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Efficient energy-saving targets for APEC economies

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Abstract

Energy-saving target ratios (ESTR) for 17 APEC economies during 1991–2000 are computed in a total-factor framework. All nominal variables are transformed into real variables by the purchasing power parity (PPP) at the 1995 price level. The data envelopment analysis (DEA) approach is used to find the energy-saving target (EST) for APEC economies without reducing their maximum potential gross domestic productions (GDPs) in each year. Energy, labor, and capital are the three inputs, while GDP is the single output. Our major findings are as follows: (1) China has the largest EST up to almost half of its current usage. (2) Hong Kong, the Philippines, and the United States have the highest energy efficiency. (3) The energy efficiency generally increases for APEC economies except for Canada and New Zealand. (4) Chile, Mexico, and Taiwan have significantly improved their energy efficiency in the last 5 years. (5) An inverted U-shape relation exists between per capita EST and per capita GDP. (6) ESTR has a positive relation with the value-added percentage of GDP of the industry sector and a negative relation with that of the service sector.

Keywords: Energy-saving target (EST); Energy-saving target ratio (ESTR); Industrial structure

1. Introduction

Energy saving has been a crucial issue for sustainable development. During the past 300 years, economic development all over the world has relied on depletable petro-fossil fuels. Therefore, before new and substitute fuels become available, energy saving is a must in order to make economic growth possible. Asia-Pacific Economic Cooperation (APEC) economies include the fastest economies in the world and have attracted the most foreign capital, technology, as well as managerial know-how during the past 20 years. Fast-developing economies and fast-growing energy consumption definitely add pressure to petro-fossil fuels' depletion. However, many people worry that drastic savings in energy will hamper economic growth. Therefore, finding efficient ESTs for APEC economies without reducing the potential maximum economic growth has become a very important issue.

Ever since the Kyoto Protocol became effective in February 2005, reducing the consumption of fossil fuels has been a focal point of environmental policy in many economies including developed and developing ones (de Nooij et al., 2003). The energy system plays a central role in the interrelated economic, social, and environmental aims of sustainable human development (WCED, 1987). Energy issues must be integrated with environmental management to achieve sustainable development, especially for fast-developing economies. Energy efficiency improvement is the key to sustainable energy management. For example, European Union estimates that realizing 10–20% of efficiency potential in the European use of electricity would save 10–20 billion ECU annually in terms of fossil fuels use. In Malaysia, it is expected that aggressive deployment of energy efficiency could save about US$1.38 billion by 2015 (Keong, 2005). The economic energy efficiency potentials of various industries range from 2% to 18% in the United States in 2010, 5% to 40% in China in 2010, and 2.2% to 28.5% in Thailand 2005 (WEC et al., 2000). Hu and Wang (2006) also indicate that China can improve its energy efficiency in various regions without reducing its potential economic

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growth. These studies also show that developing economies have more energy efficiency potentials than developed ones.

The Joint Economic Committee of the Congress of the United States (1981) proposed a commonly used indicator of energy inefficiency—the energy intensity as a direct ratio of the energy input to GDP. However, there has been widespread criticism of using energy intensity for measuring energy efficiency (Patterson, 1996). The main problem with energy/GDP, as pointed out by Wilson et al. (1994), is that it does not measure the underlying technical energy efficiency, which can lead to misleading conclusions. For example, the energy intensity may decrease solely because energy is substituted for labor, rather than any underlying deterioration in the technical energy efficiency (Patterson, 1996). Energy is the prime source of value, because other factors of production such as labor and capital cannot do without energy (Ghali and El-Sakka, 2004). The use of the energy efficiency indicator in conjunction with labor and capital can provide useful insights into whether or not energy inputs act as complements or substitutes to other inputs (Patterson, 1996).

Given the limited availability of economically viable alternative energy sources, reducing total domestic energy use without sacrificing economic growth is an important issue for economies all over the world (de Nooij et al., 2003). ESTs are hence important for all economies. In the same way, energy efficiency improvement should rely on total factor productivity improvement (Boyd and Pang, 2000). Therefore, a multiple input–output model should be applied for evaluating an EST with a total-factor model.

Data envelopment analysis (DEA) finds the efficient outputs and inputs in a total-factor framework. This technique makes use of information available in considering factors simultaneously. Efficiency is defined by the difference in the 'best practice' production frontier, as measured by DEA. The 'best practice' in the frontier is the benchmark to calculate the projected and possible energy saving for those not on the frontier. By comparing the relative practice of various inputs and output in different economies, we can identify the main amount (target) of energy saving likely to be found. Thus, the performance of the economies that have the 'best practices' can serve as a benchmark to evaluate a particular economy's energy consumption. A similar approach to construct abatement ratios from the total-factor framework can be found in Hu (2006) and Hu and Wang (2006).

Few studies apply DEA to compare productivity and efficiency by considering energy use across countries: Färe et al. (2004) used DEA to construct an environmental performance index focusing on pollution. In their study, energy is just one part of the inputs that are taken into account. Since their major objective is to find a method considering undesirable outputs, they used output-oriented DEA models. Edvardsen and Førsund (2003) and Jamasb and Pollitt (2003) analyzed the benchmarking of the electricity industry in Europe and Northern Europe at the plant level. A special feature of this across economies study herein is that the data (for 1990s) are based on a sample of APEC economies at the economy level and the focus is on the use of energy.

The causes of rapid Asian economic growth and its sustainability have generated considerable debates since the early 1990s (e.g., World Bank, 1993; Krugman, 1994; Kim and Lau, 1994, 1995; Young, 1994, 1995; Chen, 1997; Drysdale and Huang, 1997; Krüger et al., 2000; Chang and Luh, 2000). Many economies have adopted energy efficiency policies and measures, but systematic information is only available for OECD economies. There is hence a significant need to improve energy efficiency policy collaboration among APEC economies and disseminate successful practices (APERC, 2002). As such, the energy efficiency among APEC economies is worth further studying. Focusing on the international association as a partnership in sharing technology and resources, we apply the DEA approach using multiple inputs containing capital, labor, and energy consumption in order to analyze the total-factor energy efficiency of APEC economies. This analysis computes the possible energy savings without reducing the maximum potential economic outputs for APEC economies.

The paper is organized as follows: Section 2 explains how to identify the 'best practice' and construct the total-factor energy efficiency indicator based on DEA. Comparing with the frontier, the total adjustments of energy input can be obtained, and they calculate the energy-saving amount and ratio by comparing with the actual energy input in an individual economy. Section 3 includes summary statistics of the empirical data. Section 4 presents and discusses the empirical results. Finally, Section 5 concludes this paper.

2. Methods

2.1. Methodology of data envelopment analysis

This paper uses DEA to find out the input targets for each APEC economy by comparing with the annual efficiency frontier constituted by all the APEC economies in each year. There is an efficiency frontier for each APEC economy in each year constituted by data of all APEC economies in that year. Since it is an input-reducing focus, this paper uses input-orientated measures following Farrell's (1957) original ideas. In order to pursue overall technical efficiency with energy inputs, our study adopts the constant returns to scale (CRS) DEA model (Charnes et al., 1978).

Our measure of relative efficiency is based on non-parametric techniques (Färe et al., 1994). Let us first define some mathematical notations: There are K inputs and M outputs for each of N objects. For the ith object these are represented by the column vectors x_i and y_i, respectively. The $K \times N$ input matrix X and the $M \times N$ output matrix Y represent the data for all N objects. The input set $L(y_i)$ for the ith object is defined as $L(y_i) = \{x_i : y_i \geqslant f(x_i)\}$. The efficiency score θ equals the value of the distance function, $D(y_i, x_i) = \min\{\lambda : x_i\lambda \in L(y_i)\}$ (Shephard, 1970). The set $L(y_i)$ can be numerically computed by linear programming using observed data. The input-oriented CRS DEA model then solves the following linear programming problem for object i in each year:

$$
\begin{aligned}
D(y_i, x_i) &= \mathrm{Min}_{\theta,\lambda}\theta \\
\text{subject to} \quad & -y_i + Y\lambda \geqslant 0, \\
& \theta x_i - X\lambda \geqslant 0, \\
& \lambda \geqslant 0,
\end{aligned} \tag{1}
$$

where θ is a scalar and λ is a $N \times 1$ vector of constants.

The value of θ is the efficiency score for the ith object, with $0 \leqslant \theta \leqslant 1$. The value of unity indicates a point on the frontier and hence a technically efficient economy, according to Farrell's (1957) definition. The frontier is a piecewise linear isoquant, determined by the observed data points of the same year, i.e., all the economies in this study of the same year. The economy that constructs the frontier is the 'best practice' among those observed economies in that year. The weight vector λ serves to form a convex combination of observed inputs and outputs.

Fig. 1 illustrates the efficiency measurement: Each point in Fig. 1 represents a combination of inputs that all produce the same output level. Economies C and D are on the frontier and they cannot maintain the given output level by further reducing their inputs. Economies A and B are hence inefficient economies.

2.2. Slack and radial adjustment

An important issue in efficiency studies is the credibility of the assumption that all production processes can actually reach the best practice production frontier (Zofío and Prieto, 2001). In the present study, when measuring energy efficiency, it is assumed that all economies have access to the best practice. This assumption seems to be adequate since only APEC economies are considered. Currently, specialized journals, technological fairs, multinationals' global marketing strategies, etc. guarantee that new innovations are readily available to all economies (Zofío and Prieto, 2001). The international trade agreements among APEC force economies to be more competitive and the pressure of Kyoto Protocol requires updated technologies and improves input usage efficiency.

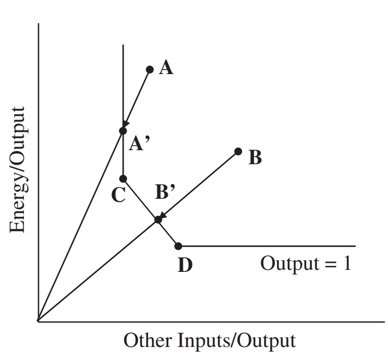

Fig. 1. DEA representation of 'best practice', target, radial adjustment, and input slacks.

The $f(x_i)$ set in the frontier is the 'best practice' production among the observed economies. The inefficient economy could reduce inputs by the amount indicated by the arrow and still remain in the input set $L(y_i)$ (Boyd and Pang, 2000). For the ith economy, the distance (amount) of it to the projected point on the frontier by radially reduction without reducing the output level, $(1-\theta)x_i$, is called 'radial adjustment'. We can illustrate this from Fig. 1. Point B is the actual input set and point B′ is the ideal or best practice input set for economy B by reducing the radial adjustment BB′.

When the frontier runs parallel to the axes, this could be a problem. In Fig. 1, point A′ is the best practice for economy A by reducing the redial adjustment AA′. Point A′ can reduce some input so as to maintain the same output level. The reduced amount is called 'input slack' (by the amount CA′). For economy A, the best practice is point C, instead of point A′, by reducing the radial adjustment AA′ and slack CA′.

The summation of slack and radial adjustment is the total reducing amount ('target') that could be reduced without decreasing output levels. With respect to energy input, the above summation is called 'EST'. The formula is as follows:

$$
\begin{aligned}
\mathrm{EST}_{(i,t)} = {} & \text{Slack Adjustment}_{(i,t)} \\
& + \text{Radial Adjustment}_{(i,t)},
\end{aligned} \tag{2}
$$

where it is in the ith economy and the tth year.

An inefficient economy can reduce or save EST in energy use without reducing the real economic growth. The CRS model may suggest the slack and radial adjustments of any individual input for all objects to be efficient. Since the actual practice can be improved to the best practice, the actual energy consumption is always larger than or equal to the ideal energy input.

2.3. Energy-saving target ratio (ESTR)

Efficiency is generally defined in terms of the ratio with which best practice compares with actual operation. The indicator of energy efficiency therefore should be the ratios of the aggregate EST from Eq. (2) to actual energy consumption. The amount of total adjustments in energy input is regarded as the inefficient portion of actual energy consumption. Based on slack and radial adjustment of energy obtained from DEA, we can calculate the ESTR considering other factors simultaneously. The target inputs of an object in a year are found by comparing its actual inputs to the efficiency frontier in that year. The formula is as below:

$$
\mathrm{ESTR}_{(i,t)} = \frac{\text{Energy-Saving Target}_{(i,t)}}{\text{Actual Energy Input}_{(i,t)}}, \tag{3}
$$

where it is in the ith economy and the tth year.

As Eq. (3) shows, the ESTR represents each economy's inefficiency level of energy consumption. Since the minimal value of EST is zero, the value of ESTR is between zero and unity. The total-factor energy efficiency (TFEE) index originally proposed by Hu and Wang (2006) has the following relation with ESTR:

$$\mathrm{TFEE}_{(i,t)} = 1 - \mathrm{ESTR}_{(i,t)}, \tag{4}$$

where it is in the ith economy and the tth year. A zero ESTR value indicates an economy on the frontier with the best total-factor energy efficiency up to one among the observed economies. A zero ESTR means that no redundant or over-consumed energy use exists (the amount of target zero) in this economy. An inefficient economy with the value of ESTR larger than zero means otherwise that the energy should and could be saved at the same economic growth level. A higher ESTR implies higher energy inefficiency and a higher energy-saving amount.

As mentioned above, many studies criticize the commonly used indicator of energy inefficiency—the energy intensity as a direct ratio of the energy input to GDP for measuring energy efficiency (e.g., Patterson, 1996; Renshaw, 1981). The ratio is only a partial-factor energy efficiency indicator since energy input is the only input-considered factor. Another argument is that this partial-factor ratio is inappropriate to analyze the impact of changing energy use over time (APERC, 2002). We then compute the energy efficiency by a total-factor framework including other inputs such as labor and capital. A total-factor efficiency indicator can provide more information and a more realistic comparative base to examine the de facto situation across economies.

3. Data description

Three analytical measures described in the preceding section are applied to a dataset of 17 APEC economies for the period 1991–2000. The economies include Australia, Canada, Chile, China, Hong Kong, Indonesia, Japan, South Korea, Malaysia, Mexico, New Zealand, Peru, the Philippines, Singapore, Taiwan, Thailand, and the United States. Brunei Darussalam, Papua New Guinea, Russia, and Vietnam are not included due to a lack of data.

To solve the data comparability problem, there are only two practical alternatives: the average rates of exchange and the purchasing power parity (PPP) as measured by OECD (Edvardsen and Førsund, 2003). The latter approach is chosen here. There are three inputs and one output factor analyzed in this study: the three inputs are capital stock, labor employment, and energy consumption. The single output is selected as real growth, gross domestic production (GDP) using purchasing power parties. It is expressed in 1995 US dollars. The data of GDP using purchasing power parties and total energy consumption come from *Energy Balances of OECD Countries* (IEA, 2002a) and *Energy Balances of Non-OECD Countries* (IEA, 2002b).

The data of labor and capital stock come from the *Penn World Tables* (Heston et al., 2002). Multiplying capital stock per worker by labor retrieves the capital stock. However, for China, Indonesia, Malaysia, and Singapore, the data on capital stock per worker are not available. They are calculated using the perpetual inventory method:

$$K_t = I_t + (1 - \delta)K_{t-1}, \tag{5}$$

where I_t denotes gross investment, which is estimated by first multiplying the real investment share by real GDP, at time t; and δ is the depreciation rate.

The choice of the rate of depreciation is problematic due to the difference between the developed economies and the developing ones. The perception is that developed economies can afford to update their equipment and apply new technology. Thus, the rate of depreciation of those economies may be greater than that of the developing ones. However, due to their backwardness and hence the leapfrogging effects, some developing economies may actually be able to adopt new technology faster than developed economies. Unless detailed data at the sector or firm level are available, it is difficult to derive a precise rate of depreciation (Wu, 2004). While the potential impact of the choice of the rate of depreciation is noted, due to data constraints this paper applies a unified rate of depreciation of 5%.

The units of real GDP, labor, real capital, and energy consumption are billions of US$, 10,000 people, billions of US$, and millions of tons of oil equivalent (Mtoe), respectively. Table 1 lists the average annual amounts and growth rates of real GDP, labor, real capital, and energy consumption for each economy. The United States, China, and Japan are the first three having real GDP, labor, real capital, and energy consumption among APEC economies. The East Asian economies, with the exception of Japan, Indonesia, and the Philippines, indeed achieved high economic growth in the 1990s. In those economies, high economic growth rates matched the rapid expansion of capital stocks. On the other hand, the average labor growth was rather modest and quite even across all APEC economies. Energy consumption growth rates also exhibited a similar pattern with real GDP growth rates. As Table 1 shows, the East Asian economies, except Japan and China, have the highest average annual growth rates in energy consumption. Hong Kong has the highest average energy consumption growth rate (9.4%) and Mexico has the lowest energy consumption growth rate (0.2%).

Table 2 shows the percentages in total energy consumption of APEC economies. The United States is the largest energy-consuming economy with almost half of the total energy consumption. For the other half of energy consumption, China, Japan, and Canada consume, respectively, around 20%, 11%, and 7% of the total consumption during the research period. The other 13 economies use only less than 13% of total energy consumption.

A correlation matrix is given in Table 3 that shows a high correlation exists between input and output factors

Table 1
Average annual amounts and growth rates of real GDP, labor, real capital, and energy consumption (1991–2000)

Economies	Real GDP		Labor		Real capital		Energy consumption	
	Billions US$	%	10,000 people	%	Billions US$	%	Mtoe	%
Australia	402.83	3.7	892.84	1.4	688.69	8.2	64.71	2.2
Canada	707.86	2.9	1500.70	1.2	1287.13	7.9	126.45	1.9
Chile	112.04	5.8	551.45	2.0	155.50	13.3	11.20	5.6
China	3394.72	9.2	73080.42	0.9	4122.14	14.7	561.20	1.1
Hong Kong, China	138.49	3.2	329.07	−0.2	226.59	15.5	10.77	9.4
Indonesia	541.37	3.3	7763.12	1.9	1033.70	7.0	50.88	6.1
Japan	3079.92	1.1	7963.75	0.3	7183.32	7.9	326.69	1.4
South Korea	620.89	5.2	1904.38	1.2	1304.90	12.7	105.29	6.1
Malaysia	154.71	6.1	739.56	2.5	263.40	16.6	22.14	7.2
Mexico	723.02	3.1	3169.47	1.8	958.60	9.6	94.15	0.2
New Zealand	64.27	2.8	172.70	1.4	107.59	7.6	11.87	3.2
Peru	102.70	3.8	1005.13	4.3	144.60	8.8	7.59	3.6
Philippines	255.98	2.9	2791.67	2.5	226.56	9.7	14.57	6.2
Singapore	69.89	7.0	179.55	3.2	274.78	7.8	8.74	4.2
Taiwan	324.35	5.4	934.49	0.9	518.57	8.3	41.98	4.4
Thailand	341.43	3.5	3143.27	0.9	748.04	13.6	35.27	6.3
United States	7758.29	3.3	13395.57	1.3	11191.59	10.1	1400.83	1.4
Average	1105.46	4.2	7030.42	1.6	1709.34	10.5	170.25	4.1

Notes: (1) Statistics in the 'GDP,' 'Capital,' 'Labor,' and 'Energy' columns are mean percentage rates of growth. (2) The base year for real GDP and real capital is 1995. (3) Source: Penn World Tables, IEA Statistics 2002 Edition.

Table 2
Percentage in total energy consumption of APEC economies (1991–2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	2.18	2.16	2.18	2.14	2.16	2.15	2.20	2.26	2.26	2.26
Canada	6.01	6.01	6.00	5.98	5.93	5.92	6.02	5.93	6.04	6.09
Chile	0.31	0.34	0.36	0.36	0.38	0.40	0.45	0.44	0.45	0.45
China	18.95	19.17	19.32	19.61	19.83	20.18	18.90	19.13	17.93	17.68
Hong Kong, China	0.27	0.32	0.32	0.34	0.33	0.32	0.33	0.40	0.44	0.55
Indonesia	1.39	1.44	1.56	1.60	1.67	1.78	1.84	1.82	1.94	2.11
Japan	11.45	11.36	11.11	11.06	11.08	10.87	11.05	11.00	11.06	10.97
South Korea	2.69	3.01	3.22	3.45	3.63	3.76	4.02	3.66	3.98	4.09
Malaysia	0.55	0.60	0.64	0.66	0.74	0.77	0.85	0.84	0.87	0.93
Mexico	3.47	3.47	3.38	3.36	3.23	3.04	3.09	3.10	2.98	2.96
New Zealand	0.38	0.38	0.38	0.39	0.40	0.40	0.41	0.41	0.43	0.44
Peru	0.24	0.23	0.23	0.24	0.26	0.26	0.27	0.27	0.29	0.28
Philippines	0.36	0.38	0.42	0.48	0.50	0.52	0.55	0.56	0.57	0.56
Singapore	0.26	0.25	0.26	0.28	0.29	0.30	0.33	0.33	0.33	0.33
Taiwan	1.24	1.30	1.33	1.38	1.39	1.41	1.45	1.53	1.57	1.59
Thailand	0.86	0.94	1.04	1.13	1.25	1.35	1.37	1.27	1.32	1.33
United States	49.39	48.65	48.24	47.54	46.92	46.56	46.85	47.03	47.53	47.40

Note: The unit is percentage.

selected for this analysis. Table 3 shows that labor employment, capital stock, and energy consumption do actually correlate to GDP performance in this analysis model. The correlation coefficient between energy input and GDP output is calculated as 0.980, which is statistically significant. The relation reveals that the more energy is consumed, the more GDP is generated. However, energy efficiency needs to be analyzed in this study in

Table 3
Correlation matrix for all inputs and output (1991–2000)

	GDP	Labor	Capital	Energy
GDP	1.000			
Labor	0.464	1.000		
Capital	0.952	0.360	1.000	
Energy	0.980	0.407	0.899	1.000

order to learn individual efficiency scores for all APEC economies.

4. Results

We use the software DEAP 2.1, kindly provided by Coelli (1996), to solve the linear programming problems as specified in Eq. (1). Table 4 reports the summary of ESTR based on Eq. (3) for each economy. Each economy's EST is also calculated. Fig. 2 shows the percentage of total APEC EST. Table 5 presents the per capita EST for each economy. Several interesting observations are summarized as follows:

(1) The ESTR score generally decreases for the APEC economies during the period considered. As seen in Table 4, the APEC economies, except Canada and New Zealand, have become more efficient in energy efficiency and energy-saving efficiency over time. In the late 1990s, they improved their energy efficiency and were closer to the frontier than in the beginning. We separate the samples into developed and developing groups: developed economies included Australia, Canada, Hong Kong, Japan, New Zealand, Singapore, and the United Sates. The other economies belong to the developing group. Since developed economies could afford to update equipment and apply new technologies, they have lower ESTR scores than those in the developing group.

(2) The ESTR scores of all the Asian economies but four (Hong Kong, Japan, Singapore, and Taiwan) are higher than the average scores during the research period. Neither any of the Central nor the South American economies are efficient EST economies. Their ESTRs are much lower than the Asian economies under a similar growth level.

(3) China has the largest EST with almost half the amount of its current usage even as it owns the highest

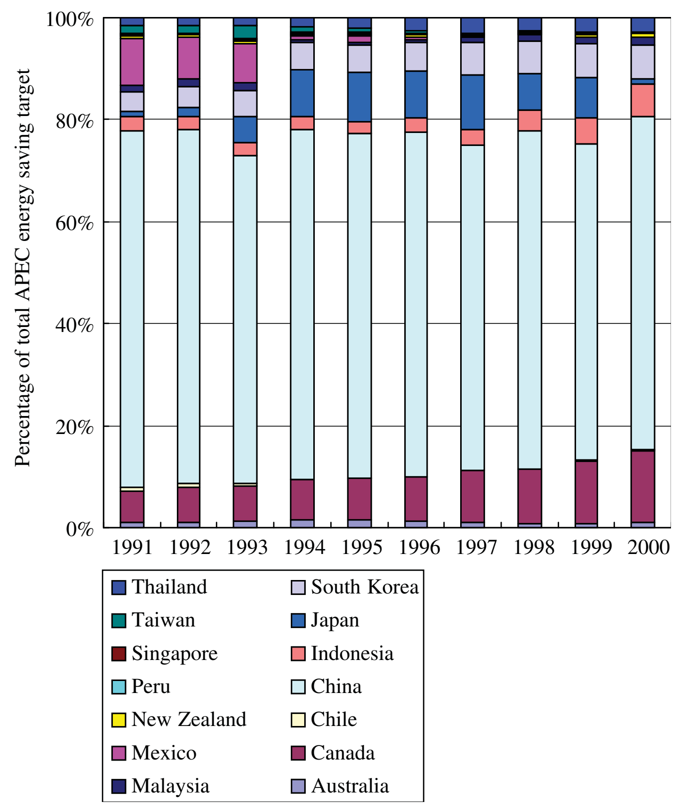

Fig. 2. Percentage of total energy-saving amount of each APEC economy (1991–2000).

Table 4
Summary of ESTR by economy (1991–2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	0.11	0.11	0.13	0.15	0.13	0.11	0.08	0.05	0.04	0.06
Canada	0.23	0.25	0.26	0.27	0.29	0.30	0.29	0.29	0.29	0.30
Chile	0.47	0.38	0.38	0.04	*0.00*	*0.00*	*0.00*	*0.00*	0.03	0.02
China	0.83	0.80	0.75	0.70	0.67	0.65	0.59	0.56	0.50	0.49
Hong Kong, China	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Indonesia	0.46	0.40	0.37	0.31	0.29	0.30	0.29	0.35	0.38	0.40
Japan	0.02	0.03	0.10	0.17	0.17	0.16	0.17	0.11	0.10	0.01
South Korea	0.31	0.31	0.37	0.32	0.29	0.28	0.28	0.28	0.24	0.21
Malaysia	0.59	0.53	0.52	0.15	0.16	0.16	0.18	0.24	0.23	0.22
Mexico	0.59	0.52	0.52	0.04	0.08	0.03	*0.00*	*0.00*	*0.00*	*0.00*
New Zealand	0.21	0.23	0.32	0.15	0.13	0.16	0.13	0.15	0.15	0.22
Peru	0.31	0.15	0.23	0.13	0.13	0.16	0.12	0.08	0.12	0.09
Philippines	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Singapore	0.22	0.20	0.19	0.19	0.17	0.16	0.15	0.12	0.08	0.04
Taiwan	0.27	0.25	0.43	0.17	0.09	0.05	0.01	*0.00*	*0.00*	*0.00*
Thailand	0.40	0.34	0.34	0.31	0.33	0.37	0.39	0.34	0.32	0.27
United States	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Average	0.295	0.265	0.289	0.182	0.172	0.170	0.158	0.151	0.146	0.137

Note: Scores with italics are those reached at the best efficiency with zero score.

Table 5
Per capita energy-saving targets (1991–2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	0.36	0.36	0.44	0.51	0.47	0.39	0.31	0.19	0.16	0.24
Canada	1.29	1.45	1.52	1.57	1.61	1.77	1.83	1.73	1.81	1.90
Chile	0.29	0.26	0.27	0.03	0.00	0.00	0.00	0.00	0.03	0.02
China	0.36	0.35	0.34	0.33	0.33	0.33	0.28	0.26	0.22	0.22
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	0.09	0.08	0.09	0.08	0.07	0.08	0.08	0.10	0.11	0.13
Japan	0.04	0.08	0.25	0.41	0.45	0.44	0.46	0.28	0.27	0.04
South Korea	0.51	0.59	0.74	0.71	0.68	0.71	0.74	0.67	0.63	0.58
Malaysia	0.46	0.45	0.47	0.14	0.17	0.19	0.22	0.28	0.27	0.28
Mexico	0.64	0.57	0.55	0.04	0.08	0.03	0.00	0.00	0.00	0.00
New Zealand	0.60	0.68	0.95	0.48	0.42	0.52	0.43	0.50	0.53	0.79
Peru	0.09	0.04	0.07	0.04	0.04	0.06	0.04	0.03	0.04	0.03
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	0.48	0.42	0.41	0.46	0.43	0.41	0.39	0.30	0.21	0.10
Taiwan	0.43	0.43	0.76	0.32	0.18	0.10	0.02	0.00	0.00	0.00
Thailand	0.16	0.15	0.17	0.17	0.21	0.26	0.28	0.22	0.22	0.19
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.341	0.348	0.414	0.311	0.302	0.311	0.299	0.268	0.265	0.266

Note: The unit is tons of oil equivalent (toe) per person.

development growth rate from 1990 to 2000. China can save around 50% of the amount of its current energy consumption by improving technology efficiency without reducing the high production level. As seen in Fig. 2, the EST of China in 2000 is by 65% of the total APEC EST. China plays a key role in energy saving and environmental protection in the association of APEC economies. However, the ESTR score decreased from 83% in 1991 down to 50% in 2000. An improvement in energy efficiency and technical and structural changes has been identified as the main factor that caused the fall in ESTR in China (Crompton and Wu, 2005).

(4) Hong Kong, the Philippines, and the United States have the 'best practice' among APEC economies and have the complete know-how of production function. They have the lowest ESTR rankings with unity over the 1990s among APEC economies. Chile, Mexico, and Taiwan significantly improved their energy efficiency in the last 7 years of the 1990s. Mexico and Taiwan possess an ESTR value of zero in the latter part of the research period. Chile's ESTR scores are at zero from 1995 to 1998, but then increase slightly in the last 2 years. These economies can share their know-how with others to improve energy efficiency in the international association by trade agreement.

(5) Canada and New Zealand are the two exceptions among APEC economies with decreasing total-factor energy efficiency when energy input is considered. Canada's ESTR score is 0.23 in 1991 and adds up to 0.30 in 2000. New Zealand improved its energy efficiency in the middle of the observed period. However, its ESTR score increased to 0.22 in 2000, which was higher than that in 1991. The same pattern applies to per capita EST in Table 5. These two developed economies have to face the situation seriously in order to be a part of the APEC economies.

(6) Chile, Malaysia, Mexico, and Taiwan enjoy a jump in ESTR from 1993 to 1994. The increment range is from 26% to 38%. There are two opposite reasons for this situation. One is that these three economies improved their productivity and efficiency, pushing them closer to the frontier. The opposite one is that other economies' efficiency turned lower and hence pushed these economies up to the efficiency frontier. The result may be caused by a combination of these two reasons. However, the distance between the frontier and these three economies (i.e., EST) was shortened and held for the rest of the period.

(7) As seen in Table 5, Canada has the highest per capita EST by 2 tons of oil equivalent (toe). Canada has to intensively promote its energy efficiency in the agricultural, manufacturing, residential, commercial, and transportation sectors. However, Canada is an outlier. Its per capita EST is too high compared with other economies. People in South Korea and New Zealand also have to save more energy than other economies for their high per capita total-factor EST.

(8) We use the Hausman test and then reject the random-effects model at a 1% level (CHISQ $= 11.57$, $p-$value $= .01$). Table 6 presents the relation of per capita EST and per capita GDP. We find that an inverted U-shape relation exists. The inverted U-shape relation is established between the per capita EST, increases with per capita income at low levels of income, and then decreases once a threshold level of per capita income level is reached. According to this

relation, a developing economy should pay more attention to energy-saving issues than developed and less-developing economies.

(9) Table 7 shows that the energy intensities of all economies except China and Hong Kong are steady with small changes. Peru and the Philippines are the two most efficient economies, and Canada is the worst. China improved its energy efficiency, but Hong Kong's efficiency was decreasing at the same time. We compare the total-factor ESTR to energy intensity as the inverse of partial-factor energy efficiency by applying the sign test and Wilcoxon signed-rank test. Both results of the sign test ($Z = -2.335$, $p - \text{value} = 0.02$) and Wilcoxon signed-rank test ($Z = -5.857$, $p - \text{value} < 0.01$) between the energy intensity and ESTR are significant at the 5% level, showing that the total-factor energy efficiency has significantly different rank patterns with the partial-factor energy efficiency. In addition, the relation between energy intensity and per capita GDP does not have a significant pattern as with the inverted U-shape relation between per capita ESTR and per capita GDP. This shows a significant substitution effect of other inputs such as labor and capital on the energy input to produce the GDP. The energy efficiency could be over-estimated or under-estimated if energy consumption is taken as a single input in the production. A certain portion of GDP output is produced not only by energy input, but also by labor and capital. This study hence applies a total-factor framework, with which the total-factor ESTR is established.

(10) We use panel data regression models to find out the relation between industrial structure and ESTR. Fifteen economies are selected, except South Korea and Singapore, since there is a limitation of data. The data of value-added percents of GDP by industry and service sectors for every economy are taken from *World Development Indicators* (World Bank, 2005). The Hausman test rejects the random-effects model at the 5% level (CHISQ = 9.43, $p - \text{value} = .02$). In the fixed-effects model's estimates shown in Table 8, ESTR has a positive relation with value-added percent

Table 6
Relation between per capita energy-saving target and per capita GDP (fixed-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
Time	−1055.24	−3.043	0.003***
Per capita GDP	244.76	4.671	<0.001***
(Per capita GDP)^2	−7.66	−4.167	<0.001***
R^2		.260	

Note: ***represents significance at the 0.01 level.

Table 8
Relation among ESTR and industrial structure indicators (fixed-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
Time	.992	2.525	0.013**
Value-added percentage of GDP by the industry sector	.649	2.525	0.013**
Value-added percentage of GDP by the service sector	−.702	−3.882	<0.001***
R^2		.572	

Note: **represents significance at the 0.05 level; ***represents significance at the 0.01 level.

Table 7
Energy intensities of APEC economies (1991–2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15
Canada	0.26	0.26	0.26	0.26	0.25	0.26	0.25	0.24	0.24	0.23
Chile	0.11	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.11	0.10
China	0.25	0.23	0.21	0.19	0.18	0.18	0.15	0.14	0.12	0.12
Hong Kong, China	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.09	0.09	0.11
Indonesia	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.11
Japan	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11
South Korea	0.15	0.16	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.16
Malaysia	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15
Mexico	0.14	0.14	0.14	0.14	0.15	0.14	0.13	0.12	0.11	0.11
New Zealand	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.19
Peru	0.08	0.07	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.07
Philippines	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Singapore	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.11
Taiwan	0.13	0.13	0.13	0.14	0.13	0.13	0.13	0.13	0.12	0.12
Thailand	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11
United States	0.20	0.19	0.19	0.19	0.19	0.19	0.18	0.17	0.17	0.16
Average	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13

Note: The unit is Mtoe/$1000 purchasing power parity, at 1995 international prices.

of GDP by industry sector and a negative relation with that of the service industry—that is, ESTR increases with industrialization and then decreases with the rising service industries. According to this relation, a newly industrializing economy will have lower total-factor energy efficiency than agriculture-dominant and service-dominant economies. The industrial structure of an economy is hence a crucial factor for energy efficiency and thus the energy-saving ratio. An industry-dominant economy can improve its energy efficiency and save energy more efficiently and effectively via shifting the economy structure toward services.

5. Concluding remarks

In summary, this paper employs a total-factor framework to analyze the energy efficiency of APEC economies. The ESTs can be obtained by comparing the ideal input amount based on the 'best practice' of the production function and actual energy input. ESTR as a total-factor energy-saving efficiency indicator is constructed based on the theory of the frontier theory through DEA, which considers multiple input/output simultaneously. ESTR advises energy efficiency and EST without scarifying real economic output for every economy. When energy is the single input to produce GDP output, there might be an over-estimation or under-estimation of efficiency. The EST and ESTR constructed in this paper are better ways to compute the energy efficiency and also the energy-saving level.

In terms of energy efficiency, APEC members have improved their energy efficiency. In particular, APEC's developed members have performed better than their developing counterparts. However, Canada appears to be inefficient behind other developed economies in terms of ESTR.

Hong Kong, the Philippines, and the United States are the best performers among APEC economies with their zero ESTR. Chile, Mexico, and Taiwan caught up in the later 1990s. In contrast, China has the largest ESTR with the highest percentage of total ESTR among APEC economies. It can save half of its current energy consumption while keeping the same output level. Furthermore, the energy efficiencies of the South-East Asian economies are lower than average. In contrast, the Central and South American economies have lower ESTRs.

An inverted U-shape relation is found between the ratio of per capita EST and per capita real income among APEC economies. The developed economies except for Canada own a better per capita income, and so the EST is a minimum concern. The same thing does not happen to developing economies since these economies consume more energy, but at a lower efficiency. According to these findings, the condition of energy efficiency and EST in the South-East Asian economies should be paid more attention. Developing economies can both pursue their urgent requirements for increased energy services and reduce their environmentally damaging emissions. They cannot exploit resources with 'no regrets' on the one hand, while wanting to reduce energy inputs and emissions in order to achieve a given outcome on the other hand.

Sharing and transferring the knowledge, technology, and know-how from an efficient economy to an inefficient economy is costly in reality. However, those APEC economies with higher energy efficiency should help the less-efficient economies to improve their energy efficiency based on their kindness, regional cooperation, and international responsibility. Based the data of 2000, the target energy saving of all APEC economies is 418.15 Mtoe, taking 13.22% of their total energy consumption. The energy-saving amount will help APEC economies to reduce pollution emission and meet the principles of Kyoto Protocol.

Developing and newly industrializing economies need not input more resources to maintain their economic growth, but can also save more energy for sustainable development. Energy efficiency can be promoted without reducing maximum potential GDPs by importing new technology, improving processes, and changing the industrial structure to reduce wasteful energy use. For example, energy efficiency can be improved by shifting from energy-intensive industries (such as mining, basic metals, chemicals, and petrochemicals) to less energy-intensive manufacturing and/or service industries, even without more effective energy end-use technologies being implemented.

Even for the same sector, energy efficiency levels can be different across economies. Older power plants in many developing countries consume from 18% to 44% more fuels per kilowatt-hour of electricity produced than those in industrialized countries (Balce et al., 2001; Pearson and Fouquet, 1996). It is an interesting topic for future research to study how industry-level energy efficiency affects macro-level energy efficiency. However, this type of work needs detailed data for several industries across many economies.

Due to data limitation, we can only find the retail prices of oil in 1997 for 17 economies from APERC (2000). However, there is neither a significant relation found between ESTR and the retail price of oil nor one between per capita EST and the retail price of oil. This may be because energy prices alone cannot determine the total energy efficiency and energy saving of an economy. The structure of energy mixes, energy efficiency, taxation, and relative prices for all energy resources includes the factors influencing energy use and the energy saving of an economy.

Industrial structure, energy policies, energy consumption type, and treatments from an economic base can be further included. The efficiency frontier shift is another interesting topic to study, which can be conducted by DEA-Malmquist models. As long as the balance between economic growth and energy consumption is reached, sustainable development for APEC economies can be achieved.

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