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Water efficiency of counties and cities in Taiwan

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Abstract: This paper computes the total-factor water efficiency of nineteen Taiwan's administrative regions during 2004-2015. The non-oriented slack-based data envelopment analysis (SBM-DEA) with undesirable outputs model proposed by Tone and Tsutsui (2011) is used. There are six inputs (employment, local government expenditure, household and commercial electricity, industrial electricity, residential water, and productive water), two undesirable outputs (SO_2 and sewage), and one desirable output (regional GDP). The target/actual input ratio as the total-factor water efficiency is applied to compute water efficiency scores of Taiwan's regions. Generally speaking, Taiwan has been very water inefficient. Its average water efficiency scores for productive use and residential use are 0.430 and 0.603, respectively, The north regions, which has higher proportion of high output value industry, are relatively much more efficient than the ones in other areas with respect to both productive and residential water inputs.

Key words: Slacks-based model (SBM); data envelopment analysis (DEA); disaggregate input efficiency; water efficiency.

1. INTRODUCTION

Water conservation is a serious sustainability issue in the world and has been a growing concern accompanied by economic development in recent years. Therefore, the effective water conservation is necessary for both improving corporate competitiveness in modern business and reducing water costs for consumers. The conservation of water resources is highly beneficial to sustainable development. Such benefits from the improved water efficiency have been incorporated into corporate strategy of firms and water policy of economies.

Water is an essential natural resource to most economic production and people's daily life. Water crucially influences economic growth directly. Figure 1 shows that the water demand in Taiwan grows, reaching a peak in 2013. The precipitation in Taiwan is 2.6 times higher than the world average. However, there are three special conditions that make each person is allotted not even 1/5 of water resources, turning Taiwan into the 19th country deficient in water around the world (Water Resource Agency, MOEA, 2013). One is the unique climatic condition, which is characterized by the unbalanced time of perception. During the flood season (May to September) the precipitation all over Taiwan reaches 70% (Water Resource Agency, MOEA, 2013). Another is the special physiographic condition, steep topography which makes the perception flows into the ocean rapidly. The other is the geography of Taiwan which is on east-pacific typhoon route. There are often typhoons and torrential rain that usually causes floods in rivers and landslides. Therefore, the utilization and management of water resources in Taiwan are doubly difficult.

As mentioned above, under the background of resource scarcity and environment pollution, how to evaluate water efficiency and which regions need to focus more on water efficiency improvement are two issues of concern in this study. It can also assist the government to know which administrative regions need to implement policies aim at the water-use areas with low efficiency.

This study attempts to compute and compare the water consumption efficiency of Taiwan's different administrative regions during 2004-2015 by utilizing the modified slack-base model (SBM) with undesirable outputs to the actual inputs. One desirable output (GDP), two undesirable outputs (SO_2 and sewage), and six inputs (local government expenditure, employment, household and commercial electricity consumption, industrial electricity consumption, water for residential use and water for productive use) are employed in our SBM model. It will be helpful if we can understand the differences of water efficiency in different areas of resource and energy use among different administrative regions.

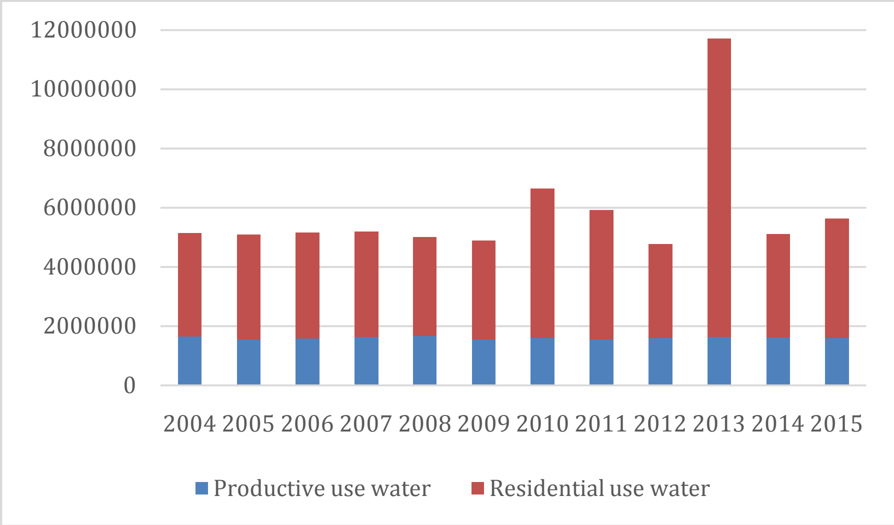


Figure 1. Productive use water and residential water.

The structure of this study is as follows. Section 2 gives literature review on energy efficiency and water efficiency and DEA approach. Section 3 introduces the methodology and the data. Section 4 presents the empirical results and discussions. The final section delivers concluding remarks and the future research suggestions.

2. LITERATURE REVIEW

2.1 Water efficiency

Following the sustainable framework, sustainable development should be introduced by covering areas on a local or regional level and then extending to the national level (Gibbs, 1998). There are two often used indices to evaluate input efficiency: Partial-factor water efficiency and total-factor water efficiency (TFWE). Based on the partial-factor evaluation framework, the most popular indices include the water intensity and water productivity. Water intensity is a direct ratio of the water input to gross domestic product (GDP) (Patterson, 1996; Renshaw, 1981), while water productivity is the reciprocal of the energy input: the GDP ratio. Both indices only take energy into account as a single input to produce GDP. However, this indicator may neglect the substitution or complement among energy and other inputs, such as labors and capital (Han et al. 2007).

In place of the partial-factor ratio approach, this study computes the energy efficiency within an ecological total-factor framework, which includes the energy input, other inputs such as labor and capital, desirable and undesirable outputs.

For the perspective of sustainable development, one needs to consider water policy (Gibbs, 2000) since water is an essential resource. In recent years, water efficiency has been investigated in India (Raju and Kumar, 2006; Manjunatha et al., 2011; Veettil et al., 2013), Tunisia (Chemak et al., 2010), and Australia (Azad et al., 2015), most of them focus on irrigation, water resources, non residential use and productive use water resources. In addition, some research focused on China; for instance Varis and Vakkilainen (2001) studied by ignoring the problem of water shortage squarely, China's annual GDP growth could be reduced by 1.5% to 1.9%. Mo et al. (2005) and Huang et al.

(2005) both examined the water use efficiency and its impact on agriculture in North China by investigating crop yields or the amount of food per unit of water consumption.

Hu et al. (2006) proposed the new index, water adjustment target ratio (WATR) and total-factor water efficiency (TFWE), discovering a U-shape relation between the total-factor water efficiency and per capita real income among areas in China with the central area having the worst water efficiency ranking.

In this study, we would like to analyze the efficiency level of water use among Taiwanese administrative regions. The results can therefore be references for improvement on water supply and consumption.

2.2 DEA approach

Data envelopment analysis (DEA) is known as a mathematical procedure using linear programming to assess the efficiencies of decision-making units (DMU) that refer to a set of firms (Coelli, 1996). Efficiency measures are calculated and compared relatively instead of absolutely among DMUs. It is an appropriate technique not only for investigating DMU efficiency, but a technique for finding efficient inputs and outputs.

The original DEA model, as initially proposed by Charnes et al. (1978), is built on the work of Farrell (1957) who is the pioneer to divide cost efficiency into technical efficiency (TE) and allocative efficiency (AE). Combining these two efficiencies generates the economic efficiency (EE). There are two types of measures or approaches in DEA: radial and non-radial. Differences exist in the characterization of input or output items.

The radial approach is represented by the CCR (Charnes et al., 1978) and BCC (Banker et al., 1984) models. Charnes et al. (1978) proposed CCR model, that had an input orientation and assumed constant returns to scale (CRS) to determine the relative efficiency of a set of homogeneous decision-making units (DMU) and calculate the best multiplier for inputs and outputs. This model finds the overall technical efficiency (OTE) score of each DMU and the score reflects the proportional maximum input (output) reduction (expansion) rate which is common to all inputs (outputs). The CRS consumption is appropriate when all firms are operating at the optimal scale. However, in real-world businesses, there are some reasons that may cause a firm to be not operating at optimal scale, such as imperfect competition, government regulation and constraints on finance. Therefore, Banker et al. (1984) suggested BCC model, which adjusts the CRS DEA model to account for variable returns to scale (VRS) situations.

The BCC model can further decompose overall technical efficiency (OTE) obtained from the CRS DEA into two components, pure technical efficiency (PTE) and scale efficiency (SE). If there is a difference in the CRS and VRS OTE scores for a particular firm, then this indicates that the firm has scale inefficiency. The above-mentioned two models, CCR and BCC, are radial approaches which deal with proportional changes of inputs or outputs. However, the inputs and outputs are not all behave in the proportional way. Some of them may change non-radially, causing a weakness of the radial models that neglect the non-radial input/output slacks. Another shortcoming of the radial models is the neglect of slacks in reporting the efficiency score (Cooper et al., 2011). Therefore, Russell (1985), Pastor et al. (1999) and Tone (2001) proposed a non-radial approach.

The non-radial slacks-based measure of efficiency (SBM) models was introduced by Tone (2001) from the basic CCR-DEA (Charnes et al, 1978) and BCC-DEA (Banker et al., 1984) models. The difference between SBM and traditional CCR and BCC models is that the slack variables are directly added into the target function. On the one hand, the SBM method solves the problem of the input and output slacks, on the other hand, it also solves the problem of efficiency evaluation, and the economic interpretation of the evaluation model is to make actual profit maximization, but not simply maximize the efficiency ratio. Cooper et al. (2007) pointed out that SBM has two important characteristics. One is that the measure is invariant with respect to the unit of measurement of each input and output item. The other is that the measure should be monotone decreasing in each input and output slack. Furthermore, the SBM model which belongs to the DEA model is characterized with non-radial and non-oriented measurements, and it avoids the radial and oriented deviation, which makes the measure has a more flexible piecewise linear function than the radial models, and it generally has no rigorous provisions with the input and output and no particular form on the data. Therefore, it is better than any other model in solving the defects of the traditional DEA model and reflecting the nature of the efficiency evaluation and it can be used to analyze the complex production process with multi-inputs and multi-outputs.

On the other hand, in real production process, inputs and outputs are not all desirable but some of them are undesirable, and this is inevitable and directly affects the efficiency measure of DMUs. Since both desirable and undesirable outputs are jointly produced, development of technologies with less undesirable outputs is an important subject of concern in every area of production. Dyckhoff and Allen (2001) pointed out that the major problem of applying DEA to ecological-related issues is the fundamental assumption that maximizes outputs relative to minimize input resources is a criterion to achieve efficiency. However, when dealing with ecological issues, undesirable outputs such as waste or pollution are playing a crucial role. In other words, it is important that DMUs can maintain the same input target while increasing the desirable outputs and reducing undesirable outputs. Therefore, undesirable outputs must be specially treated.

In the DEA literature, several authors have proposed methods to processing undesirable output. Tone (2011) proposes a new SBM model for measuring efficiency in the presence of undesirable outputs based on the SBM model (Tone 2001). Färe et al. (1989) proposed two assumptions on the production technology. The first is that outputs are weakly disposable that implies the reduction of undesirable outputs is not free, and the proportional reduction in desirable and undesirable outputs at the same time is feasible. The second is that desirable and undesirable outputs are null-joint that implies some undesirable outputs must also be produced when desirable outputs are produced. Seiford and Zhu (2002) multiplied each undesirable output by -1 and then found a proper translation vector to let all negative undesirable outputs be positive, which can evaluate the environmental efficiency by using the traditional efficiency model according to the transformed data.

This study utilizes a modified slacks-based measure (SBM) of efficiency with the non-separable undesirable outputs model proposed by Cooper et al (2007), and will be discussed in the next section.

3. METHODOLOGY AND DATA

3.1 Methodology

With the environmental conservation consciousness gaining ground, it is preferable for a region to increase GDP while reducing pollution in using energy efficiently. This section proposes the concept of disaggregate water efficiency index on the viewpoint of sustainability, which is calculated by a modified SBM with undesirable outputs (Cooper et al., 2007). Suppose that there are N decision-making units (DMUs). The slacks-based measure is non-radial and non-oriented, utilizing the input and output slacks directly to measure efficiency. This model concedes that outputs can be categorized into desirable outputs and undesirable outputs, and also observes that some outputs are closely related with some certain inputs. Therefore, inputs can be classified into separable (X^S), which are real local government expenditure and employment, and non-separable (X^{NS}), which are household and commercial electricity consumption, industrial electricity consumption, residential water and productive use water; while outputs can be decomposed into separable good output (Y^{SG}) which is real GDP and non-separable bad output (Y^{NSB}) which are SO_2 and sewage.

We define the production possibility set under constant returns to scale (CRS) as:

$$P_{NS} = \left\{ (x^S, x^{NS}, y^{SG}, y^{NSG}, y^{NSB}) \middle| \begin{array}{l} x^S \geq X^S\lambda, x^{NS} \geq X^{NS}\lambda, y^{SG} \leq Y^{SG}\lambda, \\ y^{NSG} \leq Y^{NSG}\lambda, y^{NSB} \geq Y^{NSB}\lambda, \lambda \geq 0 \end{array} \right\} \quad (1)$$

where λ is a constant vector representing the weight of each DMU. The fractional programming problem solved by the CRS-SBM model with non-separable undesirable outputs for DMU o is as follows:

$$\text{Min } \rho = \frac{1-\frac{1}{m_1}\sum_{i=1}^{m_1}\frac{s_i^{s-}}{x_{io}^{s}}-\frac{1}{m_2}\sum_{i=1}^{m_2}\frac{s_i^{NS-}}{x_{io}^{NS}}-\frac{m_2}{m}(1-\alpha)}{1+\frac{1}{s}\left[\sum_{r=1}^{s_{11}}\frac{s_r^{SG}}{y_{ro}^{SG}}+\sum_{r=1}^{s_{22}}\frac{s_r^{NSB}}{y_{ro}^{NSB}}+(S_{21}+S_{22})(1-\alpha)\right]} \tag{2}$$

subject to:

$$x_0^{s} = X^{S}\lambda + S^{s-} \tag{3}$$

$$\alpha x_0^{NS} = X^{NS}\lambda + S^{NS-} \tag{4}$$

$$y_0^{SG} = Y^{SG}\lambda - S^{SG} \tag{5}$$

$$\alpha y_0^{NSG} \leq Y^{NSG}\lambda \tag{6}$$

$$\alpha y_0^{NSB} = X^{NSB}\lambda + S^{NSB} \tag{7}$$

$$\sum_{r=1}^{s_{11}}\left(y_{r0}^{SG} + s_r^{SG}\right) + \alpha\sum_{r=1}^{s_{21}} y_{r0}^{NSG} = \sum_{r=1}^{s_{11}} y_{r0}^{SG} + \sum_{r=1}^{s_{21}} y_{r0}^{NSG} \tag{8}$$

$$\frac{s_r^{SG}}{y_{r0}^{SG}} \leq \mathrm{U}(\forall\, r) \tag{9}$$

$$s^{s-},\ s^{NS-}, s^{SG}, s^{NSB}, \lambda \geq 0, 0 \leq \alpha \leq 1 \tag{10}$$

where each region has m_1 separable inputs, m_2 non-separable inputs, and s outputs; s_{11}, s_{21}, and s_{22} are the amount of elements in SG, NSG, and NSB, respectively; $\mathrm{s} = s_{11} + s_{21} + s_{22}$; X^{s}, X^{NS}, Y^{SG}, Y^{NSG}, and Y^{NSB} are the matrices of the separable inputs, non-separable inputs, separable good outputs, non-separable good outputs, and non-separable bad outputs, respectively; S^{S-}, S^{NS-}, S^{SG}, and S^{NSB} are, respectively, the matrices of the separable input, non-separable input, separable good output, and non-separable bad output slacks. A reduction of bad outputs Y^{NSB} is designated by αY^{NSB} with $0 \leq \alpha \leq 1$ which is accompanied by a proportionate reduction in the good outputs Y^{NSG} as denoted by αY^{NSG}, as well as in the non-separate input as denoted by αX^{NS}; λ is a constant vector, and U is the upper bound to the expansion rate for the separable good outputs. Constraint (8) ensures that the total amount of good outputs remains unchanged. Constraint (9) restricts the expansion of separable good outputs in a reasonable range. The computed value of ρ is the overall technical efficiency score for the o^{th} DMU.

This study uses the total-factor water efficiency (TFWE) index proposed by Hu et al. (2006) to evaluate water efficiency under the consideration of undesirable outputs. There are three main features of this index: First, this efficiency score can cope with multiple inputs and outputs, meaning that it considers an ecological total-factor framework. Second, TFWE rescales traditional energy efficiency to a number ranging from zero to unity based on the production frontier in each period. Third, target water input can be detected that is more important for policy makers (Hu and Chang, 2016). This index can overcome possible bias in traditional energy efficiency indicator which is a partial measurement that neglects other important input factors. Also, it is a truly valuable indicator that if we only focus on one type of input variable and we can calculate the total-factor input efficiency of what is interested in.

TFWE for region i at time t in inputs can be defined as below, which is a ratio of target water input to actual water input.

$$\text{TFWE}(i.t) = \frac{Target\ \ water\ \ input\ (i.t)}{Actual\ \ water\ \ input\ (i.t)} \tag{11}$$

The target water input for each region is obtained from modified SBM with the undesirable outputs accounted for, which is defined as:

$$Target\ water\ input(i.t) = Actual\ water\ input(i.t) - Total\ water\ input\ slack(i.t) \tag{12}$$

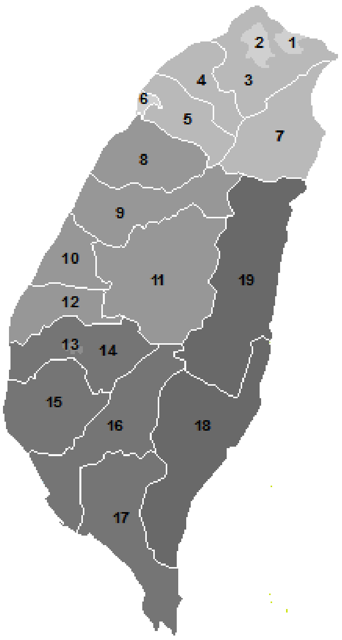
That is to say, the target input is the projection on the axis when a DMU improves and reaches the efficiency frontier. The gap between the actual and target levels is named total water input slack, which is regarded as the inefficient portion of actual water consumption.

3.2 Data and variables

This study is designed to evaluate the water efficiencies in administration region of Taiwan. Since the respective mergers of the cities and counties of Taichung, Tainan, and Kaohsiung and the county of Taipei becoming its own city (New Taipei City) in 2010; therefore, this study uses the merged data. There are twenty-two administrative regions in Taiwan: New Taipei city, Taipei City, Taichung City, Tainan City, Kaohsiung City, Yilan County, Taoyuan City, Hsinchu County, Miaoli County, Changhua County, Nantou County, Yunlin County, Chiayi County, Pingtung County, Taitung County, Hualien County, Keelung City, Hisnchu City, Chiayi City, Kinmen County, Lienchiang County and Penghu County. Owing to serious incompleteness of data, Kinmen County, Lienchiang County and Penghu County were excluded. The modified SBM model is applied to 19 administrative regions in Taiwan from 2004 to 2015.

The nineteen regions are categorized as four areas (shown in Figure 1). The four areas are the northern area (abbreviated as 'N'), the central area (abbreviated as 'C'), the southern area (abbreviated as 'S') and the eastern area (abbreviated as 'E').

In this paper, the regional data for inputs and outputs are collected from the Taiwan Statistical Data Book (Council for Economic Planning and Development, 2015), Taipower Company, Water Resource Agency, Ministry of Economic Affairs, Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan, Environmental Statistics published by the Environmental Protection Administration; and Air Pollution Inquiry System established by the Environment Protection Administration.



Northern Area	Central Area	Southern Area	East Area
1 Keelung City	8 Miaoli County	13 Chiayi City	18 Taitung County
2 New Taipei City	9 Taichung City	14 Chiayi County	19 Hualien County
3 Taipei City	10 Changhua County	15 Tainan City	
4 Taoyuan City	11 Nantou County	16 Kaohsiung City	
5 Hisnchu City	12 Yunlin County	17 Pingtung County	
6 Hisnchu County			
7 Yilan County			

Figure 2. The administrative regions and four major areas on Taiwan Island.

Taipower Company has complete statistics for the electricity consumption of each administrative region in Taiwan. Moreover, there are two categories in accordance with two different fare rates in Taipower Company's statistics, called "the electric lamp" and "the electric power," respectively. The electric lamp fare rate applies to household and commercial sectors, whereas the electric power fare rate applies to industries. Therefore, the regional amount of the electric lamp consumption is used to measure the household and commercial electricity consumption and the regional amount of the electric power consumption is used to measure the industrial electricity consumption.

Water Resource Agency has complete statistics for the water consumption of each administrative region in Taiwan. The water consumption is separated into three parts, agricultural use, residential use and productive use. In this paper, we only discuss about non-agriculture sector, residential use and productive use. The data of agricultural water consumption are unable to count accurately for each region, since they are calculated from Department of Irrigation and Engineering which does not belong to administrative region. Moreover, the total output value of agricultural industry only accounts for a small proportion (1.38%) of the Gross Domestic Product in Taiwan (Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan, 2015) which means that the economic structure is not mainly focusing on agriculture industry. Therefore, in order to avoid needless bias, this paper would not consider agricultural water consumption. However, the residential water and the productive use water, as the name imply, are for general daily activities and industrial (factory) manufacturing activities respectively.

The employment and government expenditure as another two inputs are collected from the Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan. The single desirable output is regional GDP and is calculated from the Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan. The two undesirable outputs are sewage and SO_2 which are calculated from Environmental Statistics published by the Environmental Protection Administration; and Air Pollution Inquiry System established by the Environment Protection Administration, separately. All nominal variables such as regional GDP and government expenditure are transformed into real variables at the 2011 price level by Taiwan's GDP deflators.

Table 1 shows the summary of statistics of inputs and outputs for 19 administrative regions in Taiwan (2004-2015). Table 2 shows that all inputs have positive correlation coefficients with the output.

Table 1. Summary of statistics of inputs and outputs for19 administrative regions in Taiwan (2004-2015).

Variables	Unit	Mean	SD	Min	Max
Desirable Outputs					
Real GDP (y_1)	10 million NTD	50,515	51,738	12,023	200,043
Undesirable Outputs					
SO_2 (y_2)	ppm	0.004	0.001	0.003	0.009
Sewage (y_3)	Tons/Day	14,848	11,212	371	48,841
Inputs					
Real local government expenditure (x1)	10 million NTD	4,686	4,329	1,152	17,703
Employment(x2)	Thousand people	551	490	125	1,945
Household and commercial electricity consumption (x3)	Kilowatt	6,909,983	6,746,420	462,397	22,535,363
Industrial electricity consumption (x4)	Kilowatt	3,074,078	2,976,123	715,784	11,026,320
Residential water (x_5)	KL	223,811	417,687	30,248	4,822,023
Productive water (x_6)	KL	84,424	82,773	4,920	301,830

Note: The base year is 2011.

Table 2. Correlation coefficients of the outputs and inputs.

	y_1	y_2	y_3	x_1	x_2	x_3	x_4	x_5	x_6
y_1	1								
y_2	0.391	1							
y_3	0.700	0.616	1						
x_1	0.952	0.381	0.642	1					
x_2	0.951	0.464	0.826	0.899	1				
x_3	0.965	0.442	0.807	0.899	0.992	1			
x_4	0.640	0.612	0.763	0.628	0.711	0.695	1		
x_5	0.429	0.287	0.332	0.426	0.432	0.431	0.297	1	
x_6	0.307	0.535	0.653	0.306	0.462	0.414	0.735	0.183	1

4. EMPIRICAL RESULTS

From the data collection of separate portions of water consumption in residential use and productive use, we are capable of reviewing water use efficiency at the productive use part. Water plays an important role in economic production and people's life, which significantly influences economic growth directly. Hence, analyzing efficiency of productive water use and knowing which region's efficiency needs to improve is rather important.

Table 3 shows the productive use water efficiency scores for regions in Taiwan. We can find that the counties in Taiwan can save 57% of their productive use water on average, implying the productive use water is inefficient in counties of Taiwan. For the efficiency of productive use water, Taipei City and New Taipei City are on the frontier among all regions with productive water efficiency scores of 1. Compared with the above two cities, Yunlin County (0.044) and Chiayi County (0.123), and Hualien (0.122), as three agricultural regions, have the lowest productive use water efficiency scores. As Table 3 shows, the average productive efficiency scores for four areas are north (0.670), central (0.176), south (0.326), and east (0.479) from 2004-2015. The average productive water efficiency scores in the central and south areas are quite low which may be explained by the industrial structures of the south and central areas in Taiwan. These areas focus on heavy industry and oil-refining industry, which needs large quantities of water in their production process but lower output value. These results show that improving productive water efficiency is a priority for Taiwan's non-metropolitan regions, especially in the area which has large proportion of heavy industry and oil-refining industry.

The regional residential water consumption efficiency scores in Taiwan is computed and constructed by DEA through the aforementioned method. The result is shown in Table 4. New Taipei City and Taipei City are on the water efficiency frontier among all regions with efficiency scores of 1, whereas Hsinchu City has efficiency scores of 0.923. According to statistics of Water Agency, these three regions also have higher water consumption per capita per day. In contrast with the above regions, the efficiency of residential water consumption in Yunlin County, Chiayi County, and Hualien County, can be saved the most, up to 70.1%, 60.3%, and 63.2% on average, respectively. As Table 4 shows, the empirical model shows that the residential water efficiency scores for four areas are north (0.745), central (0.461), south (0.530) and east (0.648) during 2004-2015. These numerical results show that in the central and south areas with less service industry and high output value industry, the efficiency of residential water consumption can be saved around 40% on average.

As Tables 3 and 4 indicate, over the whole data period, the efficiency in productive use water consumption remains around 0.4, declining to less than 0.3 in the last year, whereas residential water consumption remains around 0.6, increasing to 0.8 in the last two years. Therefore, these numerical results imply that the government needs to improve water efficiency, especially the productive water efficiency.

Table 3. 2004-2015 productive use water efficiency scores for regions in Taiwan.

Region	Area	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Ave.
Keelung City	N	0.782	0.853	0.769	1.000	0.799	0.816	0.893	0.853	0.746	0.795	1.000	1.000	*0.859*
New Taipei City	N	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Taipei City	N	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Taoyuan City	N	0.162	0.160	0.142	0.128	1.000	0.132	1.000	1.000	0.185	0.194	1.000	0.054	0.430
Hisnchu City	N	1.000	0.866	0.900	1.000	0.920	0.825	1.000	1.000	1.000	1.000	1.000	1.000	*0.959*
Hsinchu County	N	0.190	0.229	0.197	0.165	0.243	0.234	0.289	0.290	0.289	0.288	1.000	0.027	0.287
Yilan County	N	0.179	0.216	0.189	0.161	0.214	0.166	0.212	0.173	0.190	0.173	0.002	0.010	0.157
Miaoli County	C	0.158	0.169	0.170	0.148	0.172	0.138	0.174	0.171	0.162	0.169	0.008	0.007	0.137
Taichung City	C	0.396	0.080	0.128	0.174	0.113	0.117	0.113	0.393	0.041	0.043	0.013	0.017	0.136
Changhua County	C	0.189	0.187	0.189	0.158	0.190	0.179	0.125	0.199	0.184	0.172	0.007	0.007	0.149
Nantou County	C	0.623	0.732	0.510	0.481	0.555	0.396	0.467	0.439	0.408	0.356	0.014	0.013	0.416
Yunlin County	C	0.054	0.052	0.057	0.044	0.052	0.045	0.055	0.066	0.050	0.050	0.002	0.002	<u>0.044</u>
Chiayi City	S	0.859	1.000	1.000	0.843	1.000	0.914	0.614	1.000	1.000	1.000	1.000	1.000	*0.936*
Chiayi County	S	0.135	0.147	0.139	0.116	0.146	0.133	0.169	0.159	0.157	0.159	0.006	0.007	<u>0.123</u>
Tainan City	S	0.198	0.193	0.161	0.120	0.066	0.134	0.076	0.194	0.189	0.202	0.011	0.009	0.129
Kaohsiung City	S	0.271	0.227	0.197	0.161	0.086	0.105	0.010	0.247	0.271	0.266	0.015	0.012	0.156
Pingtung County	S	0.355	0.377	0.360	0.326	0.343	0.323	0.383	0.343	0.324	0.303	0.012	0.011	0.288
Taitung County	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.013	0.012	0.835
Hualien County	E	0.153	0.133	0.138	0.124	0.146	0.123	0.171	0.160	0.150	0.151	0.006	0.006	<u>0.122</u>
North		0.616	0.618	0.600	0.636	0.739	0.596	0.771	0.759	0.630	0.636	0.857	0.584	0.670
Central		0.527	0.244	0.211	0.201	0.216	0.175	0.187	0.254	0.169	0.158	0.009	0.009	0.176
South		0.441	0.389	0.371	0.313	0.328	0.322	0.250	0.389	0.388	0.386	0.209	0.208	0.326
East		0.325	0.567	0.569	0.562	0.573	0.562	0.586	0.580	0.575	0.576	0.010	0.009	0.479
Taiwan		0.458	0.454	0.434	0.429	0.476	0.409	0.461	0.510	0.439	0.438	0.374	0.273	0.430

Notes: Italics indicates the top five productive use water efficient regions. Underlined indicates the top three productive use water inefficient regions.

Table 4. 2004-2015 residential water efficiency scores for regions in Taiwan.

Region	Area	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Ave.
Keelung City	N	0.448	0.447	0.376	0.256	0.343	0.323	0.383	0.853	0.309	0.342	1.000	1.000	0.507
New Taipei City	N	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Taipei City	N	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	*1.000*
Taoyuan City	N	0.506	0.595	0.631	0.671	1.000	0.570	1.000	1.000	0.462	0.482	1.000	1.000	*0.743*
Hisnchu City	N	0.844	0.866	0.900	0.721	0.920	0.825	1.000	1.000	1.000	1.000	1.000	1.000	*0.923*
Hsinchu County	N	0.432	0.515	0.409	0.347	0.516	0.439	0.610	0.594	0.504	0.508	1.000	0.936	0.567
Yilan County	N	0.359	0.458	0.395	0.327	0.443	0.329	0.466	0.390	0.413	0.381	0.863	0.857	0.473
Miaoli County	C	0.363	0.400	0.383	0.324	0.376	0.316	0.443	0.430	0.360	0.375	0.823	0.727	0.443
Taichung City	C	0.276	0.675	0.778	0.646	0.660	0.661	0.674	0.824	0.629	0.683	0.734	0.698	0.661
Changhua County	C	0.405	0.345	0.408	0.328	0.391	0.314	0.550	0.411	0.373	0.372	0.763	0.702	0.447
Nantou County	C	0.344	0.382	0.401	0.313	0.388	0.355	0.477	0.422	0.411	0.385	0.853	0.739	0.456
Yunlin County	C	0.328	0.317	0.319	0.242	0.293	0.234	0.318	0.324	0.280	0.289	0.590	0.055	<u>0.299</u>
Chiayi City	S	0.394	0.567	0.456	0.357	0.468	0.338	0.613	0.641	0.555	0.720	1.000	1.000	0.592
Chiayi County	S	0.359	0.406	0.363	0.292	0.378	0.290	0.413	0.409	0.383	0.004	0.707	0.761	<u>0.397</u>
Tainan City	S	0.431	0.422	0.504	0.526	0.737	0.460	0.672	0.683	0.392	0.039	0.877	0.821	0.547
Kaohsiung City	S	0.457	0.652	0.617	0.511	0.804	0.695	0.155	0.887	0.448	0.499	0.911	0.932	0.631
Pingtung County	S	0.420	0.472	0.417	0.367	0.425	0.381	0.488	0.455	0.402	0.401	0.767	0.796	0.483
Taitung County	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.606	0.524	*0.927*
Hualien County	E	0.273	0.274	0.321	0.239	0.294	0.260	0.394	0.379	0.333	0.367	0.637	0.646	<u>0.368</u>
North		0.656	0.697	0.673	0.617	0.746	0.641	0.780	0.834	0.670	0.673	0.980	0.970	0.745
Central		0.343	0.424	0.458	0.371	0.422	0.376	0.492	0.482	0.411	0.421	0.753	0.584	0.461
South		0.412	0.504	0.471	0.411	0.562	0.433	0.468	0.615	0.436	0.333	0.852	0.862	0.530
East		0.637	0.637	0.661	0.620	0.647	0.630	0.697	0.690	0.667	0.684	0.622	0.585	0.648
Taiwan		0.507	0.568	0.562	0.498	0.602	0.515	0.613	0.669	0.540	0.518	0.849	0.800	0.603

Notes: Italics indicates the top five residential water efficient regions. Underlined indicates the top three residential water inefficient regions.

5. CONCLUSION AND SUGGESTIONS

This paper computes the total-factor water efficiency of nineteen Taiwan's administrative regions during 2004-2015. The non-oriented slack-based data envelopment analysis (SBM-DEA) with undesirable outputs model proposed by Tone and Tsutsui (2011) is used. The main findings in this paper are as follows: (i) The efficiency of water consumption still needs to put in more effort. (ii) Almost all of those inefficient regions' with water efficiency scores ranked below the average have large industrial parks and petrochemical industry clusters. (iii) The top five most water-efficient regions mostly located in northern areas, reflecting an uneven distribution of locations of headquarters and factories between northern and non-northern areas.

This study also offers some suggestions based on the findings above as follows: (i) the government should have some incentive measures such as price mechanisms in order to encourage enterprises to upgrade and transform themselves to achieve greater water efficiency; (ii) regional governments of non-northern areas should conduct administrative schemes to adopt water-saving technology or to change the industrial sector towards a higher value-added structure and a low energy-intensive setup; and (iii) the authorities should provide specific and clear information through various media and Internet channels to inform citizens that Taiwan is facing difficulties and challenges in regards to water issues.

The empirical findings support the environmentalist viewpoint that Taiwan should emphasize improvement of life quality and sustainability, instead of economic growth. In terms of average efficiency scores in Taiwan, an interesting phenomenon is that the efficiency scores of productive water usage deteriorate after 2009. Based on this finding, more attention should be paid on productive water usage. In the light of this, the government can encourage businesses to achieve greater water efficiency by providing some benefits or subsides.

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