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Environment-adjusted regional energy efficiency in Taiwan

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ABSTRACT

This study applies the four-stage DEA procedure to calculate the energy efficiency of 23 regions in Taiwan from 1998 to 2007. After controlling for the effects of external environments, only Taipei City, Chiayi City, and Kaohsiung City are energy efficient. Note that Kaohsiung City reaches the efficiency frontier due to the adjustment via partial environmental factors such as higher education attainment and transport vehicles. We also find a worsening trend for Taiwan's energy efficiency. Not only is there a gap of energy efficiency between Taiwan's metropolitan areas and the other regions, but the gap has also widened in recent years. Those inefficient counties should be given priority and the savings potential. Except for road density, the evidence indicates that each environmental factor has partial incremental effects on input slacks. As more cars and motorcycles are unfavorable externalities affecting partial energy efficiency, the central government should help local governments retire inefficient old motor vehicles, encourage energy-saving vehicle models, and provide convenient mass transportation systems. Besides, people with higher education cause industrial energy inefficient in Taiwan. The conscious of effective energy saving is necessary to schools, communities, and employee accordingly.

1. Introduction

With the growing concern over global warming and sustainable energy usage, every region needs to improve its energy efficiency. In 2009, Taiwan's imported energy accounts for 99.7% of total energy consumption [1] and its energy consumption growth is much higher than economic growth in recent years. From 1999 to 2007, Taiwan's value of energy imports to GDP ratio rose from 2.69 to 11.31, and per capita energy consumption went from 3,894.74 (barrel of oil equivalent) to 5,301.66. At this time, however, energy productivity fell from 111.48 (NT$/oil quantities) in 1999 to 108.20 in 2007 [1].

In 1998, 2005, and 2009, Taiwan held three National Energy Councils to address energy-related policy issues, in which efforts to improve energy efficiency were of priority concern. Following the 2005 council, the Bureau of Energy [2] published the Energy White Paper, which declares six policy guidelines that focus on stabilizing energy supply, improving energy efficiency, opening up energy industries, emphasizing environmental protection, strengthening research and development capabilities, and accelerating educational dissemination. In 2008, the Ministry of Economic Affairs [3] announced the Framework of Taiwan's Sustainable Energy Policy, which states that sustainable energy policies should increase the efficiency of using limited energy resources to create a win–win–win solution for energy, environment, and economy. Thus, energy efficiency has become one of the most important issues in Taiwan's public policy.

An economy's energy efficiency improvement has to be based on regional energy efficiency promotion. For instance, in 2007, the per capita electricity consumption was 6382 kW h in Taipei City, Taiwan's capital and largest city, while Taitung County, a typical rural region in eastern Taiwan, consumed only 3589 kW h [4]. Understanding how administrative regions differ in energy efficiency would greatly facilitate efforts to coordinate energy policies and set action agendas.

According to the mentions of Patterson [5] and Ang [6], energy efficiency is a relative concept. Different people may have different definitions of energy efficiency. Three indicators are commonly used to measure it, namely, monetary-based, physical-based, and thermodynamic indicators. The former refers to the energy requirement per unit currency output (e.g., per unit US dollar output). Relatively, monetary-based and physical-based indicators are often used at the macro-level such as in making regional, economy-wide and sectoral energy policy [6]. At the macro-economy level, data envelopment analysis (DEA) has recently become popular in measuring energy efficiency. It provides a simple assessment method to deal with multiple inputs and outputs in explaining

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relative energy efficiency. DEA is addressed by Charnes et al. [7,8] and extended by Banker et al. [9]. To overcoming the limitations of traditional ratio analysis, this method also provides an alternative framework for the estimation of the production frontier involving multiple inputs and outputs.

So far, fewer studies focus on the quantitative analyses of energy efficiency of a region. Wei et al. [10] proposes an energy efficiency index based on the DEA analysis approach to examine energy efficiency on 29 provinces in China. They document that there exist remarkable differences in energy efficiency among provinces and regions. Most of the eastern provinces are close to benchmark, while the underdeveloped western area has the lowest energy efficiency levels. Shi et al. [11] consider desirable and undesirable outputs in measuring Chinese industrial energy efficiency and explore the maximum energy-saving potential in 28 administrative regions in China. From the scale efficiency perspective, they show that the industrial structure in the east area does not depend on the consumption of a large amount of energy to gain benefits as they have constant returns to scale or decreasing returns to scale. On the contrary, other regions have increasing returns to scale, which largely causes these regions to expand their industrial economy at the expense of energy saving.

Comparing in the analysis of regional energy efficiency, previous studies concentrated mainly on total-factor energy efficiency such as electricity use or the amount of gasoline consumed. Hu and Wang [12], Chien and Hu [13], and Honma and Hu [14] utilize a total-factor method to observe energy efficiency in China, Organization for Economic Corporation and Development (OECD) and non-OECD countries, and Japan, respectively. Lee [15] used DEA and regression methods to evaluate the energy efficiency of Taiwan government office and buildings. Yang and Pollitt [16] evaluated the performance of Chinese coal-fired power plants. They find that some plants with relatively low efficiency scores were inefficient partially due to their relatively unfavorable operating environments. Lee and Lee [17] classified energy performance into the scale and management factors to analyze the energy efficiency of 47 government office buildings in Taiwan. By using CCR and BCC models to calculate the technical, pure technical and scale efficiencies for farmers categories-wise and zone-wise in India, Nassiri and Singh [18] show that small farmers had higher energy-ratio and low specific energy requirement.

However, these studies with measuring specific-state energy efficiency by DEA method may still have some limitations: First, they did not take into account the environmental effects. The ability of a producer to transform the inputs into outputs is not only affected by controllable inputs, also by uncontrollable external operating environments. For example, this could be transportations, location characteristics, human capital, and regional size. Second, some producers may operate under a favorable external operating environment, while others operate under an unfavorable external operating environment. At this time, an unfavorable external environment makes firms' efficiency under-estimated. An unfavorable external operating environment refers to additional inputs are required to produce the same level of output in order to overcome the external disadvantage. If we ignore this circumstance, efficiency assessment resembles penalizing good producers who operate in an unfavorable external operating environment and rewarding poor producers who operate in a favorable external operating environment. This will bias the efficiency assessment results and lead to misleading conclusions [19]. For instance, we may wrongly blame a local government for poor management in energy use, but in fact the local government's management is good. Lower energy efficiency found in the administration region is due to unfavorable environmental factors.

In order to comprise the influences of external environmental factors, this study applies the four-stage DEA procedure developed by Fried et al. [19] to evaluate the pure managerial energy efficiency of the 23 administrative regions in Taiwan. Each administrative region in Taiwan can be treated as a decision-making unit (DMU). The managerial efficiency of DMUs can be evaluated in terms of their ability to either minimize input usage under the production of given output or to maximize output production with given inputs. The four-stage DEA model rests on the premise that DMUs operating in relatively unfavorable environments are at a disadvantage in the traditional DEA model. In other words, a relatively efficient DMU may be wrongly labeled as inefficient if the impacts of unfavorable environments are not removed in the efficiency-estimation approach. To the best of our knowledge, exactly how the various administrative regions in Taiwan differ in energy efficiency has not yet been addressed. In particular, the environment-adjusted energy efficiency of a region is left to be first examined by this study.

The paper is organized as follows. Section 2 provides a brief discussion of the methodology. Section 3 interprets data sources and descriptive statistics. Section 4 presents and discusses empirical results. The final section gives the conclusion and some policy implications.

2. Methodology

According to the rationale of Fried et al. [19], the four-stage DEA approach can be introduced as follows. The first stage calculates a DEA frontier by using the selected inputs and outputs according to standard production theory while the environmental variables are excluded. The piecewise linear input requirement set under variable returns to scale is defined as follows:

$$L(y) = \left\{ x : Yz \geqslant y,\ Xz \leqslant x,\ Iz = 1, z \in R_+^K \right\}, \tag{1}$$

where y is an $(M \times 1)$ vector of M outputs, x is an $(N \times 1)$ vector of N inputs used to produce output y, Y is an $(M \times K)$ matrix of outputs, X is an $(N \times K)$ matrix of inputs, z is a $(K \times 1)$ vector of activities or weights, I is a $(1 \times K)$ vector of ones, K is the number of DMUs, M is the number of outputs, and N is the number of inputs. Given output vector y, all input vectors that are feasible for producing output vector y are in the input requirement set. All convex combinations of input vectors, which are less than or equal to the input bundle x and are feasible to produce at least output vector y, establish the isoquant or reference frontier for output y and is the basis for calculating the Farrell [20] technical efficiency.

Given the piecewise linear input requirement set in (1), the DEA model used to compute the Farrell technical efficiency for unit k, $k = 1, \ldots, K$, is formulated as the following linear programming problem:

$$\begin{aligned} & TE^k = \min_{z,\lambda} \lambda \\ & \text{s.t. } Yz \geqslant y^k, \\ & Xz \leqslant \lambda x^k, \\ & Iz = 1 \\ & z \in R_+^K, \end{aligned} \tag{2}$$

where TE is a measure of efficiency under the restriction that a linear combination of efficient units produces the same or more of all outputs and that the reduction in inputs is equi-proportionate; y^k and x^k are output and input vectors for unit k, respectively; λ is a scalar value representing a proportional contraction of all inputs, holding input ratios and output level constant. The minimum value of λ that satisfies all constraints is the Farrell radial technical efficiency measure.

The radial measure computed in the first stage evaluates the performance of a DMU relative to best practice, predicated upon the inputs and the outputs included in the model. Other variables, however, influence the managerial ability to transform the inputs into outputs, but which are outside the managerial control. These variables refer to the external environment. Unfavorable external conditions mean that additional inputs are required to produce the same level of output in order to overcome the external disadvantage. In other words, the radial efficiency score generated by the initial model in the first stage overstates the efficiency of DMUs operating under favorable conditions and understates the efficiency of DMUs operating under unfavorable conditions.

The second stage is to estimates the N input slack equations using an appropriate econometric method such as the Tobit regression in this study. The dependent variables are radial plus non-radial input slack, while the independent variables are the measures of external conditions applicable to the particular input. The purpose is to quantify how the external environment affects the excessive use of inputs. The N equations are specified as follows:

$$ITS_j^k = f_j\left(Q_j^k, \beta_j, u_j^k\right), \quad j = 1, \ldots, N \quad k = 1, \ldots, K, \tag{3}$$

where ITS_j^k is unit k's total slack for input j based on the DEA results from the first stage, Q_j^k is a vector of variables characterizing the external environment for unit k that may affect the utilization of input j, β_j is a vector of coefficients, and u_j^k is a disturbance term. These equations explain the variation in total by-variable considerations of inefficiency. The independent variables characterizing the operating environment in (3) are not limited to be the same across equations, need not have a linear relationship with the dependent variables and can be a mixture of continuous and categorical variables.

The third stage uses the estimated parameters from the second stage to predict total input slack ($I\hat{T}S_j^k$) for each input and each unit based on its external environmental variables:

$$I\hat{T}S_j^k = f_j\left(Q_j^k, \hat{\beta}_j\right), \quad j = 1, \ldots, N \quad k = 1, \ldots, K. \tag{4}$$

These predictions can be used to adjust the primary input data for each unit according to the difference between maximum predicted slack and predicted slack:

$$x_j^{kadj} = x_j^k + \left[\mathrm{Max}^k\{I\hat{T}S_j^K\} - I\hat{T}S_j^K\right] \quad j = 1, \ldots, N \quad k = 1, \ldots, K. \tag{5}$$

The region with maximum input slack is the one faces the least favorable environmental conditions. The maximum predicted input slack thus serves as a benchmark for the least favorable set of external conditions. A region with external variables corresponding to this benchmark level would not have its input vector adjusted. A region with external variables generating a lower level of predicted slack would have its input vector adjusted upward to put it on an equal footing with the country having the least favorable external environment. Eq. (5) creates a new pseudo dataset where the inputs are adjusted for the effect of external environment.

The fourth stage re-runs the DEA model under the initial input–output specification and generates new radial measure of efficiency by using the adjusted dataset. These new radial scores measure the efficiency that is attributable to management. The result excludes any influence from environmental variables and, therefore, can reflect efficiency more accurately.

3. Data and variables' descriptions

This paper examines 23 administrative regions in Taiwan. As Golany and Roll [21] illustrated, the number of evaluated DMUs should be more than five times the total selected number of input and output; otherwise, the validity and credibility of study's results will be seriously compromised. Hence, this study selects six factors as the inputs and outputs.

The relationship among output, energy use, and employment are build upon econometric framework. From a policy viewpoint, the direction of causality between these variables has important implications [22,23]. If unidirectional causality runs from electricity consumption to income or employment reducing electricity consumption could lead to a fall in income and/or employment [24]. Lean and Smyth [25] find that there is unidirectional Granger causality running from electricity consumption and emissions to economic growth for five ASEAN, implying that these countries are energy dependent countries. The direct effect of energy consumed for commercial use which generates higher rates of economic growth, higher electricity consumption results in an increase in energy production, which has the indirect effect of generating employment and infrastructure in energy services. Narayan and Wong [26] find that oil consumption, oil prices, and state income are panel cointegrated in Australia. Moreover, estimated long-run elasticities reveal that oil prices have had a statistically insignificant impact on oil consumption while income has had a positive and statistically significant effect on oil consumption. Utilizing the generalized forecast error variance decomposition technique, Sari and Soytas [27] document that the total energy consumption explains 21% of forecast error variance of GDP in the case of Turkey. Besides, energy consumption appears to be almost as important as employment.

Based on the aforementioned literature, real income can be treated as the function of electricity consumption and oil sales. Five factors to serve as the inputs: total employment (Employ), household and commercial electricity consumption (Houelec), industrial electricity consumption (Indelec), gasoline sales (Gas), and diesel sales (Diesel). Note that Taipower Company [4] has two categories in accordance with two different fare rates in Taipower Company's statistics, called 'the electric lamp' and 'the electric power'. The 'electric lamp' fare rate applies to the household and commercial sectors, whereas the 'electric power' fare rate applies to industries. Therefore, we use the regional figure of the electric lamp consumption to measure household and commercial electricity consumption, and the regional figure of the electric power consumption is used to measure industrial electricity consumption. The nature candidate of output factor used in the DEA model is the total real income (Income) of each region, as measured in millions New Taiwan dollars (NTD) of constant 2001. The data are provided annually from 1998 to 2007. All nominal variables are transformed into real variables at the 2001 price level by Taiwan's GDP deflators. The research data are compiled from Bureau of Energy [28], Taipower Company [4] and Taiwan National Statistics [29].

Due to locating in different environments, administrative regions have different performance form each other. A part of this difference is caused by nondiscretionary environmental factors such as location characteristics and educational attainment. Hence, the environmental factors used in the second stage include the number of profit organizations (Profit), the ratio of higher education attainment of population aged 15 and over (Highedu), road density (Roaden), the number of cars (Car), the number of motorcycles (Bike), and the number of local phones (Phone). Table 1 summarizes the definitions of variables used in this study. Table 2 presents the descriptive statistics for each variable.

4. Results and discussion

4.1. Stage one: initial DEA

Efficiency scores for all administrative regions are first calculated using the DEA model with the output and seven inputs.

Table 1
Definitions of variables.

Variables	Definitions and units
Output	
Income	Total real income of a region, in millions of constant 2001 NTD
Inputs	
Employ	Employment, total
Houelec	Household and commercial electricity consumption, in kilowatt hours
Indelec	Industrial electricity consumption, in kilowatt hours
Gas	Gasoline sales, in thousand liters
Diesel	Diesel sales, in thousand liters
External environment variables	
Roaden	Road density (km per sq. km)
Profit	Number of profit organizations
Highedu	Higher education attainment of population aged 15 and over (% of total people)
Car	Number of cars, in thousand
Bike	Number of motorcycles, in thousand
Phone	Number of local phones, in thousand

Table 2
Descriptive statistics (1998–2007).

Variables	Mean	Standard deviation	Minimum	Maximum
Output				
Income	345,800.6	378,915.2	17,221.4	1,621,601.2
Inputs				
Employ	420,478.3	356,875.0	31,000.0	1,753,000.0
Houelec	2,250,735.7	2,223,870.6	149,971.9	10,742,804.0
Indelec	4,555,612.5	4,389,452.3	93,099.0	21,417,491.2
Gas	424,703.9	334,255.8	19,644.0	1,559,655.0
Diesel	146,116.9	105,659.2	3,121.0	483,538.0
External environment variables				
Roaden	2.6	2.6	0.3	8.8
Profit	47,911.4	46,990.7	4,072.0	197,914.0
Highedu	24.2	9.4	8.0	55.3
Car	222,020.8	180,300.8	10,713.0	781,974.0
Bike	531,174.8	411,324.0	49,709.0	2,155,791.0
Phone	561,306.3	610,303.4	35,175.0	2,470,616.0

Note: Data sources are compiled from the Bureau of Energy [28], Taipower Company [4] and Taiwan National Statistics [29].

Table 3 reports those results. According to this table, urban areas appear to be more energy efficient than rural areas in Taiwan. For instance, Penghu County, Keelung City, Chiayi City, and Taipei City perform the best with efficiency scores of 1, indicating that these regions create more value-added by using the same resources and energy inputs. Taipei City is the largest city in Taiwan owning the most public service and commercial activities. Keelung City is an urban area neighboring Taipei City in northern Taiwan. However, Kaohsiung City and Taichung City appear to be less energy efficient than other large cities. They are the largest city in Taiwan's central area and the largest city in southern Taiwan, respectively. As for the rural areas, Miaoli County, Yunlin County, Chiayi County, and Hualien County (i.e. the typical rural regions in Taiwan) appear to be less energy efficient. The efficiency score of Chunghua County is as low as 0.670 in 1998 and Taichung County is as low as 0.561 in 2007. These results are perhaps that the efficiency of regions in unfavorable circumstances will be under-estimated, and vice versa. Therefore, we have to quantify the effects of the external environment on inputs, and the efficiency scores should be re-estimated.

4.2. Stage two: quantifying the effects of the operating environment

The second stage of analysis adopts Tobit regressions to quantify the environmental effects embedded in the input slacks computed using the DEA analysis. The Tobit model is a regression model dealing with a censored dependent variable. There are five regressions, one for each input. The dependent variables are the total input slacks of administrative regions. Single Tobit equations are estimated since the independent variables are the same across the five input slack equations. For further details for Tobit regression model, see Greene [30]. The parameter estimates and standard errors are summarized in Table 4.

The positive (negative) coefficients suggest that environment is unfavorable (favorable) owing to it's associated with greater (less) excess use of the input. Table 4 exhibits the estimated results of five Tobit regressions, one for each input. The regressors include road density, the number of profit organizations, the ratio of higher education attainment of population aged 15 and over, the number of cars, the number of motorcycles, and the number of local phones.

The results of Table 4 suggest that a higher road density is an unfavorable environment for the efficiency of household electricity consumption and gasoline use. Besides, a larger number of profit organizations offer a favorable environment for gasoline use, but an unfavorable environment for employment. Similarly, a larger share of higher education is a favorable environment for the efficiency of employment and gas use, while an unfavorable environment for household electricity consumption. More cars produce an unfavorable environment for energy efficiency in terms of gas use. The number of motorcycles is positively associated with the slack in gas use, household and industrial electricity consumption. Interestingly, the number of cars is negatively associated with the slack in household and industrial electricity consumption, implying that more transportation vehicle can offer a favorable environment for electricity use. Ultimately, more telephones produce a favorable environment for employment and diesel use, indicating that the use of communication technology can substitute for the use of transportation facilities.

The above-mentioned results exhibit that promoting efficiency of household and industrial electricity consumption could be a beneficial influenced by car quantity, while a disadvantage influenced by partial transport facilities (i.e., motorcycles), education attainment and road density. A region with a ratio of higher education enjoys an unfavorable environment in industrial energy efficiency. This finding is possibly owing to that, although individuals with a high education and income may be more conscious of environmental protection issues, they also tend to use products and services that consume more energy (e.g., large cars, TVs, and refrigerators). This will lead to produce negative externalities, worsening energy efficiency. On the other hand, higher transport facilities have an unfavorable environment in efficiency of gasoline use, while higher communication facilities are to be a favorable environment in efficiency of diesel use. More transport facilities use will harm the efficiency of gasoline use. On the one hand, this outcome could be caused by lacking of energy-saving facilities on vehicles. On the other hand, lower energy prices let people to ignore the importance of energy-savings. The energy market in Taiwan generally belongs to monopolies due to the policy regulations and law restrictions. Compared to neighboring East Asian economies, energy prices in Taiwan are relatively much lower, worsening its energy efficiency accordingly.

4.3. Stage three: data adjustment

The parameter estimates presented in Table 4 are utilized to adjustment the dataset utilized in stage 1 according to Eq. (5). The adjusted data controls for the influence of the external operating environment. The adjustment essentially amounts to penalizing the region for its ability to use fewer inputs under favorable external conditions. By increasing the input quantity and leaving

Table 3
Technology efficiency scores of the stage one in years 1998–2007.

Regions	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Taipei County	0.770	0.783	0.724	0.788	0.850	0.843	0.811	0.846	0.856	0.832
Yilan County	0.842	0.860	0.771	0.705	0.679	0.753	0.698	0.781	0.715	0.675
Taoyuan County	0.777	0.765	0.751	0.751	0.754	0.739	0.783	0.746	0.734	0.723
Hsinchu County	0.864	0.884	0.866	0.800	0.799	0.815	0.829	0.878	0.760	0.700
Miaoli County	0.760	0.734	0.691	0.714	0.677	0.698	0.659	0.676	0.725	0.685
Taichung County	0.675	0.697	0.616	0.587	0.615	0.586	0.588	0.566	0.565	0.561
Chunghua County	0.670	0.612	0.594	0.575	0.631	0.647	0.635	0.610	0.638	0.595
Nantou County	0.799	0.917	0.794	0.749	0.723	0.722	0.762	0.784	0.815	0.723
Yunlin County	0.673	0.724	0.626	0.688	0.624	0.625	0.654	0.612	0.700	0.604
Chiayi County	0.669	0.701	0.750	0.696	0.630	0.647	0.669	0.698	0.694	0.628
Tainan County	0.719	0.716	0.688	0.657	0.642	0.687	0.673	0.624	0.652	0.627
Kaohsiung County	0.687	0.700	0.652	0.608	0.636	0.613	0.659	0.666	0.601	0.654
Pingtung County	0.742	0.698	0.689	0.647	0.704	0.705	0.644	0.692	0.681	0.714
Taitung County	0.844	0.830	0.909	0.875	0.895	0.845	0.744	0.699	0.804	0.891
Hualien County	0.776	0.743	0.757	0.758	0.673	0.702	0.681	0.620	0.651	0.655
Penghu County	0.858	0.941	1.000	0.876	0.850	0.816	0.899	0.809	0.907	0.829
Keelung City	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hsinchu City	0.829	0.845	0.864	0.885	0.821	0.828	0.901	0.826	0.874	0.889
Taichung City	0.812	0.800	0.698	0.812	0.702	0.755	0.671	0.654	0.705	0.758
Chiayi City	1.000	0.878	0.922	0.949	1.000	0.932	0.742	0.895	0.923	0.852
Tainan City	0.733	0.683	0.708	0.682	0.702	0.716	0.714	0.667	0.682	0.729
Taipei City	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Kaohsiung City	0.911	0.955	0.906	0.940	0.853	0.892	0.904	0.944	0.918	0.926
Mean	0.800	0.803	0.781	0.771	0.759	0.764	0.753	0.752	0.765	0.750
Standard deviation	0.105	0.111	0.127	0.128	0.127	0.117	0.118	0.128	0.125	0.129
Minimum	0.669	0.612	0.594	0.575	0.615	0.586	0.588	0.566	0.565	0.561
Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4
Tobit regression results ($N = 230$).

Variables	Slacks				
	Employ	Houelec	Indelec	Gas	Diesel
Intercept	66213.18*** (12351.96)	−1019560*** (70055.39)	1845479 (1137997)	37580.15** (15936.64)	102235.4*** (27865.66)
Roaden	3818.12 (3697.92)	60508.5** (23656.86)	−225797.2 (524146.8)	9298.02** (4419.07)	9052.76 (8416.90)
Profit	1.52*** (0.50)	4.05 (5.93)	68.02 (56.39)	−3.87*** (0.65)	0.30 (0.73)
Highedu	−1304.61** (519.14)	−1119.51 (3994.06)	117525.7** (53181.5)	−1608.96*** (590.33)	207.05 (857.22)
Car	0.01 (0.11)	−4.34*** (1.56)	−44.09*** (11.63)	0.71*** (0.17)	0.38 (0.22)
Bike	−0.003 (0.04)	2.25*** (0.42)	8.08** (3.33)	0.13*** (0.04)	−0.09 (0.05)
Phone	−0.14*** (0.03)	−0.18 (0.21)	−3.27 (2.49)	0.04 (0.04)	−0.21*** (0.04)
Log-likelihood	−2120.68	−510.37	−2572.01	−2303.14	−2179.64
Sigma	39025.33*** (13036.59)	544073.5*** (128391.7)	4933675*** (1699160)	49513.07*** (8981.67)	107665.4*** (28624.5)

Note: Numbers in parentheses are standard errors.
** Significance at the 5% level.
*** Significance at the 1% level.

the output unchanged, the region's external advantage over generating income is removed. This makes it possible to isolate net managerial efficiency by re-running the DEA model on the adjusted pseudo dataset.

4.4. Stage four: re-computing efficiency measures

The final stage is to re-compute efficiency scores with the initial DEA model by using the adjusted data. The new efficiency scores incorporate the effects of the external environmental effects. The descriptive statistics of adjusted efficiency scores are shown in Tables 5 and 6 compares the differences from stage 1 to stage 4.

In general, after controlling for the effects of environmental factors, the average efficiency scores, minimum scores, and number of efficient regions all decrease. The decrease in the average scores implies that without controlling for the external environment, the benefit to regions operating under favorable environments is greater than the penalty to regions operating under unfavorable environments. The annual minimum efficiency scores obtained in stage 4 are much lower than in stage 1, indicating the region with the worst managerial energy efficiency operates under favorable environments. The decrease in the number of efficient regions means that without controlling for the external environment, the number of inefficient regions operating under favorable circumstances and misjudged to be efficient is larger than the number of efficient regions operating under unfavorable circumstances and misjudged to be inefficient.

Comparing to the results of Tables 3 and 5, the efficiency scores show that some efficient regions in the first stage such as Penghu County (efficient in 1 year) and Keelung City (efficient in 10 years) are inefficient regions operating under favorable environmental conditions. After controlling for the effects of external environments, Keelung City is inefficient. Chiayi City and Kaohsiung City, inefficient in Table 3 and efficient in Table 5, are both efficient regions operating under unfavorable environmental conditions. After controlling for the effects of external environment, only one in metropolitan areas, one in North Taiwan (Taipei City) and the other in South Taiwan (Kaohsiung City and Chiayi City) are efficient over the sample period. The average values of efficiency scores present a declining pattern from 0.852 to 0.697 since 1998 to 2007, implying

Table 5
Technology efficiency scores with environmental-adjusted scores of stage four in years 1998–2007.

Regions	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Taipei County	0.928	0.919	0.853	0.884	0.895	0.906	0.947	0.947	0.951	0.941
Yilan County	0.550	0.590	0.555	0.503	0.491	0.554	0.515	0.559	0.506	0.454
Taoyuan County	0.720	0.700	0.692	0.676	0.697	0.686	0.722	0.694	0.683	0.685
Hsinchu County	0.499	0.540	0.562	0.536	0.558	0.574	0.606	0.648	0.579	0.512
Miaoli County	0.464	0.480	0.468	0.491	0.481	0.503	0.488	0.484	0.515	0.468
Taichung County	0.629	0.634	0.560	0.522	0.563	0.536	0.537	0.517	0.522	0.532
Chunghua County	0.629	0.540	0.532	0.496	0.574	0.579	0.560	0.518	0.549	0.511
Nantou County	0.502	0.549	0.452	0.442	0.453	0.448	0.482	0.481	0.500	0.415
Yunlin County	0.539	0.516	0.456	0.484	0.442	0.441	0.460	0.418	0.481	0.406
Chiayi County	0.443	0.426	0.456	0.415	0.389	0.395	0.423	0.424	0.428	0.369
Tainan County	0.606	0.572	0.576	0.539	0.547	0.581	0.571	0.516	0.555	0.531
Kaohsiung County	0.684	0.648	0.621	0.569	0.621	0.586	0.630	0.623	0.574	0.632
Pingtung County	0.757	0.677	0.673	0.623	0.670	0.679	0.618	0.637	0.639	0.682
Taitung County	0.405	0.419	0.439	0.440	0.457	0.442	0.464	0.411	0.429	0.408
Hualien County	0.523	0.515	0.538	0.554	0.498	0.520	0.525	0.455	0.472	0.442
Penghu County	0.453	0.483	0.520	0.431	0.413	0.413	0.498	0.430	0.452	0.368
Keelung City	0.802	0.827	0.775	0.720	0.663	0.677	0.823	0.797	0.722	0.757
Hsinchu City	0.610	0.642	0.674	0.708	0.687	0.693	0.775	0.716	0.790	0.796
Taichung City	0.785	0.771	0.667	0.770	0.659	0.713	0.645	0.623	0.671	0.665
Chiayi City	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tainan City	0.855	0.763	0.821	0.780	0.794	0.802	0.808	0.734	0.771	0.838
Taipei City	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Kaohsiung City	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.669	0.661	0.647	0.634	0.633	0.640	0.656	0.636	0.643	0.627
Standard deviation	0.191	0.183	0.181	0.191	0.191	0.190	0.190	0.197	0.191	0.216
Minimum	0.405	0.419	0.439	0.415	0.389	0.395	0.423	0.411	0.428	0.368
Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 6
Differences of stage 1 and stage 4 efficiency scores.

	Average efficiency		Minimum scores		*M–U* statistics
	Stage 1	Stage 4	Stage 1	Stage 4	
1998	0.800	0.669	0.669	0.405	2.63 (0.007)***
1999	0.803	0.661	0.612	0.419	3.01 (0.003)***
2000	0.781	0.647	0.594	0.439	2.97 (0.003)***
2001	0.771	0.634	0.575	0.415	2.80 (0.003)***
2002	0.759	0.633	0.615	0.389	2.85 (0.003)***
2003	0.764	0.640	0.586	0.395	2.94 (0.003)***
2004	0.753	0.656	0.588	0.423	2.45 (0.014)***
2005	0.752	0.636	0.566	0.411	2.43 (0.015)***
2006	0.765	0.643	0.565	0.428	2.67 (0.008)***
2007	0.750	0.627	0.561	0.368	2.26 (0.024)***

Note: Numbers in parentheses are *p*-values. Data sources are compiled from the Bureau of Energy [28], Taipower Company [4] and Taiwan National Statistics [29].
*** Significance at the 1% level.

that regional energy efficiency in Taiwan is worsen. It is worth to note that Kaohsiung City is inefficient in stage 1, but is efficient in all stages when environmental factors are considered. The reason is due to the ratio of higher education grows from 24.99% in 1998 to 38.64% in 2007 and car quantities apparently grows from 310,000 in 1998 to 370,000 in 2007. Besides, the actual values of higher education and cars multiplying the estimated coefficients will increase the slacks, resulting in new inputs promotion. Compared to other county, the increments of adjusted inputs in Kaohsiung City are most significant. This outcome signifies that higher education attainment and transport vehicle are important favorable externalities for Kaohsiung City to improve it energy efficiency.

We further investigate the difference of regional energy efficiency in the analysis of stages 1 and 4, as shown in Table 6. The Mann–Whitney *U* statistics reject the null of equality of two-stage efficiency scores. This implies that there indeed exists difference of unadjusted and adjusted regional energy efficiency at 1% significance level. Besides, this evidence also confirms the importance of controlling for the external environmental factors. Under such circumstance, we may refine the true outcomes of regional energy efficiency.

5. Conclusions

Given Taiwan's declining energy productivity in recent years, energy efficiency is a critical policy issue. This study applies the four-stage DEA procedure developed by Fried et al. [19], which can purge away the effects of external environments, to calculate the pure managerial efficiency of energy for the 23 administrative regions in Taiwan. Empirical evidence indicate that, even compared with Taiwan's own benchmark on energy efficiency, most regions are inefficient in energy use. After controlling for the effects of external operating environments, only Taipei County, Chiayi City, and Kaohsiung City (forming the major metropolitan areas in North and South Taiwan) reach efficiency scores of 1. The evidence further reveals a worsening trend in Taiwan's energy efficiency over the period of 1998–2007. Taiwan relies heavily on imported energy and should be concerned about energy efficiency issue more seriously. As such, more public efforts and better policy coordination are necessary.

Taiwan's cities are generally more efficient in energy use than rural areas. However, after controlling for the external environments, we find that partial cities appearing to be efficient in the first stage of initial DEA, including Keelung City, Penghu County, are actually inefficient regions operating under favorable environmental conditions. On the contrary, Kaohsiung City, which appears to be inefficient in the first stage, is an energy-efficient region operating under favorable environmental conditions due to the promotion of higher education attainment and transport facilities. The annual average efficiency scores obtained in stage four and stage one exists significantly discrepancy and become much lower than without considering external noise factors. These results indicate that the input data must be adjusted for environmental effects since the four-stage DEA procedure can avoid misleading results. For the effects of environmental factors, we find that a higher population density, a higher ratio of population with a higher education, more cars, and more motorcycles are unfavorable environmental conditions for efficient energy use. A higher road density, more profit organizations, a larger share of total employment by industry, a larger share of total employment by service, and more telephones are favorable environmental conditions for efficient energy use.

Our findings have important policy implications. For energy efficiency, not only does a gap exist between Taiwan's metropolitan areas and other regions, but the gap has also widened in recent years. More public efforts should be put forth on improving the energy efficiency of non-metropolitan regions. Besides, the central government should make different energy policies across regions. Taking into consideration the discrepant energy efficiency and the savings potential, those inefficient counties or cities should be given priority and be allocated more energy saving quotas. To improve energy efficiency, as more cars and motorcycles are unfavorable externalities, the central government should help local governments retire inefficient old motor vehicles, encourage energy-saving vehicle models, and provide convenient mass transportation systems. People with higher education cause industrial energy inefficient in Taiwan. The conscious of effective energy saving is necessary to schools, communities, and employees.

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