A Study for Relative Efficiency of Taiwan Water Corporation's Branches

Ming-Te Liu[1*] and Chun-Ju Lee[2]
Department of Business Administration, China University of Technology, Taiwan[1]
Water Quality Section, Third Branch, Taiwan Water Corporation, Taiwan[2]
mtliu@cute.edu.tw[1], leecl0628@gmail.com[2]
*Corresponding Author

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Abstract

This study applied data envelopment analysis (DEA) models to conduct a comparative analysis of various Taiwan Water Corporation (TWC) branches in terms of pure technical efficiency, scale efficiency, and cross-efficiency using operational data on 12 TWC branches for 2015–2016. The four DEA models comprise different combinations of five inputs (water supply consumers, distributed water quantity, personnel expense, cost of water delivery, and cost of water sold) and three outputs (percentage of revenue water, quantity of water sold per employee, and water sales revenue). To the best of the authors' knowledge, studies are yet to use the costs of water delivery and water sold as inputs to examine branch-level efficiency.

Given the challenges of data deficiencies, we conducted the comparative analysis by compiling data on the costs of water delivery and water sold at the branch level. Further, we conducted analyses with and without the two inputs. In addition, to evaluate the effects of changes in outputs, we used the quantity of water sold per employee as an output since TWC, a state-owned enterprise, is relatively constant in its organizational structure, and more importantly, in its staffing. The models comprising different combinations of inputs and outputs were used to analyze the relative efficiency and efficiency ranking of different TWC branches.

This study's empirical results indicate that both adding the costs of water delivery and water sold as inputs and changing outputs influence branches' relative efficiency across different models. We further analyzed each branch's efficiency level using CEM and found that the efficiency rankings in all the models for both years were affected. For 2015, the intersection among branches with relatively high efficiency (PTE and SE=1) suggests that the top-five branches (2, 3, 6, 8, and 12) could be clustered. These branches report relatively high efficiency in terms of pure technical efficiency, scale efficiency, and cross-efficiency. For 2016, the intersection among branches with relatively high efficiency indicates that the top-three branches (3, 8, and 12) could be clustered. These branches also show relatively high efficiency in terms of pure technical efficiency, scale efficiency, and cross-efficiency. In general, regularity in the influence of the inputs on outputs could not be confirmed.

Keywords: Taiwan Water Corporation, data envelopment analysis, water delivery cost, water sale cost, relative efficiency

1. Introduction

Taiwan Water Corporation (TWC) is a state-owned enterprise that is operated under the governance and supervision of Congress authorities and thus, its production and pricing inherently differ from those of private businesses; moreover, the policy tasks and corporate social responsibilities are unique to TWC. Therefore, a method that objectively measures operational performance would benefit TWC in improving its revenue and ability to contribute to the national treasury in the capacity expected of a state-owned enterprise. At present, TWC has 12 geographically demarcated branches that are regionally operated and centrally administered. However, regional differences and political factors affect these branches, making consistent performance appraisals rather difficult. This study, thus, attempts to measure and compare the efficiency of these TWC branches from an input–output perspective with the objective of stimulating overall operational performance.

To do so, we use data envelopment analysis (DEA) models to measure the relative efficiency of the TWC branches, treating each branch as an individual decision-making unit (DMU), and perform DEA using select inputs and outputs. For the DEA analysis, we compiled published and unpublished data on TWC for 2015 and 2016. Relative efficiency is composed of pure technical efficiency, scale efficiency, and cross-efficiency. We use cross-efficiency to analyze each branch's efficiency level and ranking. Unlike existing studies, we adopt the branch-level costs of water delivery and water sold as inputs and change outputs to form four models with different combinations of inputs and outputs, thus enabling the analysis of 12 branches' relative efficiency. Further, we discuss the impact of different inputs and outputs on relative efficiency and examine variations in branches' efficiency ranking using the aforementioned models. The results identify the efficiency level of leading branches, which will serve as a benchmark for authorities in output goal planning and input resource allocation.

2. Literature Review

2.1 Data Envelopment Analysis (DEA) and Efficiency Level

Drawing on Farrell's (1957) predictive theory, Charnes, Cooper, and Rhodes (1978) proposed the data envelopment analysis to measure production efficiency. However, predictive theory includes non-predictive production functions, and thus, is applicable to only cases with a single output. Thus, Charnes, Cooper, and Rhodes added the concept of linear programming and setup an efficiency-measuring model that could measure multiple inputs and outputs for decision-making units (DMUs), calling it data envelopment analysis; it is also known as the Charnes, Cooper, and Rhodes (CCR) model. The efficiency level obtained using the CCR model is called total technical efficiency (TTE), which emphasizes fixed-scale efficiency (FSE). In other words, every unit of input added increases one unit of output.

Banker, Charnes, and Cooper (1984), however, showed that an increase in input does not necessarily lead to a rise in output. Further, they argued that the CCR model fails to explain that an inefficient decision-making unit is attributable to technical or scale inefficiency. Thus, the authors developed the Banker, Charnes, and Cooper (BCC) model to measure efficiency using variable returns to scale (VRS). The BCC model not only calculates pure technical efficiency (PTE) and scale efficiency (SE), but also evaluates if the returns to scale (RTS) classifies as increasing returns to scale (IRS), constant returns to scale (CRS), or decreasing returns to scale (DRS). Multiplying pure technical efficiency (PTE) by scale efficiency (SE), which is estimated using the BCC model, determines the total technical efficiency (TE) of the CCR model.

Sun (2004) highlighted that by conducting a DEA, actual data can be compared with a DMU's production frontier using a mathematical model to measure its relative efficiency and inefficiency and the results highlight ways to improve relative efficiency. Nevertheless, it is impossible to identify truly efficient DMUs solely on the basis of relative efficiency measures or input and output weight estimations. To address this problem, Sexton, Silkman, and Hogan (1986) proposed a cross-efficiency measure (CEM), although it is subject to bias when comparing DMUs using subjective evaluations. As a remedy, Doyle and Green (1994) introduced average per assessment.

CEM was primarily designed to identify truly efficient DMUs by applying optimal weights selected by other assessed DMUs and estimate the average; thus, it is also known as the measurement of average peer efficiency. Cross-efficiency entails the maximizing of self-assessment efficiency, the minimizing of other DMUs' efficiency level, and the use of a cross-efficiency matrix to calculate average peer efficiency to obtain the efficiency ranking of certain DMUs. Golany and Roll (1989) summarize three main steps for DEA-based efficiency assessment: define and select DMUs; select and verify DMUs' inputs and outputs; and conduct a DEA to calculate the relative efficiency and efficiency levels and accordingly, analyze the results.

2.2 Taiwan Water Corporation (TWC)

Established in 1974, TWC is the largest tap water supplier in Taiwan. The Corporation initially belonged to the Taiwan Provincial Government; however, as a result of provincial downsizing, in 1999, it changed from a province-owned enterprise to a state-owned one under the supervision of the Ministry of Economic Affairs. Later, in 2007, it was formally renamed to Taiwan Water Corporation and since, has been operating according to the Administrative Law of State-Owned Enterprise. TWC is regionally operated and centrally administrated and has one head office, 12 branches, and three regional engineering offices, which is in line with organizational regulations for divisions of work including water treatment, water supply, water delivery and sales, user services, and construction supervision.

In recent years, global climate changes, environmental challenges, and increased consumer awareness have led to greater quality and quantity demands for tap water in Taiwan. Given these difficulties, it is critical for TWC to uphold its responsibility of stable water supply. According to a Central News Agency report (May 9, 2018), the water tariff in Taiwan is lower than those in other countries. In fact, at the international level, the average water fee in Taiwan is the third lowest and the charges for industrial water are even lower. This is because the water tariff does not account for excavation costs and has violated the user charge principle. In addition, the high penetration rate of tap water has considerably increased the maintenance costs of water supply facilities and pipes in Taiwan. On the other hand, it is inappropriate to increase the amount of water sold owing to water conservation. In sum, the abovementioned factors increase water sales revenue but at the same time, render operational performance increasingly challenging.

2.3 Application of DEA to TWC Performance

Research on water utility largely focuses on water tariff structures, reasonable water tariffs, leakage prevention and control, privatization, and improvement in production technology. By contrast, few studies have been conducted on TWC's operational efficiency (Lin and Chiu, 2016). These exceptions include Tsai (2002), Chang (2004), Chuang and Chang (2004), Hsu (2006), and Lin (2016) (see Table 1). However, these analyses do not account for the costs of water delivery and water sold at the branch level, which are key factors influencing operational performance. While TWC is a state-owned enterprise, its branches function under a central administrative system. Thus, we assert that only DEAs considering the costs of water delivery and water sold as inputs can effectively identify all key factors affecting the operational efficiency of TWC's branches.

Table 1: Inputs and Outputs Used in Studies on TWC's Operational Efficiency

Researchers	Inputs	Outputs
Tsai (2002)	personal expense, total assets, production cost, operating expense, other costs	operating revenue, penetration rate
Chang (2004)	head count, fixed assets	metered water consumption, water supply consumers, water sales revenue
Chuang & Chang (2004)	head count, fixed assets	metered water consumption, water supply consumers, water sales revenue
Hsu (2006)	personnel expense, material costs, repair and maintenance expenses, depreciation and amortization expense	water sales revenue
Lin (2016)	personnel expense, repair and maintenance expense	operating revenue, leakage ratio

3. Methods

3.1 Research Framework

This study investigates the operational efficiency of TWC's 12 branches using an empirical research framework that involves the selection of DEA models and variables, an efficiency analysis, and an examination of the results (Figure. 1).

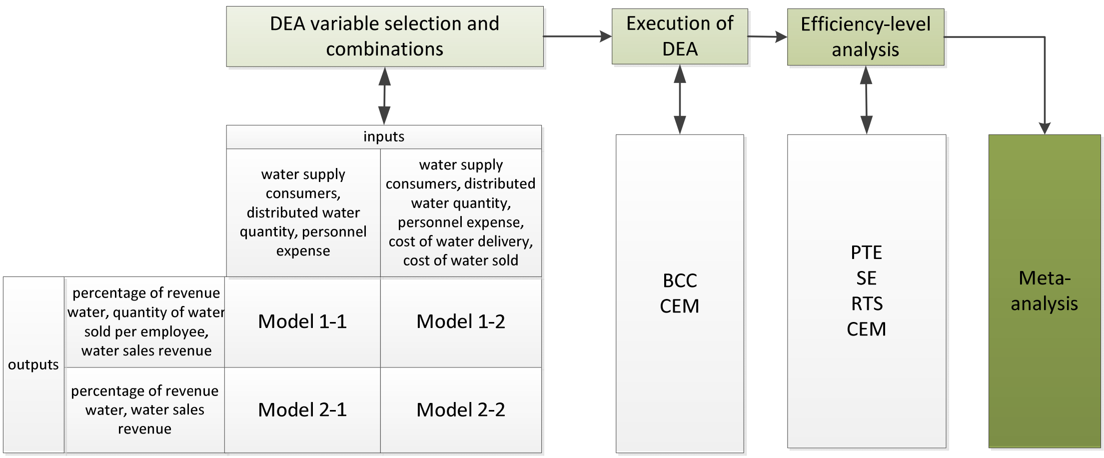

Figure 1: Research Frame

3.2 Subjects and Data Sources

This study conducts an efficiency analysis of 12 TWC branches. Data are for 2015–2016 and from the following sources: TWC subsidiaries' annual reports (March 18–19, 2018), statistical yearbook for TWC (March 20–21, 2018), and TWC's cost reports on water supply systems for 2015 and 2016.

3.3 Design and Application of DEA Models

3.3.1 Variable Selection and Definitions

To measure the operational efficiency of each branch, this study selects water supply consumers, distributed water quantity, personnel expense, the branch-level cost of water delivery, and the branch-level cost of water sold as inputs and the percentage of revenue water, the quantity of water sold per employee, and water sales revenue as outputs.

We define the five inputs as follows. Water supply consumers are represented by the number of households using metered tap water. Distributed water quantity is the amount of water supplied by TWC's water supply system (water treatment plant) within a certain time period to meet the demands of its served area. Personnel expenses include employee wages, overtime remuneration, bonuses, allowances, benefits, retirement and reparation payments, and severance pay and contribution. The branch-level costs of water delivery is estimated as the sum of the costs for raw water, water treatment, water delivery, and marketing and administration; the branch's apportioned expenses; and water supplied by the branch within a certain time period. Finally, the branch-level costs of water sold is the sum of the costs for raw water, water treatment, water delivery, and marketing and administration; the branch's apportioned expenses; and water sold by the branch within a certain time period.

Following are the definitions for output. Percentage of revenue water is the aggregate of the percentages of water delivery for support and water sold in the sum of water yielded and water received for support. Quantity of water sold per employee is the amount of water sold divided by the number of employees. Water sales revenue is the income generated from metered water consumption, including revenue generated from basic fees, water sold, and water stations. Water sales revenue is the key operating revenue for TWC given than water sale is its core business.

3.3.2 Variable Combinations

We combine five input and three output variables into four models (models 1-1, 1-2, 2-1, and 2-2). Table 2 lists the inputs and outputs used in each model.

Table 2: Inputs and Outputs Used in Each Model

Variables \ Model	Model 1-1	Model 1-2	Model 2-1	Model 2-2
inputs				
water supply consumers	√	√	√	√
distributed water quantity	√	√	√	√
personnel expense	√	√	√	√
cost of water delivery		√		√
cost of water sold		√		√
outputs				
percentage of revenue water	√	√	√	√
quantity of water sold per employee	√	√		
water sales revenue	√	√	√	√

3.3.3 Execution of DEA

We use variable returns to scale (VRS) from the BCC model to determine pure technical efficiency (PTE), scale efficiency (SE), and RTS. Then, we apply CEM to measure the efficiency level of each branch, thereby identifying the truly efficient DMU.

4. Empirical Results

4.1 Basic Descriptive Statistical Analysis

Table 3 summarizes the basic descriptive statistical analysis on the inputs and outputs of various branches, in particular, the average, standard deviation, and maximum and minimum of each variable. Notably, the statistical differences for each variable in the same year are insignificant.

4.2 Efficiency-level Analysis

This study uses the Distributed Evolutionary Algorithms in Python (DEAP) software program to execute the BCC method and determine the PTE, SE, and relative efficiency levels. A branch whose relative efficiency level is less than 1 is deemed relatively inefficient, whereas a branch that reports a value of 1 is considered to be relatively efficient. The BCC model also estimates RTS and its trend. We write linear planning models to calculate the weights of DMUs in CEM and assess the average peer efficiency level. Table 4 presents the efficiency levels measured using DEA.

4.2.1 Pure Technical Efficiency

In the BCC model, the PTE value determines if an input is effectively used to maximize output: the greater the PTE value, the more efficient is the input use. We incorporate the costs of water delivery and water sale as input in all the models. The result show that, for both 2015 and 2016, the PTE values of branches 1, 4, 5, and 11 increased, while those of the remaining eight efficient branches (2, 3, 6–10, and 12) remain unchanged (Table 4).

4.2.2 Scale Efficiency

Scale efficiency is the ratio of TTE to PTE, indicating the relationship between a branch's input and its optimal production-scale input at a known output level. A scale with a higher SE value is considered more appropriate in terms of size and is closer to the optimal scale. Table 4 shows that adding the costs of water delivery and water sold as inputs decreases the SE values of three branches (1, 5, and 11), while those of the other branches increase or remain unchanged. For both years, adding the costs for water delivery and water sold as inputs as well as changes in outputs cause the SE values to vary, although these variations appear to be irregular.

4.2.3 Returns to Scale

In terms of efficiency level, branches can report increasing, decreasing, or constant returns to scale. As shown in Table 4, after adding the costs of water delivery and water sold as inputs, the results of all the models for 2015 indicate that branches 1, 5, and 11 were in the increasing returns-to-scale stage, whereas the remaining nine were in the constant returns-to-scale stage. The results for 2016 suggest that branches 1, 5, and 11 were in the increasing returns-to-scale stage, one (branch 6) was in the decreasing returns-to-scale stage, and the remaining eight were in the constant returns-to-scale stage.

4.2.4 Cross-efficiency

Table 4 also presents the CEM ranking for TWC's branches. For 2015, Model 1-1 lists branches 8, 3, 12, 2, and 6 as the top-five branches. After adding the costs of water delivery and water sold as inputs, the top-five branches as per Model 1-2 are branches 12, 3, 6, 8, and 2 and according to Model 2-1, they are branches 8, 12, 3, 6, and 2. In Model 2-2, changes to outputs result in branches 6, 3, 8, 2, and 12 ranking among the top five. For 2016, branches 8, 9, 3, 12, and 10 are the top-five branches as per Model 1-1, and after adding the costs of water delivery and water sold as inputs, the top-five branches are branches 12, 3, 6, 2, and 8 according to Model 1-2. Finally, the top-five branches according to Model 2-1 are branches 8, 9, 10, 3, and 12, and following changes to the outputs, the top-five branches as per Model 2-2 are branches 3, 6, 2, 12, and 8.

Table 3: Basic Descriptive Statistical Analysis of Inputs and Outputs

Research Variable \ Analysis Item	Unit	Year	Average	Standard Deviation	Maximum	Minimum
Water Supply Consumers	1,000 households	2015	563	358	1,177	66
		2016	573	364	1,194	66
Distributed Water Quantity	1,000 m^3	2015	259,909	188,005	632,661	26,553
		2016	263,124	188,766	632,053	27,880
Personnel Expense	1,000 NTD	2015	208,383	119,612	428,275	63,329
		2016	203,451	118,275	425,794	61,019
Branch-level Cost of Water Delivery	NTD / m^3	2015	8.525	1.908	12.684	5.205
		2016	8.338	1.965	12.327	5.106
Branch-level Cost of Water Sold	NTD / m^3	2015	11.694	3.275	19.358	7.617
		2016	11.381	3.353	18.963	7.355
Percentage of Revenue Water	%	2015	74.48	5.88	82.81	63.43
		2016	74.43	5.56	81.01	64.19
Quantity of Water Sold Per Employee	m^3	2015	444	205	839	125
		2016	454	204	832	128
Water Sales Revenue	1,000 NTD	2015	2,137,604	1,557,091	5,383,890	181,419
		2016	2,183,849	1,578,358	5,395,084	189,111

Table 4: Efficiency-level Analysis for the Four DEA Models

Branches	2015								2016							
	Model 1-1				Model 1-2				Model 1-1				Model 1-2			
	PTE	SE	RTS	CEM (Ranking))	PTE	SE	RTS	CEM (Ranking)	PTE	SE	RTS	CEM (Ranking)	PTE	SE	RTS	CEM (Ranking)
1	0.818	0.999	-	0.708(11)	0.931	0.885	IRS	0.661(11)	0.822	0.996	IRS	0.689(11)	0.916	0.894	IRS	0.641(11)
2	1.000	1.000	-	0.867(4)	1.000	1.000	-	0.777(5)	1.000	1.000	-	0.809(6)	1.000	1.000	-	0.790(4)
3	1.000	1.000	-	0.891(2)	1.000	1.000	-	0.849(2)	1.000	1.000	-	0.838(3)	1.000	1.000	-	0.868(2)
4	0.844	0.977	DRS	0.684(12)	1.000	1.000	-	0.667(10)	0.864	0.960	DRS	0.641(12)	1.000	1.000	-	0.683(10)
5	0.917	0.999	DRS	0.713(10)	0.922	0.995	IRS	0.740(8)	0.910	1.000	-	0.693(10)	0.911	0.999	IRS	0.742(7)
6	1.000	1.000	-	0.860(5)	1.000	1.000	-	0.848(3)	1.000	0.976	DRS	0.781(7)	1.000	0.991	DRS	0.833(3)
7	1.000	0.966	DRS	0.793(7)	1.000	1.000	-	0.726(9)	1.000	0.948	DRS	0.727(9)	1.000	1.000	-	0.735(8)
8	1.000	1.000	-	0.922(1)	1.000	1.000	-	0.842(4)	1.000	1.000	-	0.942(1)	1.000	1.000	-	0.772(5)
9	1.000	1.000	-	0.828(6)	1.000	1.000	-	0.755(7)	1.000	1.000	-	0.900(2)	1.000	1.000	-	0.692(9)
10	1.000	1.000	-	0.787(8)	1.000	1.000	-	0.638(12)	1.000	1.000	-	0.818(5)	1.000	1.000	-	0.549(12)
11	0.902	1.000	-	0.755(9)	0.967	0.977	IRS	0.763(6)	0.905	1.000	-	0.741(8)	0.986	0.984	IRS	0.748(6)
12	1.000	1.000	-	0.871(3)	1.000	1.000	-	0.865(1)	1.000	1.000	-	0.832(4)	1.000	1.000	-	0.873(1)
Branches	**Model 2-1**				**Model 2-2**				**Model 2-1**				**Model 2-2**			
1	0.816	0.985	IRS	0.718(11)	0.931	0.863	IRS	0.657(11)	0.820	0.992	IRS	0.690(11)	0.916	0.889	IRS	0.641(11)
2	1.000	1.000	-	0.867(5)	1.000	1.000	-	0.778(4)	1.000	1.000	-	0.808(6)	1.000	1.000	-	0.789(3)
3	1.000	1.000	-	0.887(3)	1.000	1.000	-	0.847(2)	1.000	1.000	-	0.838(4)	1.000	1.000	-	0.868(1)
4	0.843	0.978	DRS	0.698(12)	1.000	1.000	-	0.671(10)	0.864	0.960	DRS	0.640(12)	1.000	1.000	-	0.686(10)
5	0.917	0.999	DRS	0.739(10)	0.922	0.995	IRS	0.738(8)	0.910	1.000	-	0.694(10)	0.911	0.999	IRS	0.747(7)
6	1.000	1.000	-	0.874(4)	1.000	1.000	-	0.848(1)	1.000	0.976	DRS	0.780(7)	1.000	0.991	DRS	0.835(2)
7	1.000	0.966	DRS	0.810(7)	1.000	1.000	-	0.736(9)	1.000	0.948	DRS	0.727(9)	1.000	1.000	-	0.740(8)
8	1.000	1.000	-	0.920(1)	1.000	1.000	-	0.829(3)	1.000	1.000	-	0.946(1)	1.000	1.000	-	0.772(5)
9	1.000	0.985	DRS	0.834(6)	1.000	1.000	-	0.748(7)	1.000	1.000	-	0.920(2)	1.000	1.000	-	0.702(9)
10	1.000	1.000	-	0.801(8)	1.000	1.000	-	0.648(12)	1.000	1.000	-	0.851(3)	1.000	1.000	-	0.570(12)
11	0.902	0.998	DRS	0.772(9)	0.967	0.977	IRS	0.755(6)	0.905	0.999	DRS	0.744(8)	0.986	0.984	IRS	0.749(6)
12	1.000	1.000	-	0.889(2)	1.000	1.000	-	0.772(5)	1.000	1.000	-	0.832(5)	1.000	1.000	-	0.781(4)

4.2.5 Meta-analysis

This section summarizes the conclusions derived from the analysis presented thus far. First, we discuss the results for branches' operational efficiency assessed on the basis of pure technical efficiency (PTE). In both years, we added the costs of water delivery and water sold as inputs and found that doing so increased the branches' PTE values, although this addition had no effect on the branches whose efficiency levels were already high. In addition, changing the outputs, excluding the percentage of revenue water per employee, had a limited influence on the PTE values. Second, in terms of branches' operational efficiency assessed by scale efficiency, the results suggest irregular SE variations across both years. Further, we observed that adding the costs of water delivery and water sold as inputs influenced TWC's SE values and changing the outputs significantly impacted the PTE values. Third, we examined the operational efficiency of branches on the basis of returns to scale (RTS). The results indicate that, in both years, adding the costs of water delivery and water sold as inputs and changing the outputs significantly influenced TWC's RTS values.

Finally, our analysis of the branches' operational efficiency using cross-efficiency revealed the following results. Across the models for 2015, the intersection among the branches with relatively high efficiency (PTE and SE=1) suggests that the top-five branches are the same (branches 2, 3, 6, 8, and 12), albeit in different orders. In the models for 2016, which includes the costs of water delivery and water sold as inputs, the intersection among branches with relatively high efficiency highlight the top-five branches, although among these branches, only three are constant (branches 3, 8, and 12; see Table 5). Further, the incorporation of the costs of water delivery and water sold as inputs in the 2016 model influenced not only the order of the top-five branches but also that of the remaining branches. By contrast, changing the outputs only impacted the order of the top-five branches. The results for all the top-five branches, except for branch 6, are consistent with those of PTE; branch 6's SE value for 2016 indicates low relative efficiency.

Table 5 Results for the Intersection of Models Among Branches with Relatively High Efficiency (PTE and SE=1)

	2015	2016
Model 1-1	8, 3, 12, 2, 6	8, 9, 3, 12, 10
Model 1-2	8, 12, 3, 6, 2	12, 3, 6, 2, 8
Model 2-1	12, 3, 6, 8, 2	8, 9, 10, 3, 12
Model 2-2	6, 3, 8, 2, 12	3, 6, 2, 12, 8

6. Conclusions

This study's empirical results indicate that both adding the costs of water delivery and water sold as inputs and changing outputs influence branches' relative efficiency across different models. To elucidate branches' levels of efficiency and ranking, we further analyzed each branch's efficiency level using CEM and found that the efficiency rankings in all the models for both years were affected. For 2015, the intersection among branches with relatively high efficiency suggests that the top-five branches (2, 3, 6, 8, and 12) could be clustered. These branches report relatively high efficiency in terms of pure technical efficiency, scale efficiency, and cross-efficiency. For 2016, the intersection among branches with relatively high efficiency indicates that the top-three branches (3, 8, and 12) could be clustered. These branches also show relatively high efficiency in terms of pure technical efficiency, scale efficiency, and cross-efficiency. In general, regularity in the influence of the inputs on outputs could not be confirmed.

In addition, the models formed using different inputs and outputs suggested varying analytic results for relative efficiency. This is supported by our analysis results. In other words, the relative efficiency of the assessed TWC branches highly depends on the combinations of variables forming the models. For instance, the costs of water delivery and water sold as inputs impacted the branches' operational performance.

This study is not free from limitations. We only prove that the addition led to changes in relative efficiency, particularly CEM efficiency rankings. We recommend that authorities use comprehensive data available to them to further verify the influence of inputs, such as the costs of water delivery and water sold, on the relative efficiency and efficiency levels. In addition, we suggest they perform an annual comparison of the impact of the two inputs on performance to improve the operational performance of the state-owned enterprise with limited resources.

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About Authors

Ming-Te Liu is a Professor in the Department of Business Administration at China University of Technology. He has published refereed papers in Online Information Review, Asia Pacific Management Review, Journal of Customer Satisfaction, Neural Computing and other Chinese management journals. His research interests include marketing management, consumer behavior and service management.

Chun-Ju Lee is a Clerk in the Water Quality Section of the Third Branch at Taiwan Water Corporation.