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Environment-adjusted total-factor energy efficiency of Taiwan's service sectors

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HIGHLIGHTS

- The technical efficiency and energy-saving target of service sectors are assessed.
- The pre-adjusted and environment-adjusted total-factor energy efficiency scores in services are assessed.
- The industrial characteristic differences are examined by the panel-data, random-effects Tobit regression model.
- Labor, capital, and energy and an output (GDP) are included in the DEA model.
- Future new capital investment should also be accompanied with energy-saving technology in the service sectors.

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ABSTRACT

This study computes the pure technical efficiency (PTE) and energy-saving target of Taiwan's service sectors during 2001–2008 by using the input-oriented data envelopment analysis (DEA) approach with the assumption of a variable returns-to-scale (VRS) situation. This paper further investigates the effects of industry characteristics on the energy-saving target by applying the four-stage DEA proposed by [Fried et al. \(1999\)](#). We also calculate the pre-adjusted and environment-adjusted total-factor energy efficiency (TFEE) scores in these service sectors. There are three inputs (labor, capital stock, and energy consumption) and a single output (real GDP) in the DEA model. The most energy efficient service sector is finance, insurance and real estate, which has an average TFEE of 0.994 and an environment-adjusted TFEE (EATFEE) of 0.807. The study utilizes the panel-data, random-effects Tobit regression model with the energy-saving target (EST) as the dependent variable. Those service industries with a larger GDP output have greater excess use of energy. The capital–labor ratio has a significantly positive effect while the time trend variable has a significantly negative impact on the EST, suggesting that future new capital investment should also be accompanied with energy-saving technology in the service sectors.

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1. Introduction

Energy is one of the critical resources for economic development in a country as well as one of the most important input production factors for driving business growth. In accordance with the Kyoto Protocol, which is the international treaty to mitigate global warming, each country is required to reduce its greenhouse gas emissions down to 1990 levels. As energy consumption is the main source of carbon dioxide emissions, the energy efficiency issue has been addressed by both developed and developing economies.

Because Taiwan is a small open and developing economy, it relies heavily on overseas supplies for its energy needs, and as a

result the international economic environment has continuously impacted the country's energy prices. For example, in 2010 the percentage of Taiwan's imported energy accounted for 99.4% of total energy supplies, in contrast to 0.6% of indigenous energy, with total energy supplies in Taiwan hitting 145,561 thousands of kiloliter of oil equivalent (KLOE). In the same year, Taiwan's total energy domestic consumption achieved a record high of 120,308 thousands of KLOE ([Energy Statistics, 2012](#)). Saving energy has thus become an extremely important issue in Taiwan, with existing research studies addressing energy efficiency or productivity on the region level or country level (for example [Bian and Yang \(2010\)](#), [Greening et al. \(1997\)](#), [Guo et al. \(2011\)](#), [Honma and Hu \(2008, 2011\)](#), [Howarth et al. \(1991\)](#), [Hu and Kao \(2007\)](#), [Shi et al. \(2010\)](#), [Worrell et al. \(1997\)](#)). Some researches focused on the fossil fuel power plants with considering the undesirable outputs ([Sueyoshi and Goto, 2012](#)). Furthermore, the capital–labor ratio as the proxy of technology level is one of the important indicators in

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the energy economics. Wu (2012) proposed that the capital–labor ratio reduces inefficient energy use, because new capital utilizes energy-saving technology. However, Blomberg et al. (2012) indicated that even bigger companies with high capital in Sweden might have challenges to improving energy efficiency because of possible risks for production disruptions and the associated costs. However, there is a paucity of research investigating the energy issue in the service sectors as well as the impact of the capital–labor ratio toward the energy efficiency even though the relative share of services in total gross domestic production (GDP) has been increasing and accounts for nearly 70% in Taiwan. Especially, the growth rate of energy consumption in the service sectors from 2001 to 2008 is 20.44% in contrast to the 19.67% as of the industrial sectors in Taiwan. Hence, this paper's objective is to bridge the gap in the literature by measuring the energy efficiency for different subsectors under the service aggregation sectors in Taiwan and to validate the hypothesis of the impact of capital–labor ratio on the energy efficiency in the service sectors.

Ang (2006) defined that energy efficiency is a relative concept. Hu and Wang (2006) indicated that other inputs (for example, labor and capital) together with energy consumption ought to be considered in assessing the energy efficiency. Furthermore, Hu and Wang (2006) developed the index of total-factor energy efficiency (TFEE) to analyze energy efficiencies of 29 administrative regions in China during 1995–2002. Their paper employed data envelopment analysis (DEA), using labor, capital stock, energy consumption, and total sown area of farm crops as the four inputs and real GDP as the single output in order to find the target energy input of each region in China for each particular year. A U-shape relation between an area's TFEE and per capita income in the areas of China empirically confirms the scenario that energy efficiency eventually improves with economic growth.

Hu and Kao (2007) further used constant-returns-to-scale (CRS) DEA by incorporating three inputs (energy, labor, and capital) and a single output (GDP) to establish the energy-saving target (EST) and then measured energy-saving target ratios (ESTRs) for 17 APEC economies during 1991–2000. The empirical results indicate a U-shape relation between per capita EST and per capita GDP. ESTR has a positive relation with the value-added percentage of GDP of the industry sectors and a negative relation with that of the service sectors.

Researchers have also focused on energy efficiency in the energy and manufacturing sectors (for example Blomberg et al. (2012)), though few studies have looked at the energy efficiency of specific industrial sectors. Gouyette and Perelman (1997) took input-oriented DEA and the Malmquist index, including GDP as the single output and labor and capital inventory as two inputs, to measure efficiency and productivity of the manufacturing and service sectors for 13 OECD countries over the 1970–1987 period. The results indicate that the productivity of the service sectors in OECD countries slightly increased, which is mostly caused by an increase in efficiency change. Boyd and Pang (2000) examined the differences in plant-level electricity and fossil fuel intensity in the glass industry. Productivity differences between plants are statistically significant in explaining differences in plant energy intensity. Productivity has a significantly positive impact on the energy efficiency for flat glass, but not for container glass.

Honma and Hu (2013) used DEA with the assumption of variable-return-to-scale (VRS) by incorporating three inputs (energy consumption, labor, and capital stock) and a single output (the value added in each sector) to estimate the TFEE of 17 sectors in Japan during 1998–2005. The empirical result presents that the TFEE is relatively higher in the mining, general machinery, real estate and housing service, and the financial and insurance and service sectors in Japan, in contrast to the relatively lower energy intensity for the agricultural sector, as well as the transportation

and communication sector. Honma and Hu (2011) further computed and analyzed the TFEE of 11 industries in 14 developed countries during 1995–2005 using the DEA approach and by considering four inputs (labor, capital stock, intermediate inputs other than energy, and energy) and one output (the value added). The most inefficient industry is the metal industry, with an average TFEE of 40.6%. The results also identify the most efficient countries in each different time period of 1995–1998, 1999–2002, and 2003–2005. Shi et al. (2010) also used fixed asset, energy consumption, and labor as the inputs of the DEA model to assess the efficiency of 28 different regions in China.

Many studies have criticized energy intensity (EI), which is a commonly used indicator of energy efficiency in the past. EI stands for the energy consumption for producing every unit of real GDP within a certain time frame. Renshaw (1981) and Patterson (1996) suggested that EI considers only partial factors of energy consumption without embracing capital and labor factors. Another critic noted that this partial factor index is inappropriate for investigating the impact of changing energy use over time (Asia Pacific Energy Research Center (APEREC), 2002). Hence, the objective of this paper is three-fold. First, this paper analyzes the pure technical efficiency (PTE) and assesses the energy-saving target of Taiwan's service sectors by employing VRS–DEA. Second, the paper computes the energy-saving target ratio and TFEE for each service subsector developed by Hu and Wang (2006). Third, this study further investigates the effects of industry characteristics on the energy-saving target by applying the four-stage DEA proposed by Fried et al. (1999). We also calculate the pre-adjusted and environment-adjusted total-factor energy efficiency (TFEE) scores in these service sectors.

This paper is organized as follows. The next section describes the theoretical model, which briefly introduces VRS–DEA, TFEE, and the four-stage DEA along with the data collected and variables used. The section following that applies VRS–DEA, and the four-stage DEA to measure pre-adjusted TFEE and environment-adjusted TFEE indices on Taiwan's service sectors. We also examine the hypothesis of capital–labor ratio toward the energy efficiency by applying the panel random-effects Tobit regression. The final section then presents some concluding remarks and future research direction.

2. Efficiency model and TFEE

2.1. VRS–DEA

The paper uses VRS–DEA to determine the input targets for each service sector by comparing the efficiency frontier that is established by all service sectors in Taiwan. The paper utilizes input-oriented measures following Farrell's (1957) work. In order to control the effects of scale, this study adopts the VRS–DEA model (Banker et al., 1984).

A higher efficiency score means that the decision making units (DMUs) use fewer inputs to obtain a given level of outputs (Charnes et al., 1978). All DMUs at the same time constitute the reference set for constructing the efficiency frontier for each DMU_{*i*}. Banker et al. (1984) developed the so-called BCC–DEA model by expanding the CRS–DEA model into a VRS situation as follows:

$$\begin{aligned}
 & \text{Min} && \theta_i \\
 & \theta_i, \lambda_1, \dots, \lambda_N \\
 \text{s.t.} &&& -y_i^m + \sum_{j=1}^N \lambda_j y_j^m \geq 0, \quad m = 1, \dots, M, \\
 &&& \theta_i x_i^k - \sum_{j=1}^N \lambda_j x_j^k \geq 0, \quad k = 1, \dots, K, \\
 &&& \sum_{j=1}^N \lambda_j = 1, \\
 &&& \lambda_1, \dots, \lambda_N \geq 0,
 \end{aligned} \tag{1}$$

where θ is a scalar and the PTE for the i th DMU, with $0 \leq \theta \leq 1$; there are K inputs and M outputs for each of the DMU, respectively. The i th DMU is represented by the column vectors x_i and y_i , and λ is an $N \times 1$ vector of constants.

The value $\theta=1$ indicates a point on the efficient frontier and hence presents technically efficient sectors, in accordance with Farrell's (1957) definition. The frontier is a piecewise linear isoquant, determined by the observed data points of the same year. The sectors that construct the frontier are the efficient sectors among those observed sectors in that year. The weight vector λ forms a convex combination of observed inputs and outputs.

The set on the frontier is the production of best practices among the observed sectors. For the i th sector, the distance (amount) from the projected point on the frontier by radial reduction without reducing the output level, $(1-\theta)x_i$, is called the 'radial adjustment'.

2.2. Four-stage DEA Models & TFEE index

Technical efficiency reflects the ability of firms to use as little input as possible to obtain a given level of output. Fried et al. (1999) introduced a four-stage DEA. The management component of inefficiency is separated from the influences of the external environment, because the management level is not able to control these influences. The result is a radial measurement of managerial efficiency. It is indeed the assessment of managerial competence on running a business. The first stage calculates a DEA frontier using the observable inputs and outputs according to the VRS model in Eq. (1).

The summation of slack and radial adjustments is the total amount ('target') that can be reduced without decreasing the output levels. With respect to energy input, the above summation is called the 'energy-saving target' (EST), and the formula is

$$EST_{(i,t)} = \text{Non-radial Slack Adjustment for Energy}_{(i,t)} + \text{Radial Adjustment for Energy}_{(i,t)}, \quad (2)$$

where $EST_{(i,t)}$ refers to the EST in the i th sector and the t th year.

An inefficient sector can reduce EST in energy use without reducing real economic growth. The DEA model suggests that the input slack and radial adjustments of any individual input for all objectives are efficient. The actual energy consumption is larger than or equal to the ideal energy input, because the actual practice is able to improve to become the best practice.

Efficiency is generally defined as the ratio of the value of the best practice compared to that of the actual practice. The energy-saving target ratio (ESTR) index is therefore the ratio of the aggregate energy-saving target from Eq. (2) to actual energy consumption. The total adjustments in energy input are regarded as the inefficient portion of actual energy consumption. Hu and Wang (2006) indicated that the ESTR in Eq. (3) can be measured based on the slack and radial adjustments of energy obtained from the DEA model

$$ESTR_{(i,t)} = \frac{EST_{(i,t)}}{\text{Actual Energy Input}_{(i,t)}}, \quad (3)$$

where $ESTR_{(i,t)}$ refers to the ESTR in the i th sector and the t th year.

As Eq. (3) indicates, the ESTR represents each sector's inefficient level of energy consumption. Since the minimal value of EST is zero, the value of ESTR lies between zero and unity. The total-factor energy efficiency (TFEE) index originally developed by Hu and Kao (2007) and Honma and Hu (2008) is related to the ESTR as in Eq. (4)

$$TFEE_{(i,t)} = 1 - ESTR_{(i,t)}, \quad (4)$$

where $TFEE_{(i,t)}$ refers to the TFEE in the i th sector and the t th year.

A zero ESTR value means a sector is on the frontier with the best TFEE (up to one) among the observed sectors and also indicates that no redundant or over-consumed energy use exists in this sector; otherwise, an inefficient sector with the value of ESTR larger than zero shows that energy needs to be saved at the same economic growth level. A higher ESTR and lower TFEE imply higher energy inefficiency and a higher energy-saving amount, and vice versa.

The different industry characteristics generate different impacts on the EST. In order to incorporate these industry characteristics, the second stage of Fried et al. (1999) used a cross-sectional Tobit regression to adjust these environmental impacts. This study estimates the energy consumption equation by implementing a panel Tobit regression in Eq. (5). The dependant variables are radial plus slack input movement for energy consumption; the independent variables are measures of environmental variables applicable to this particular input. The objective is to quantify the effect of external conditions on the excessive use of inputs.

$$EST_{(i,t)} = f(E_{(i,t)}, \beta_{(i,t)}, u_{(i,t)}); \quad i = 1, \dots, N; \quad t = 1, \dots, T. \quad (5)$$

where $EST_{(i,t)}$ is the total radial plus slack movement for the energy input of service sector i on time T based on the DEA results from stage 1; $E_{(i,t)}$ is a vector of variables characterizing the operating environment for different service i that may affect the utilization of the input; $\beta_{(i,t)}$ is a vector of coefficients and $u_{(i,t)}$ is a disturbance term.

The third stage uses the estimated coefficients from the above-mentioned equations to predict the total input slack for each service sector based on its industry characteristic difference:

$$EST_{(i,t)} = f(E_{(i,t)}, \beta_{(i,t)}); \quad i = 1, \dots, N; \quad t = 1, \dots, T \quad (6)$$

These predictions are used to adjust the primary energy data for each service sector based on the difference between maximum predicted total energy slack and predicted total energy slack:

$$AEI_{(i,t)} = \text{Actual Energy Input}_{(i,t)} + [\text{Max}\{EST_{(i,t)}\} - \hat{E}(EST_{(i,t)}|E_{(i,t)})]; \quad i = 1, \dots, N; \quad t = 1, \dots, T. \quad (7)$$

This study uses the concept of using the least favorable operating environment as the basis from Fried et al. (1999). The notation AEI means the adjusted energy input. This generates a new projected dataset where the inputs are adjusted for the influence of external conditions.

The final stage uses the adjusted dataset to re-compute the DEA model under the initial output data and adjusted input data. The result generates new radial and slack measures of inefficiency. These radial and slack scores measure the inefficiency that is attributable to environmental characteristics.

$$ADJ_EST_{(i,t)} = \text{Non-radial Slack Adjustment for Energy}_{(i,t)} + \text{Radial Adjustment for Energy}_{(i,t)} \text{ after the final-stage DEA}, \quad (8)$$

where $ADJ_EST_{(i,t)}$ refers to the adjusted EST in the i th sector and the t th year after incorporating the industrial characteristics.

This study yields the adjusted energy-saving target (ADJ_EST) and adjusted energy-saving target ratio (ADJ ESTR) in Eq. (9), incorporating the different industrial characteristics

$$ADJ_ESTR_{(i,t)} = \frac{ADJ_EST_{(i,t)}}{AEI_{(i,t)}}, \quad (9)$$

where $ADJ_ESTR_{(i,t)}$ refers to the ADJ ESTR in the i th sector and the t th year.

The environment-adjusted total-factor energy efficiency (EATFEE) index is related to the ADJ_EST as in Eq. (10):

$$EATFEE_{(i,t)} = 1 - ADJ_ESTR_{(i,t)}, \quad (10)$$

where $EATFEE_{(i,t)}$ refers to the environment-adjusted TFEE in the i th sector and the t th year.

Existing research studies have criticized the commonly used indicator of energy inefficiency, which is the EI, as a direct ratio of energy consumption to GDP. The ratio is only a partial factor of the energy efficiency index without considering the capital and labor inputs. Hence, this paper measures energy efficiency using the TFEE index by a total-factor framework, extending to include EATFEE after incorporating the industry characteristic differences using the four-stage DEA in order to provide more information and a more realistic comparative base to examine the de facto situation across sectors.

3. Empirical results and analysis

3.1. Data and variables

The first major objective of this section is to derive PTE and TFEE in Taiwan's service sectors over the 2001–2008 periods. Service is defined as the aggregation of four service sectors in Taiwan including: (1) wholesale and retail trade sector; (2) transportation and storage sector; (3) lodging and catering sector; and (4) finance, insurance and real estate sector.

We apply the DEA to a dataset of these 4 service subsectors during the 2001–2008 periods. The paper uses three inputs (capital input, labor employment, and energy consumption) and a single output (real GDP) to assess the PTE of each sector.

Data regarding real GDP (NT\$ million) were collected from the Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan. Two data inputs (capital input and labor employment) were obtained from the database of Advanced Retrieval and Econometric Modeling System (AREMOS) and a third data input, energy consumption, from the Bureau of Energy (Bureau of Energy, Ministry of Economic Affairs, 2013). All nominal variables are transformed into real variables at the 2006 price level by Taiwan's GDP deflators. The units of real GDP, labor employment, real capital, and energy consumption are NT\$

million, 1000 persons, NT\$ million, and millions of tons of oil equivalent (Mtoe), respectively. Table 1 shows the summary statistics of these inputs and output. Table 2 presents the correlation coefficients of the input and output variables. The isotonicity property—that an output should not decrease with an increase in an input—is not violated.

3.2. Empirical results and analysis

3.2.1. PTE from BCC-DEA

This study uses the software DEAP 2.1 provided by Coelliet al. (2005) to assess the annual PTE from Eq. (1). The average PTEs for these 4 service sectors during 2001–2008 are 0.84, 0.84, 0.83, 0.83, 0.84, 0.89, 0.95, and 0.95 in Table 3, respectively. Even though there is an increasing trend in terms of PTE after 2004, the result shows that there is a 5–18% improvement in input resource savings.

Table 3 also reveals that the PTEs of the two sectors of finance, insurance and real estate and transportation and storage are higher than the other two sectors. The financial service sector has been apparently continuous working on business process reengineering (BPR). The financial holding companies established since 2002 have also created capital efficiency in the financial service sector. The transportation and storage sector has the second highest efficiency score among these four service sectors over the period 2001–2008. The wholesale and retail trade sector obtains the lowest efficiency in the service sectors during 2001–2008. This result indicates that the financial service and

Table 2
Correlation coefficients of inputs and output.

	Real GDP (y_1)	Capital (x_1)	Labor (x_2)	Energy consumption (x_3)
y_1	1.0000			
x_1	0.3530	1.0000		
x_2	0.5956	0.5545	1.0000	
x_3	0.0443	0.0834	0.7419	1.0000

Table 1
Description and summary statistics of variables.

Variables	N	Mean	Std dev	Maximum	Minimum
Real GDP (NT\$ million)	32	1,112,970	843,781	2,345,685	202,018
Wholesale and retail trade	8	2,038,974	230,703	2,345,685	1,757,734
Transportation and storage	8	379,052	26,704	414,210	344,197
Lodging and catering	8	220,420	17,126	243,592	202,018
Finance, insurance and real estate	8	1,813,434	178,896	2,047,154	1,615,800
Capital (NT\$ million)	32	2,732,851	1,617,469	5,149,814	683,808
Wholesale and retail trade	8	4,507,343	422,392	5,149,814	3,954,886
Transportation and storage	8	3,995,252	410,556	4,523,873	3,414,821
Lodging and catering	8	761,472	57,750	849,419	683,808
Finance, insurance and real estate	8	1,667,336	277,015	2,054,554	1,272,692
Labor (Thousand persons)	32	804	550	1782	407
Wholesale and retail trade	8	1729	38	1782	1679
Transportation and storage	8	415	4	421	407
Lodging and catering	8	622	55	687	532
Finance, insurance and real estate	8	451	29	485	413
Energy consumption (Mtoe)	32	892,979	551,674	1,605,268	273,620
Wholesale and retail trade	8	1,491,469	108,389	1,605,268	1,312,870
Transportation and storage	8	438,732	50,388	508,718	373,240
Lodging and catering	8	1,351,341	181,981	1,548,068	1,110,760
Finance, insurance and real estate	8	290,376	10,588	300,847	273,620

Note: The base year for real GDP and real capital is 2006.

Table 3
Pure technical efficiency (PTE) for the service sectors in Taiwan during 2001–2008.

Service sectors Index	2001 PTE	2002 PTE	2003 PTE	2004 PTE	2005 PTE	2006 PTE	2007 PTE	2008 PTE
Wholesale and retail trade	0.38	0.39	0.39	0.42	0.52	0.73	0.98	1.00
Transportation and storage	0.97	1.00	0.98	0.97	0.99	0.98	0.98	0.98
Lodging and catering	1.00	0.99	0.94	0.92	0.90	0.88	0.85	0.82
Finance, insurance and real estate	1.00	1.00	1.00	1.00	0.97	0.98	1.00	1.00
Mean	0.84	0.84	0.83	0.83	0.84	0.89	0.95	0.95

transportation and storage sectors have a competitive capability for using less capital, labor, and energy to yield a certain GDP.

From the statistics of the Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan, total employment in the wholesale and retail trade sector is the highest among the service sectors, accounting for 1.77 million persons (17%), in contrast to 0.69 million persons (6.6%) in the lodging and catering sector, and 74,000 persons (0.7%) in the real estate sector. This finding shows that the wholesale and retail trade sector needs much improvement in the input of resources, especially on labor savings. The PTE of the lodging and catering sector obviously decreases after 2003. The severe acute respiratory syndrome (SARS) outbreak in 2003 weakened Taiwan's economy as well as its tourism industry. This event also proved that the slowdown in the economy had a great impact on lodging and catering businesses.

3.2.2. Four-stage DEA, TFEE, and environment-adjusted TFEE indices

This study further utilizes Eqs. (2)–(4) to measure TFEE for each service sector in Table 5. The result of TFEE presents a similar pattern with that of PTE. The financial service sector has the highest TFEE among the service sectors herein. Particularly, energy in the financial service sector might be consumed less than in the other service sectors. Honma and Hu (2013) also indicated that the financial and insurance sector has the high level TFEE in Japan. They pointed out that the tertiary industries, except for the transportation and communication sector, have higher TFEE scores in Japan, which is consistent with this paper's finding. The government needs to develop financial service businesses to yield a relatively higher GDP under the given labor and energy. Weber (2005) further indicated that banks have pursued cost saving effects by reducing their consumption of energy, water, and resource materials. Banks also have demonstrated their environmental strategy of 'going for green' to attract more customers. The TFEE in the wholesale and retail trade sector dramatically increases to a record high in 2008. The 3R (recycling, reuse, and refill) policy in Taiwan has resulted in obvious progress in the wholesale and retail trade sector. The popular recycle containers in supermarkets have helped promote the concept of energy conservation, while the severe price-cutting competition among wholesalers and retailers in Taiwan have also indirectly had a positive impact on the energy-saving action.

The TFEE of the transportation and storage sector has deteriorated since 2003. In contrast with a GDP growth rate of 17% in this sector, the input resource consumption growth rate of capital and energy in this sector increased 27.2% and 30%, respectively. This finding is a reminder to the management of this sector to pay attention to resource efficiency. This finding is consistent with the work in Japan by Honma and Hu (2013), as they indicated that the transportation and communication sector in Japan had high fuel consumption. Chen et al. (2009) suggested that the efficient use of energy, the introduction of non-fossil fuels, and the development of innovative technologies are essential strategies for establishing a robust renewable energy technology portfolio plan.

Table 4
Panel random-effects Tobit regression for EST.

Variable	Coefficient	Standard error
GDP share for each service industry	3,467,059*	1,803,212
Labor share for each service industry	−3,895,604	2,798,850
Energy share for each service industry	7,004,991**	3,244,409
Capital–labor ratio	143.03**	69.62
Time trend	−37,735.13*	19,657.99
Constant	−1,810,437**	815,727.50
Wald statistic	81.15	
Log likelihood	−437.73	

* Significant at the 10% level.

** Significant at the 5% level.

To understand the industrial variation in EST and its determinants, we compute four industrial characteristics indices, including GDP shares, labor use shares, energy consumption shares, and capital–labor ratio, by using the panel random-effects Tobit regression for EST in Eq. (6). Metcalf (2008) indicated that energy and technology might have a substitution effect.

Wu (2012) used the capital–labor ratio as the proxy of the technology level and hypothesized that the capital–labor ratio reduces inefficient energy use, because new capital utilizes energy-saving technology. This study also includes a time trend variable to capture the trend of change over time. Table 4 shows that a (positive) negative coefficient on these environmental variables suggests that the environment is (un)favorable for a DMU, since it is associated with (greater) less excess use of energy.

Several findings can be drawn from the estimation results of the random-effects Tobit regression. A GDP share variable has a significantly positive effect on the EST, which indicates that those service industries with more GDP output have greater excess use of energy. The capital–labor ratio also has a significantly positive effect on the EST, which is not consistent with Wu's findings on regions in China. This may be because more high-tech service industries in Taiwan use more energy-consuming facilities that are not so energy-efficient. Blomberg et al. (2012) also indicate that even bigger companies in Sweden may face significant barriers to improving energy efficiency because of possible risks for production disruptions and the associated costs. Meanwhile, the medium sized companies also have the lower priority to increase the capital turnover in order to address on the energy efficiency issue (Blomberg et al., 2012). Therefore, the service industries in Taiwan should pay attention to energy efficiency of newly acquired facilities. A time trend variable has a significantly negative impact on the EST and indicates less excess use of energy over 2001–2008 among the service industries in Taiwan.

Table 5 compares the TFEE and environment-adjusted TFEE (EATFEE) for the individual services industry in Taiwan. Fig. 1 indicates the comparisons of TFEE and EATFEE for the wholesale and retail trade sector during 2001–2008. The graph illustrates that the EATFEE and TFEE have a similar increasing pattern for this sector, with the EATFEE obviously higher than the TFEE after incorporating the industrial characteristics. The GDP real growth

Table 5
TFEE and environment-adjusted TFEE (EATFEE) for the service sectors in Taiwan during 2001–2008.

Service sectors	2001		2002		2003		2004		2005		2006		2007		2008	
	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE	TFEE	EATFEE
Wholesale and retail trade	0.23	0.48	0.22	0.52	0.21	0.35	0.20	0.45	0.29	0.65	0.55	0.82	0.89	1.00	1.00	1.00
Transportation and storage	0.97	1.00	1.00	1.00	0.96	0.45	0.94	0.47	0.90	0.50	0.80	0.49	0.80	0.43	0.76	0.38
Lodging and catering	1.00	1.00	0.99	0.89	0.91	0.55	0.84	0.56	0.76	0.55	0.73	0.52	0.72	0.49	0.71	0.45
Finance, insurance and real estate	1.00	1.00	1.00	0.66	1.00	0.39	1.00	0.64	0.97	0.86	0.98	1.00	1.00	1.00	1.00	0.90
Mean	0.80	0.87	0.80	0.77	0.77	0.43	0.74	0.53	0.73	0.64	0.76	0.71	0.85	0.73	0.87	0.68

Note: TFEE and EATFEE stand for total factor of energy efficiency and environment-adjusted energy efficiency, respectively.

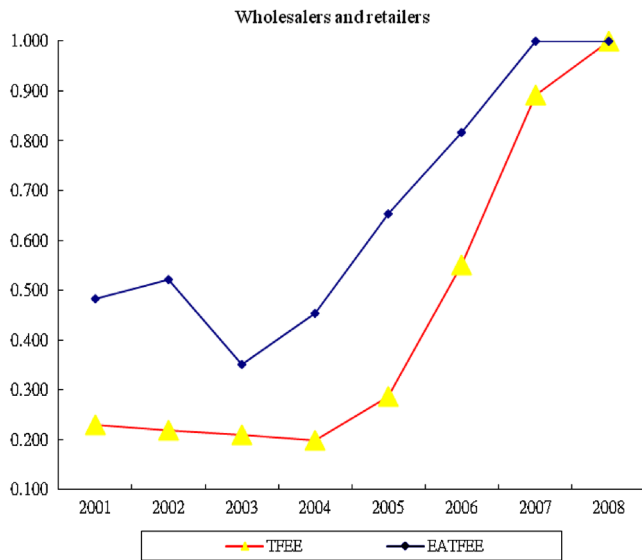


Fig. 1. The trend of TFEE and EATFEE in the wholesaler and retailer sector during 2001–2008.

rate in Taiwan was 3.67% in 2003, and had increasingly to 6.19% in 2004, respectively (Directorate General of Budget, Accounting and Statistics of the Executive Yuan, 2013), which led to the dramatically jump for the TFEEs in the wholesale and retail trade sector. Meanwhile, the Bureau of Energy, Ministry of Economic Affairs in Taiwan had firstly established in 2004 leading to the possible positive impact on the energy efficiency since 2004. However, this finding suggests that there is much room for energy-saving improvement among wholesalers and retailers after incorporating the unfavorable factors (GDP, energy consumption, capital–labor ratio) compared to capital and labor. Hence, this finding also offers a recommendation for wholesale and retail trade to keep up their cost savings through energy-saving actions even though there is a significant movement toward the efficient frontier for the TFEE and EATFEE in 2008.

Fig. 2 illustrates the comparisons of TFEE and EATFEE in the transportation and storage sector. The empirical results reveal a worsening trend in TFEE in this sector over 2005–2008. As a result of controlling for the industrial characteristics, the EATFEE has decreased in the sector since 2003 and indicates that without controlling for the industrial difference, the penalty to this sector operating under favorable factors is less than the benefit to this sector operating under favorable industrial characteristics. These favorable environments (less energy consumption and lower capital–labor ratio in the transportation and storage sector) provide much benefit for the TFEE of this sector.

Fig. 3 illustrates that the TFEE and EATFEE in the lodging and catering sector have a decreasing trend in the 2003–2008 period. During the same period, the TFEE and EATFEE in this sector

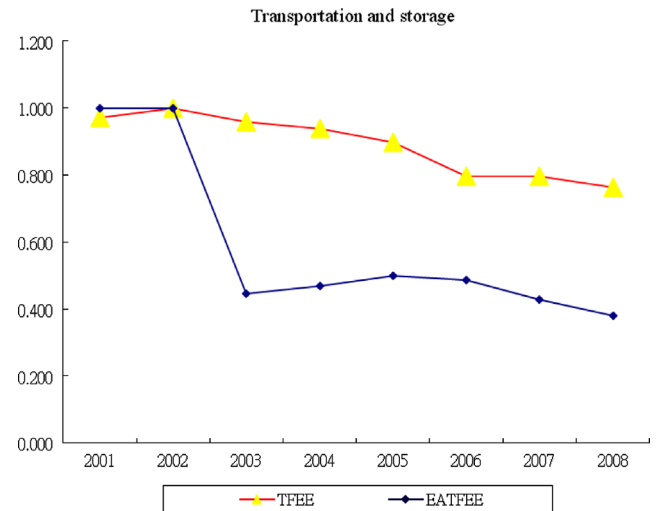


Fig. 2. The trend of TFEE and EATFEE in the transportation and storage sector during 2001–2008.

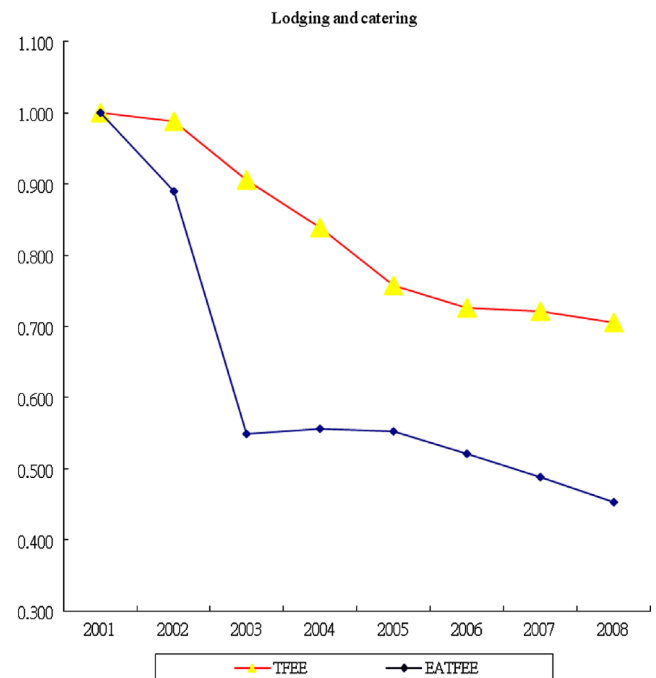


Fig. 3. The trend of TFEE and EATFEE in the lodging and catering sector during 2001–2008.

present a similar pattern with the transportation and storage sector. These favorable environments (less energy consumption and lower capital–labor ratio in the lodging and catering sector)

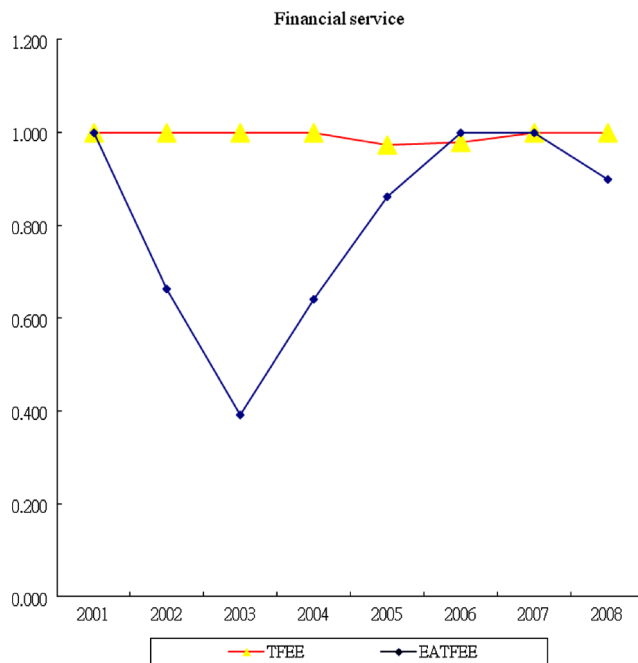


Fig. 4. The trend of TFEE and EATFEE in the financial service sector during 2001–2008.

provide much benefit for the TFEE of this sector. Even though Taiwan's environmental law has restricted the use of non-washable dining utensils in restaurants since 2006, which possibly led to the slightly drop for the TFEE and EATFEE in the sector of lodging and catering. This finding shows that energy efficiency also needs improvement in the lodging and catering sector.

Fig. 4 shows the trend of TFEE and EATFEE in the financial service sector in the 2001–2008 periods. The results show that TFEE and EATFEE hit the efficient frontier in the financial service sector during 2006–2007. The comprehensive conclusion in the National Energy Conference in 2005 alleged that the energy service company (ESCO) establishment in Taiwan had led the energy efficiency improvement for the peripheral banking and leasing business because of the increasing loan amounts for procurements of energy-saving equipment since 2005. Aside from the synergy creation in financial holding companies since 2003, merger and acquisition activities in this sector have also promoted cost savings, capital efficiency, and cross selling to yield overall efficiency. The unfavorable industrial characteristics (second highest GDP share, second highest capital–labor ratio) benefit the TFEE in this sector.

Being a small open economy highly dependent on imported energy, Taiwan needs to put forth a lot of effort and a better policy execution on energy saving and conservation. To achieve better performance in improving energy efficiency, those service sectors with worsening and/or poor energy efficiency should receive more attention from policy makers. Particularly, the Taiwan Tourism Bureau (TTB) needs to offer incentives for lodging and catering businesses to offer green hotels or green restaurants. In order to accomplish energy-saving benefits in the lodging industry, TTB could include “green” criteria in TTB's hotel star-rating system. Offering incentives to use solar water heaters and green furniture in the service sectors could also minimize the gap between the PTE and TFEE.

Önüt and Soner (2006) suggest that the lodging industry could install solar energy systems for different departments such as swimming pools and laundry. Meanwhile, the hoteliers could control and repair all water related equipment as soon as possible and it was also suggested monitoring water consumption

periodically. To encourage water saving programs by a permanent promotion program for employees and customers, and using low flow shower heads are the way to save the energy consumption.

The financial services sector has the best performance among the four service sectors in terms of TFEE and EATFEE. This result is consistent with the work from Honma and Hu (2013) on Japan's financial industries. Their empirical result indicates that the TFEE is relatively higher in the real estate and housing service sector as well as the financial and insurance service sector in Japan.

From the statistics of the Directorate General of Budget, Accounting and Statistics of the Executive Yuan in Taiwan, total employment in the wholesale and retail trade sector is the highest among the service sectors, accounting for 1.77 million persons (17%). The TFEE and EATFEE in the group sector of lodging and catering show a deteriorating trend, as the severe acute respiratory syndrome (SARS) in 2003 weakened Taiwan's economy. In fact, the tourism industry experienced the highest stock price decline (Chen et al., 2007) during this time.

4. Concluding remarks and future research

This research utilizes the VRS–DEA to assess the PTE, TFEE, and EATFEE of service sectors in Taiwan over the period 2001–2008. In contrast to the traditional EI, which considers only the direct ratio of energy input to GDP for assessing energy efficiency without embracing capital and labor factors, we measure TFEE and EATFEE by incorporating the industrial characteristics and extending the four-stage DEA proposed by Fried et al. (1999), which includes inputs such as energy, labor, and capital. A better comprehensive indicator for energy efficiency provides more information for improvement and more comparative suggestions for different service subsectors.

The results herein show that there is a 5–18% potential improvement on input resource savings in Taiwan's service sectors, although there is an increasing trend in terms of PTE after 2004. The PTE of two sectors (the finance, insurance and real estate sector and the transportation and storage sector) is higher than that of the other two sectors. The financial service sector has been dramatically working on BPR and organizational reshuffling in order to establish financial holding companies or push mergers among financial institutions, causing consolidation synergy to gradually appear. The empirical result also indicates that TFEE and EATFEE of the finance, insurance and real estate sector have the highest score among all service sectors during 2001–2008. Both the wave of mergers and acquisitions and the establishment of financial holding companies during 2002–2004 helped motivate energy efficiency in the financial service arena. This result also confirms that 3C (cross-selling, capital-efficiency, and cost-saving) synergy in the financial service sector was created, because financial holding companies were established. At the same time, the financial institutions pursued cost savings effects by reducing their consumption of energy, water, and materials and demonstrated their environmental strategy of ‘going for green’ in order to attract more customers (Weber, 2005).

The PTE of the wholesale and retail trade sector is the worst, and this group sector needs a lot of improvement on input resources, especially labor savings. The PTE of the lodging and catering sector had an obvious decreasing trend after 2003. The SARS outbreak in 2003 and the global financial turmoil in 2008 weakened Taiwan's economy as well as its tourism industry. These events also prove that a slow economy has a great impact on lodging and catering businesses.

This study further utilizes the panel-data, random-effects Tobit regression model with the EST as the dependent variable. Those service industries with more GDP output have greater excess use

of energy. The capital–labor ratio has a significantly positive effect, while the time trend variable has a significantly negative impact on the EST, indicating that more high-tech service industries in Taiwan use more energy-consuming facilities that may not be more energy-efficient. Therefore, the service industries in Taiwan should pay attention to energy efficiency of their newly acquired facilities. A time trend variable has a significantly negative impact on the EST, indicating less excess use of energy over 2001–2008 among the service industries in Taiwan.

The EATFEE is obviously higher than the TFEE after incorporating the industrial characteristics in the wholesale and retail trade sector. This finding suggests that there is much room for energy-saving improvement among wholesalers and retailers after incorporating the unfavorable factors (GDP, energy consumption, capital–labor ratio) compared to capital and labor. Hence, this finding also offers a recommendation for wholesalers and retailers to keep up their cost savings through energy-saving actions even though they show a significant achievement toward the efficient frontier for the TFEE and EATFEE in 2008.

The TFEE of the transportation and storage sector has been decreasing since 2003, showing that this sector has relatively high fuel consumption. This finding is consistent with the results in Japan (Honma and Hu, 2013). Establishing a robust renewable energy technology portfolio plan should yield an efficient use of energy (Chen et al., 2009). After controlling for the industrial characteristics, the EATFEE also has been decreasing in the transportation and storage sector since 2003 and indicates that without controlling for the industrial difference, the penalty to this sector for operating under favorable factors is less than the benefit to this sector for operating under favorable industrial characteristics.

The TFEE in the wholesale and retail trade sector dramatically increased to a record high in 2008. The 3R (recycling, reuse, and refill) policy in Taiwan has resulted in obvious progress for this sector. For example, popular recycle containers in supermarkets help promote the concept of energy conservation. The most energy efficient service sector is finance, insurance and real estate. It has an average TFEE of 0.994 and environment-adjusted TFEE (EATFEE) of 0.807.

Being a small open economy highly dependent on imported energy, Taiwan has to put forth a lot of effort and a better policy execution on energy savings and conservation. In fact, Taiwan's indigenous energy supply has fallen so much that it has only accounted for less than 1% of total energy supply since 2003 (Energy Statistics, Bureau of Energy, Ministry of Economic Affairs) in contrast to more than 99% of energy supply being imported. Policy makers should pay more attention to those service sectors with poor energy efficiency. For example, the Taiwan Tourism Bureau (TTB) could offer incentives for green hotels or green restaurants in order to improve energy efficiency in the catering and lodging sector. The TTB could further combine 'green' criteria into the on-going hotel star-rating system. Taiwan's government should encourage restaurateurs to measure, list, and mitigate their carbon footprint on each menu item. Even though Taiwan government alleges main six promotions for energy saving: "(1) Promote energy saving light bulb; (2) Apply thermostat timer on water dispenser and water fountain machine; (3) Set up one degree more for the temperature in summer time and clean the filter; (4) Be sure to power off the computer, instead of idling for a while; (5) Promote unplugging the electric appliance; (6) Promote turning off the light for an hour during lunch break for governmental and regular business office buildings (Bureau of Energy, Ministry of Economic Affairs)," offering financial incentives to use solar water heaters, green furniture, and other energy-saving equipment in the service sectors could also enhance energy efficiency through electricity, gas, and other energy-saving plans.

The government in Taiwan at the same time needs to address the issue of whether new capitals bring energy-saving technology into the rapidly expanding service sectors. According to this study's empirical findings on the service industries in Taiwan, a high capital–labor ratio tends to have excess energy consumption during the period of 2001–2008. Hence, the replacement of old equipment and infrastructure and new capital inflow with energy-saving technology are two very important issues among the service sectors in Taiwan.

Future research can focus on assessing energy efficiency in a specific service industry, such as banking, securities, insurance, etc. Measuring energy efficiency by a total-factor framework and extending it to include more input resources will enhance the comprehensiveness of energy efficiency and offer policy makers further industry structure suggestions to improve a country's overall energy efficiency.

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