, #18, #20, #22, #25, #33, #38 and #41 are benchmarked by few inefficient universities with low number of intensity values. The top three referenced universities are DMUs #23, #26 and #35. They are respectively, benchmarked by inefficient DMUs #14, #8 and #5. The top referenced university DMU#23 has the highest level of educational resources.

Table 4 reports the efficient targets and the actual data for the considered inputs and outputs, calculated by equation (3), for each inefficient university. The targets of some inefficient universities (e.g., DMUs #5, #14, #16, #19, #21, #28, #30, #32, #36 and #40) for the domestic academic staff, graduates, published papers and patents are the same as their actual input and outputs. This indicates that educational performance of these inefficient universities regarding their input and outputs is close to targeted efficiency. In contrast, the targets and the actual data of DMUs #14, #16, #19, #21, #28, #30, #32, #36, #37, #39 and #40 for the input of domestic students and the outputs of received financial amounts and cooperating foreign countries are large difference. This indicates that these universities are the most inefficient units regarding the input and outputs. In fact, a large difference between the target and the actual output of cooperating foreign countries is observed for all inefficient universities. This reflects that all of the inefficient universities are most inefficient regarding their output of cooperating foreign countries.

Due to the non-oriented feature of the SE-SBM model, benchmarking can simultaneously identify the optimum level of educational resources used and educational outcomes produced to improve DMUs. Benchmarking can also help decision makers find the closest targets required to achieve efficiency from both sides of input reduction and output augmentation. Information provided by the targets can generally be used to suggest potential directions for inefficient universities to improve their educational performance. For example, the most crucial factor of inefficiency of all inefficient universities in the case study is the number of cooperating foreign countries. Hence, to achieve efficiency, the number must be extended by all the inefficient universities. We deduce that research and teaching universities in Taiwan are weak in their cooperating with other foreign universities over the examined period.

Table 2 Efficiency measures of Taiwanese universities

DMU	*Efficiency score*	*Super efficiency score*	*Rank*	*DMU*	*Efficiency score*	*Super efficiency score*	*Rank*	*DMU*	*Efficiency score*	*Super efficiency score*	*Rank*
1	1,000	1,241	7	15	1,000	1,016	25	29	1,000	1,067	17
2	1,000	1,539	2	16	0.599	1,000	31	30	0.609	1,000	27
3	1,000	1,046	20	17	1,000	1,198	11	31	1,000	1,037	22
4	1,000	1,071	16	18	1,000	1,080	14	32	0.499	1,000	35
5	0.5763	1,000	32	19	0.488	1,000	38	33	1,000	1,552	1
6	0.4968	1,000	36	20	1,000	1,042	21	34	1,000	1,035	23
7	1,000	1,062	18	21	0.492	1,000	37	35	1,000	1,175	12
8	0.5747	1,000	33	22	1,000	1,418	3	36	0.508	1,000	34
9	1,000	1,031	24	23	1,000	1,218	8	37	0.481	1,000	39
10	1,000	1,077	15	24	1,000	1,096	13	38	1,000	1,394	4
11	0.299	1,000	41	25	1,000	1,208	10	39	0.711	1,000	28
12	1,000	1,213	9	26	1,000	1,242	6	40	0.700	1,000	29
13	0.904	1,000	26	27	1,000	1,061	19	41	1,000	1,268	5
14	0.613	1,000	30	28	0.460	1,000	40				

Table 3 Inefficient universities and intensity values of their benchmarks

Inefficient universities	*DMUs*	*Efficient universities*																								
		1	*2*	*3*	*4*	*7*	*9*	*10*	*12*	*15*	*17*	*18*	*20*	*22*	*23*	*24*	*25*	*26*	*27*	*29*	*31*	*33*	*34*	*35*	*38*	*41*
	5	0	0	0	0	0	0	0.239	0	0	0	0	0	0	0.486	0	0	0.022	0	0	0	0	0	0.271	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.474	0	0	0.525	0	0	0	0	0	0	0	0
	8	0	0	0	0.015	0.460	0	0	0.228	0	0	0	0	0	0.295	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0.054	0.026	0	0.006	0	0	0	0	0.233	0	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0.343	0	0	0.591	0	0	0	0	0	0	0.025	0
	14	0	0	0	0	0	0	0	0	0	0	0	0.379	0	0.269	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0.080	0.285	0	0	0	0.255	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0.287	0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0.065	0.043	0	0	0	0.495	0	0	0	0	0	0	0	0	0	0	0
	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0.195	0	0	0.317	0	0	0	0	0	0.486	0	0
	30	0	0	0	0	0	0	0	0	0.084	0	0	0	0	0.181	0	0	0	0	0	0	0	0	0.733	0	0
	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0.108	0	0	0.211	0	0	0	0	0	0.009	0	0
	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0.129	0	0	0.633	0	0	0	0	0	0.057	0	0
	37	0	0	0	0	0.249	0	0	0	0	0	0	0	0	0.113	0	0	0.636	0	0	0	0	0	0	0	0
	39	0	0	0	0	0	0	0	0.079	0	0	0	0	0	0	0	0	0.460	0	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0	0.409	0	0	0	0	0	0.102	0	0.225	0	0	0	0	0	0	0	0	0.263
Number of times as referent		*0*	*0*	*0*	*1*	*2*	*0*	*1*	*3*	*3*	*2*	*1*	*2*	*1*	*14*	*0*	*2*	*8*	*0*	*0*	*0*	*1*	*0*	*5*	*1*	*1*

Table 4 Actual data and targets of inefficient universities

Inefficient university		*Inputs*			*Outputs*				
		x_1	x_2	x_3	y_1	y_2	y_3	y_4	y_5
		No. of domestic staff	*No. of international staff*	*No. of domestic students*	*No. of graduates*	*No. of published articles*	*Received financial amounts*	*No. of patents*	*No. of Cooperating foreign countries*
5	Data	326	413	9,928	2,335	0	30	0	13
	Target	326	116,836	9,928	2,335	0	44,394	0	19,250
6	Data	501	174	12,239	2,592	0	31	0	11
	Target	388,488	146,466	11,655.32	2,592	0	56,128	0	25,965
8	Data	515	206	10,502	2,328	0	65	0	8
	Target	394,710	206	10,502	2,363.046	0	65	0	22,388
11	Data	292	45	7,404	1,346	193	16	0	4
	Target	292	45	5,967.979	1,346	1,741.964	20.16038	0	4.758274
13	Data	228	79	6,128	1,309	0	26	0	12
	Target	204.1840	73,455	6,128	1,340.527	0	26	0	13,187
14	Data	524	591	17,604	3,762	0	47	0	14
	Target	524	458,619	16,030.18	3,762	0	58,755	0	29,809
16	Data	443	344	15,934	3,324	0	26	0	13
	Target	443	327,724	15,004.18	3,324	0	61,112	0	19,205
19	Data	742	1,334	26,924	5,651	0	26	0	18
	Target	742	1,334	24,132.69	5,651	0	71,523	0	39,281

Table 4 Actual data and targets of inefficient universities (continued)

Inefficient university		Inputs			Outputs				
		x_1	x_2	x_3	y_1	y_2	y_3	y_4	y_5
		No. of domestic staff	*No. of international staff*	*No. of domestic students*	*No. of graduates*	*No. of published articles*	*Received financial amounts*	*No. of patents*	*No. of Cooperating foreign countries*
21	Data	371	569	12,357	2,690	0	22	0	19
	Target	371	275,738	11,874.39	2,690	0	60,014	0	23,421
28	Data	316	315	10,886.52	2,364	0	11	0	11
	Target	316	83,776	10,895	2,364	0	25,391	0	17,725
30	Data	387	271	14,733	3,160	0	12	0	13
	Target	387	245,867	14,506.02	3,160	0	26,769	0	19,649
32	Data	370	62	10,732	2,430	0	9	0	5
	Target	370	62	10,607.93	2,430	0	22,712	0	12,322
36	Data	325	78	11,324	2,153	0	8	0	10
	Target	325	78	9,963.875	2,153	0	24.38053	0	16,127
37	Data	294	280	8,870	1,749	0	11	0	18
	Target	294	127,464	8,705.706	1,840.372	0	33.0441	0	18
39	Data	233	29	6,668	936	0	9	0	4
	Target	228,543	29	6,498.200	1,435.987	0	9	0	6,490
40	Data	355	50	10,080	2,220	0	13	0	7
	Target	355	50	9,394.980	2,220	0	27.84432	0	7,289

5 Conclusions

The radial super efficiency model can technically discriminate efficient and inefficient units, and then rank the efficient units. However, the model may face an infeasibility issue in some cases of the VRS technology. To address this issue, an SE-SBM model that can simultaneously deal with the slacks of input excesses and output shortfalls, as well as the slacks of input saving (the amount of inputs that can be increased to achieve the feasibility) and output surplus (the amount of outputs that can be decreased to achieve the feasibility), was proposed by Tone (2002). The model discriminates efficient and inefficient DMUs and ranks high performing DMUs via a two-stage procedure. This paper utilises the SE-SBM model to measure the efficiency of 41 research and teaching universities in Taiwan.

The empirical results showed that of the 41 universities, 25 universities achieved the super efficiency status since they could increase their educational inputs and/or decrease their educational outputs simultaneously to achieve the feasibility. The SE-SBM model offers a higher power in discriminating among efficient universities over the radial model since it considers the slacks of inputs and outputs. In addition, the ranking of efficient and inefficient universities was performed. The top ranked university (i.e., DMU#33) reflects its ability to increase its educational inputs and/or decrease its educational outputs better than the other efficient universities enhances it to preserve the super efficiency status. In contrast, the lowest ranked university (i.e., DMU#11) reflects that it has a significant gap between the actual data and targets of its numbers of domestic students and published articles compared with other inefficient universities. This information would be useful for decision makers of the Taiwanese universities to develop new strategies and policies to maintain the status of efficient universities.

In addition, the SBM model identified benchmarking and target setting for each inefficient university to improve the consumption of its educational inputs and the production of its educational outputs by identifying the optimum levels of inputs and outputs. Based on the benchmarking and target setting, decision makers can identify the closest target required by the inefficient universities to achieve the efficiency status and then suggest various strategies for their efficiency improvement. As a matter of fact, all of the efficiency measures were calculated in terms of VRS technology. If this technology was dropped from the model by ignoring the convexity constraint, it would then be run under the CRS technology to calculate the scale efficiency of the evaluated universities to determine whether they are operating at their optimal sizes or not.

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Notes

1 Any reduction in inputs or augmentation in outputs is impossible unless worsening other inputs or outputs.