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Analyzing the Relationship between CO_2 Emission and Economic Efficiency by a Relaxed Two-Stage DEA Model

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ABSTRACT

This article modifies the conventional two-stage DEA model to construct an analytical model for energy-related efficiency with undesirable outputs. Our proposed model relaxes the constraint that the inputs of the second process must come from the first process. As a result, our proposed model is more flexible than the original model in terms of the application of energy-related efficiency measurement analysis, and more policy implications may thus be provided by the decomposition of efficiencies for different processes. For demonstration purposes, the proposed model is applied to measure the energy use efficiency and the economic efficiency of 28 OECD countries during 2005 to 2007. The demonstration results reveal the following three findings. First, the average values of energy use efficiency are smaller than those of the average economic efficiency during the three-year period. It is shown that the OECD countries are only interested in economic development and are not concerned about energy use efficiency. Second, a tradeoff relationship exists between energy use efficiency and economic development for the OECD countries. Third, the differences of the initial carbon dioxide (CO_2) emissions from the optimal CO_2 emissions as well as the average economic efficiency increase year by year. These results indicate that the OECD countries still discharge too much CO_2. Finally, this article establishes a managerial decision-making matrix to divide 28 OECD countries into different positions according to their energy use and economic efficiencies, and provides improvement suggestions to policy makers.

Keywords: Two-stage data envelopment analysis; Carbon dioxide emissions; Energy-related efficiency; Undesirable output; Distance function.

INTRODUCTION

The Industrial Revolution facilitated national economic development and improved the material life of the people, but at a cost reflected by the excessive depletion of natural resources and a failure to protect the Earth's environment. Humankind gradually began to be concerned about the issue of sustainable development as abnormal climate change started to manifest itself all over the world. In recent years, more and more scientific evidence has verified that the reason for the global warming is primarily the anthropogenic emissions of greenhouse gases. In order to reduce the impact from the global warming effect caused by greenhouse gas (GHG) emissions, many countries worldwide in 1992 signed the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janiero, Brazil, and 38 of them went on to sign the Kyoto Protocol in 1997, which required all signatories to reduce GHG emissions between 2008 and 2012 (a.k.a., the first stage of emission reduction) to an average of 5.2% below the 1990 level.

GHGs are mostly generated from the energy conversion of fossil fuels, which are also the driving force behind the economic growth. Therefore, a reduction in fossil fuel energy use would reduce GHG emissions but would also be accompanied with a slowdown in economic growth as prices increase with no changes in production technology and efficiency (Yu and Choi, 1985; Tonn, 2003). That is why some countries remain uncommitted regarding the reduction in carbon dioxide (CO_2) emissions. As a result, the issues in how to take into consideration of both economic growth and sustainable development have caught the attention of academics in recent years (Lin *et al.*, 2012; Liu *et al.*, 2013).

To formulate effective environmental economic policies, extensive studies have been conducted to investigate the economic impact resulting from a reduction in GHG emissions. From a methodological perspective, various

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alternative approaches have been developed to measure the trade-off effect between environmentally harmful by-products and economic performance for different types of decision-making unit (DMU). Among these approaches, the production efficiency measurement with undesirable outputs to evaluate economic performance takes the undesirable outputs of the production process into account based on the theory of production economics, so that more policy insights into the improvement of the resource utilization efficiency in the production process could be provided (Dyckhoff and Allen, 2001; Zhou *et al*., 2006; Zhang and Yongrok, 2014). Thus, this approach has been regarded as a useful tool for evaluating the performance of a DMU in an economic-environmental context.

Conceptually, efficiency measurement with undesirable outputs is based on an environmental index constructed from the distance function and directional distance function. A specific DMU would be defined as performing better than others in terms of efficiency if it were to produce more desirable outputs (e.g., economic outputs) and less undesirable outputs (e.g., pollution) during the production process. Both the distance function and directional distance function are applied on the basis of quantitative data without any price data requirement, and there is no need for any assumptions to be imposed on the functional form of the production function. Such functions have been widely applied in the previous economic-environmental efficiency measurement studies (Chung *et al*., 1997; Zaim and Taskin, 2000; Dyckhoff and Allen, 2001; Lee *et al*., 2002; Färe *et al*., 2005; Ramanathan, 2005; Lozano and Gutiérrez, 2008; Zhou *et al*., 2008; Lozano *et al*., 2009; Sueyoshi and Goto, 2010; Zhou *et al*., 2010; Chiu *et al*., 2012). However, since the directional distance function does not take account of random factors, the efficiency evaluation of the method is easily affected by exceptional values. Accordingly, another method (called stochastic frontier analysis) was proposed by Aigner *et al*. (1977) and it has also been applied to the fields of energy and environmental efficiencies (Zhou *et al.*, 2012; Wang *et al*., 2013). Wang *et al*. (2013) integrated the directional distance function with stochastic frontier analysis techniques to estimate the total factor CO_2 emissions performance index.

The majority of the previous studies on the economic-environmental efficiency application of DEA only discussed a one-stage evaluation process and assumed a black box production system. Therefore, in order to take a closer look at the production process that was based on the energy-related efficiency context, at least two stages (sub-processes), i.e., energy use and economic output generation, could be identified and different management insights were raised accordingly. However, the efficiency measurement using the distance function and directional distance function in the existing literature was usually based on the inputs, desirable outputs, and undesirable outputs being only able to be reduced to a single solution process. Further decomposition of the efficiency into energy use efficiency and economic efficiency was not allowed due to the type of model structure.

Some previous studies have divided the production process into two stages (Seiford and Zhu, 1999; Färe and Grosskopf, 2000). These studies, however, assumed that the production process of each stage was not interrelated and, thus, independently measured the production efficiency for each stage. This assumption does not conform to the reality because the production stages are not entirely independent of each other. Consequently, in order to take the attribute of compound production processes mentioned above into account in an efficiency analysis framework, Chen and Zhu, (2004) proposed a two-stage data envelopment approach (DEA) model, a.k.a., the CZ model, to measure the efficiencies of decision processes which can be divided into two stages. According to the concept of the CZ model, the first stage (i.e., intermediate process) of the production processes uses inputs to generate outputs and then the outputs of this stage become the inputs of the second stage (i.e., the final process). As a result, the efficiencies of the initial stage and final stage could be estimated simultaneously through solving a linear programing problem. Afterwards, the relational two-stage DEA model was proposed to measure the technical and scale efficiencies of the entire process and the two sub-processes (Kao and Hwang, 2008, 2011). Although the CZ model has the advantage of dealing with the issue of the efficiency measurement of multiple production processes, the limitation of the original CZ model is that the outputs of the first stage are restricted to equaling the inputs of the second stage, an assumption that is not usually common in real situations.

Given the above-mentioned background, this article modifies the conventional two-stage DEA model proposed by Chen and Zhu (2004) (CZ model) to construct an analysis model for energy-related efficiency with undesirable outputs. The proposed model in this article inherits the attributes of the two-state CZ model and thus is allowed to measure the energy use efficiency and economic efficiency in the two-stage DEA context. Aside from that, this proposed model relaxes the constraint that the inputs of the second stage could only come from the first stage. As a result, the proposed model is more flexible than the original model when it comes to applying energy-related efficiency measurement analysis and more policy implications could thus be provided from the decomposition of efficiencies into different processes. For illustrative purposes, the proposed model is applied to measure the energy use efficiency and economic efficiency of 28 OECD countries during the years 2005 to 2007.

The remainder of this article is organized as follows. Section 2 illustrates the technical details of the proposed model. Then the data sources and the results of the empirical analysis are presented in Section 3. Finally, Section 4 summarizes the conclusions.

METHODOLOGY

Conventional DEA is believed to be capable of fully explaining the efficiency of a DMU by analyzing the relative efficiencies of inputs and outputs. However, DEA cannot fully reflect the DMU's managerial information that forms part of the production processes. Accordingly, the conventional DEA frequently ignores the influence of intermediate procedures, and thus cannot detect the efficiency of individual processes. Consequently, Chen and Zhu, (2004) established the two-stage CZ model to deal with the intermediate measures in one of the DEA implementations. The two-stage CZ model is comprised of input-oriented and output-oriented DEA models. The first-stage and second-stage efficiency are solved simultaneously and the optimal intermediates thereby resolved.

Suppose that there are n DMUs, each having m inputs, l intermediates, and s outputs, where the intermediates are regarded as an output for the first stage and an input for the second stage. The mathematical model assesses the efficiency of DMU_k by solving the following linear programming problem:

$$
\begin{aligned}
\textbf{Min} \quad & \varphi_1 - \varphi_2 \\
\textbf{s.t.} \quad & \varphi_1 x_{ik} \geq \sum_{j=1}^{n} x_{ij}\lambda_j, \quad i = 1,\ldots,m, \\
& \tilde{z}_{pk} \leq \sum_{j=1}^{n} z_{pj}\lambda_j, \quad p = 1,\ldots,l, \\
& \tilde{z}_{pk} \geq \sum_{j=1}^{n} z_{pj}\mu_j, \quad p = 1,\ldots,l, \\
& \varphi_2 y_{rk} \leq \sum_{j=1}^{n} y_{rj}\mu_j, \quad r = 1,\ldots,s, \\
& \sum_{j=1}^{n} \lambda_j = 1, \sum_{j=1}^{n} \mu_j = 1, \quad j = 1,\ldots,n, \\
& \lambda_j \geq 0,\ \mu_j \geq 0,
\end{aligned} \tag{1}
$$

where, $x_{ik}, \tilde{z}_{pk}, y_{rk}$ represent the DMU_k for the i-th input, p-th intermediate, and r-th output, respectively. $\varphi_1, \varphi_2, \tilde{z}_{pk}$ are unknown decision variables that will be solved simultaneously in model (1). However, the restriction of the two-stage CZ model (value-chains model) is that the outputs of the first stage are restricted to equal the inputs of the second stage. Fig. 1 describes the common framework of the two-stage model. Therefore, this study proposes the use of a modified two-stage CZ model in order to solve the restriction.

The modified two stage CZ model is stated as follows. This study assumes the existence of n countries, each having I inputs, P intermediates, H intermediate inputs and R final outputs, where the intermediates are regarded as an output for the first stage and an input for the second stage. Note that the intermediate inputs $g \in \mathbb{R}_+^H$ are not necessarily generated from the first stage. We use the inputs $x \in \mathbb{R}_+^I$ to produce the intermediates $z \in \mathbb{R}_+^P$ in the first process, and then the intermediates $z \in \mathbb{R}_+^P$ and intermediate inputs $g \in \mathbb{R}_+^H$ are used to produce the final outputs $y \in \mathbb{R}_+^R$ in the second process. The modified two-stage CZ model can divide the production process of countries into two stages to assess energy use efficiency and economic efficiency, respectively. The mathematical model assesses the efficiency of the DMU_k by solving the following linear programs:

$$
\begin{aligned}
\textbf{Min} \quad & \alpha - \beta \\
& \text{(Stage-1: Energy use efficiency)} \\
\textbf{s.t.} \quad & \sum_{j=1}^{n} x_{ij}\lambda_j \leq \alpha x_{ik}, \quad i = 1,\ldots,I, \\
& \sum_{j=1}^{n} z_{pj}\lambda_j \geq \tilde{z}_{pk}, \quad p = 1,\ldots,P, \\
& \sum_{j=1}^{n} \lambda_j = 1, \quad j = 1,\ldots,n, \\
& \text{(Stage-2: Economic efficiency)} \\
& \sum_{j=1}^{n} z_{pj}\mu_j \leq \tilde{z}_{pk}, \quad p = 1,\ldots,P, \\
& \sum_{j=1}^{n} g_{hj}\mu_j \leq g_{hk}, \quad h = 1,\ldots,H, \\
& \sum_{j=1}^{n} y_{rj}\mu_j \geq \beta y_{rk}, \quad r = 1,\ldots,R, \\
& \sum_{j=1}^{n} \mu_j = 1, \quad j = 1,\ldots,n, \\
& \lambda_j \geq 0,\ \mu_j \geq 0,
\end{aligned} \tag{2}
$$

where $x_{ik}, \tilde{z}_{pk}, g_{hk}, y_{rk}$ represents the DMU_k for the i-th input, p-th intermediate, h-th intermediate input, and r-th final output, respectively; (λ_i, μ_j) represents the weight of the reference corresponding to the first and second processes, respectively; the efficiency scores of the first and second stages are α and β, respectively; the intermediate measure target is regarded as $\tilde{z}_{pk}$, and is determined by the benchmarks of the first or second stages in the modified two-stage CZ model.

The energy use efficiency of the first stage is defined as α (the input-oriented efficiency), if the efficiency that is equal to the unit representing DMU_k is efficient in the first stage. Otherwise, the efficiency could be between zero and that unit, and the unit that represents the DMU_k is inefficient. The economic efficiency of the second stage is defined as β (output-oriented efficiency), if the efficiency is equal to the unit that represents DMU_k and is efficient in the second stage. Otherwise, the efficiency could be more than the unit that represents DMU_k as being inefficient. The intermediate

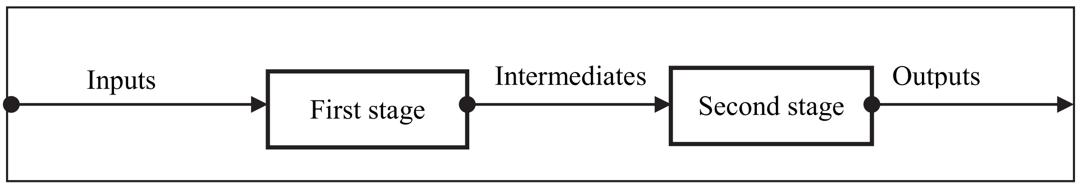

Fig. 1. The framework of the two-stage CZ model.

measure target is regarded as $\tilde{z}_{pk}$, and is determined by benchmarks of the first or second stages in the modified two-stage CZ model.

EMPIRICAL ANALYSIS

Data Sources

The empirical research focuses on the relative energy use efficiency and economic efficiency of 28 OECD countries during 2005 to 2007, with the data being obtained from the data bank of World Development Indicators (WDI) of the World Bank, the International Labour Organization (ILO), and the Climate Analysis Indicators Tool (CAIT) of the World Resource Institute (WRI). The analyzed sample is a panel dataset comprising 87 observations. In terms of variable choice, this study chooses the input for the first stage to be energy consumption, while the intermediate input is CO_2 emissions. The intermediate inputs for the second stage are the labor force and real capital formation while the final output is real gross domestic product (GDP), as shown in Fig. 2. The variables for real capital formation and real GDP are deflated by the consumer price index (CPI) in the year 2000 to eliminate the price effect.

Results and Analysis

The energy use efficiency and economic efficiency for 28 OECD countries are computed by applying the modified two-stage CZ model and are shown in Table 1. The second, fourth and sixth columns in Table 1 represent the energy use efficiency of the OECD countries during 2005 to 2007. The third, fifth and seventh columns in Table 1 represent the economic efficiency of the OECD countries during 2005 to 2007. Finally, the eighth and ninth columns in Table 1 present the average values of the energy use efficiency and economic efficiency for the three years. Each figure in parentheses beside the efficiency scores represents the performance ranking.

The energy use efficiency and economic efficiency of the OECD countries are as follows, where two of the 28 OECD countries had two-stage efficiency scores of unit, namely, the United States and Iceland, respectively, from 2005 to 2007. This result shows that the performance of these two countries outperformed the other OECD countries before the subprime mortgage crisis in the United States in 2007. There are eight countries (i.e., Japan, Germany, France, the United Kingdom, Italy, Norway, Sweden and Switzerland) that only perform efficiently with a score of unit in the economic efficiency measure during the three years. This means that an improvement in their energy use efficiency can be observed for these countries, while France and Sweden perform more poorly than the average annual yearly value. According to the results of the eighth and ninth columns of Table 1, Hungary, the Czech Republic and Poland are relatively inefficient in terms of their average energy use efficiency from 2005 to 2007, while Australia, the Republic of Korea and the Czech Republic are relatively inefficient in terms of their average economic efficiency from 2005 to 2007.

In addition, this study found the average values of energy use efficiency to be 0.498, 0.492 and 0.488, which were smaller than the average economic efficiency of 0.853 (which is equal to the reciprocal of 1.172), 0.875 (which is equal to the reciprocal of 1.142) and 0.885 (which is equal to the reciprocal of 1.130) during the years 2005 to 2007, respectively. The results reveal that the OECD countries only attached importance to economic development, and they did not have an efficient application of energy use. Furthermore, the average energy use efficiency for 2005 outperformed that for 2006 and 2007, but the average economic efficiency for 2005 performed worse than that in 2006 and 2007. These results show that the better the energy use efficiency is, the worse the economic efficiency is. This means that a tradeoff relationship exists between energy use efficiency and economic development.

Analysis of the Optimal CO_2 Emission

Table 2 lists the results regarding the differences between the initial and optimal CO_2 emissions. The initial CO_2 emissions represent the observations of the raw data for the period from 2005 to 2007, and the optimal CO_2 emissions are calculated using the modified two-stage CZ model. The difference is the optimal CO_2 emissions minus the initial CO_2 emissions. Seven of the 28 OECD countries do not change their CO_2 emissions, namely, the United States, Japan, the United Kingdom, Norway, Sweden, Iceland and Switzerland, during the three-year period. The remaining OECD countries should have reduced their CO_2 emissions to achieve the energy use efficiency and economic efficiency. From the results of Table 1 and Table 2, we discover the differences of the initial CO_2 emissions from the optimal CO_2 emissions as well as the average economic efficiency are shown to increase year by year.

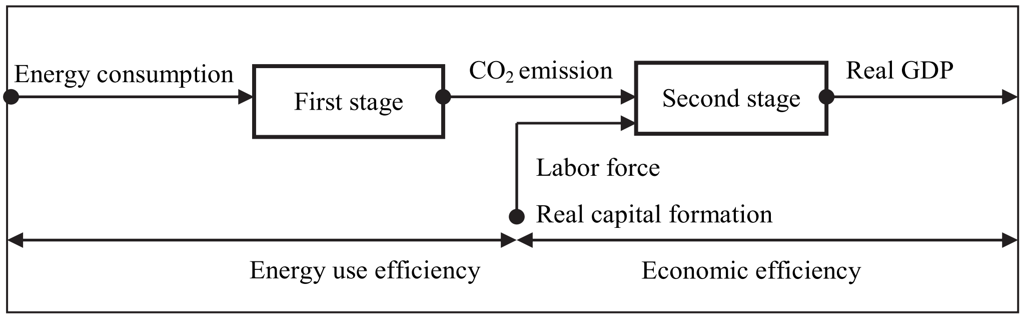

Fig. 2. The evaluation framework for the modified two-stage CZ model.

Table 1. Efficiency analysis of the modified two-stage CZ models for OECD countries.

Countries	2005		2006		2007		Average efficiency	
	Energy use efficiency	Economic efficiency	Energy use efficiency	Economic efficiency	Energy use efficiency	Economic efficiency	Energy use efficiency	Economic efficiency
United States	1	1	1	1	1	1	1 (1)	1 (1)
Canada	0.353	1.246	0.353	1.248	0.358	1.237	0.355 (20)	1.244 (23)
Japan	0.912	1	0.936	1	0.903	1	0.917 (3)	1 (1)
Germany	0.887	1	0.768	1	0.901	1	0.852 (5)	1 (1)
France	0.477	1	0.458	1	0.471	1	0.469 (11)	1 (1)
United Kingdom	0.863	1	0.886	1	0.883	1	0.878 (4)	1 (1)
Italy	0.511	1	0.504	1	0.484	1	0.499 (9)	1 (1)
Australia	0.411	1.407	0.410	1.399	0.374	1.423	0.398 (18)	1.41 (27)
New Zealand	0.444	1.399	0.451	1.207	0.420	1.208	0.438 (15)	1.272 (24)
Belgium	0.304	1.145	0.287	1.126	0.276	1.142	0.289 (26)	1.137 (17)
Netherlands	0.384	1.068	0.347	1.005	0.326	1.000	0.352 (22)	1.024 (11)
Denmark	0.597	1.041	0.577	1.061	0.559	1.067	0.578 (7)	1.056 (14)
Ireland	0.635	1.074	0.648	1.059	0.641	1.031	0.641 (6)	1.055 (13)
Greece	0.419	1.257	0.388	1.221	0.405	1.191	0.404 (16)	1.223 (22)
Spain	0.448	1.303	0.464	1.340	0.462	1.333	0.458 (12)	1.325 (25)
Portugal	0.403	1.306	0.397	1.195	0.401	1.131	0.400 (17)	1.211 (20)
Norway	0.438	1	0.497	1	0.430	1	0.455 (13)	1 (1)
Sweden	0.330	1	0.330	1	0.329	1	0.329 (24)	1 (1)
Iceland	1	1	1	1	1	1	1 (1)	1 (1)
Switzerland	0.567	1	0.571	1	0.538	1	0.559 (8)	1 (1)
Austria	0.459	1.211	0.435	1.178	0.426	1.120	0.440 (14)	1.17 (18)
Turkey	0.342	1.220	0.294	1.233	0.322	1.191	0.319 (25)	1.214 (21)
Mexico	0.378	1.140	0.327	1.130	0.381	1.063	0.362 (19)	1.111 (16)
Czech Rep.	0.186	1.586	0.197	1.516	0.185	1.475	0.189 (28)	1.525 (29)
Hungary	0.232	1.165	0.272	1.014	0.234	1.000	0.246 (27)	1.06 (15)
Poland	0.157	1.156	0.167	1.193	0.151	1.280	0.158 (29)	1.210 (19)
South Korea	0.505	1.600	0.431	1.535	0.487	1.439	0.474 (10)	1.525 (28)
Slovak Rep.	0.303	1.505	0.377	1.326	0.320	1.313	0.333 (23)	1.382 (26)
Average	0.498	1.172	0.492	1.142	0.488	1.130	0.493	1.148

Managerial Decision-Making Matrix

After evaluating the modified two-stage CZ model, this study designs a managerial decision-making matrix to provide an improvement direction to the policy makers of 28 OECD countries according to the results of energy use and economic efficiencies, as shown in Fig. 3.

In Fig. 3, each of the horizontal and vertical axes has two end values above and below the median efficiency, respectively. In Fig. 3, according to the energy use and economic efficiencies, the 28 OECD countries can be divided into four quadrants: leader, economic development, follower, energy conservation quadrants, which are discussed in detail as follows.

Leader quadrant: The countries in this quadrant perform relatively well in both energy use and economic efficiencies, which include 11 countries, such as United States, Japan, Germany, France, UK, Italy, Denmark, Ireland, Norway, Iceland and Switzerland. These countries should constantly maintain economic development and energy conservation advantages.

Economic development quadrant: The energy use and economic efficiencies of the countries in this quadrant are simultaneously below median. Two countries, i.e., the Netherlands and Sweden, belong to this quadrant. These countries should learn the energy conservation technique of the countries at the leader quadrant to reduce their energy consumption capability.

Follower quadrant: The countries in this quadrant possess simultaneously energy use inefficiency and economic inefficiency. The quadrant contains 12 countries, including Canada, Australia, New Zealand, Belgium, Greece, Portugal, Turkey, Mexico, Czech Republic, Hungary, Poland and Slovak Republic. Initially, it is suggested that these countries should focus on either energy use or economic development strategies to achieve a short term improvement.

Energy conservation quadrant: These countries show relatively energy use efficiency, but have less economic development ability than others. Three countries, i.e., Spain, Austria and South Korea, belong to this quadrant. This study suggests that these countries should refer the economic development strategy of the countries at the leader quadrant to promote its economy.

Table 2. Difference between initial and optimal CO_2 emissions from 2005 to 2007.

Countries	2005			2006			2007		
	Initial CO_2 emission	Optimal CO_2 emission	Difference	Initial CO_2 emission	Optimal CO_2 emission	Difference	Initial CO_2 emission	Optimal CO_2 emission	Difference
United States	5975800	5975800	0	5891900	5891900	0	5972800	5972800	0
Canada	571300	322608	–248692	552800	323032	–229768	587400	320547	–266853
Japan	1293600	1293600	0	1275300	1275300	0	1307100	1307100	0
Germany	856400	856400	0	871200	871200	0	848300	740188	–108112
France	423800	423800	0	415300	415300	0	407100	402366	–4734
United Kingdom	582600	582600	0	585600	585600	0	571300	571300	0
Italy	493000	314544	–178456	499100	295775	–203325	481900	303018	–178882
Australia	401500	175556	–225944	406400	163766	–242634	412900	178600	–234300
New Zealand	40400	18849	–21551	41400	15647	–25753	39800	15398	–24402
Belgium	144600	63205	–81395	143600	56100	–87500	142600	55007	–87593
Netherlands	247900	113900	–134000	245800	92730	–153070	245500	101725	–143775
Denmark	53900	35592	–18308	62400	34893	–27507	57900	32668	–25232
Ireland	48900	26697	–22203	50400	26598	–23802	49800	25472	–24328
Greece	113900	41704	–72196	114400	39528	–74872	119000	37904	–81096
Spain	399000	219814	–179186	394900	225435	–169465	408600	229763	–178837
Portugal	70900	33154	–37746	64800	28822	–35978	64100	26377	–37723
Norway	40400	40400	0	40600	40600	0	42000	42000	0
Sweden	59700	59700	0	58000	58000	0	56100	56100	0
Iceland	2800	2800	0	2900	2900	0	3100	3100	0
Switzerland	50000	50000	0	49800	49800	0	48100	48100	0
Austria	78100	53467	–24633	78000	49861	–28139	73700	46855	–26845
Turkey	244200	108134	–136066	269300	113449	–155851	295700	107637	–188063
Mexico	436300	228255	–208045	453600	229959	–223641	479400	208512	–270888
Czech Republic	122700	23474	–99226	123900	22463	–101437	125600	22019	–103581
Hungary	58600	15134	–43466	58100	12974	–45126	56400	13985	–42415
Poland	302400	49461	–252939	315200	50531	–264669	315300	54553	–260747
South Korea	535200	355094	–180106	545500	347917	–197583	557400	322589	–234811
Slovak Republic	40000	12180	–27820	39400	11043	–28357	38800	11557	–27243
Total	13935800	11609821	–2325979	13895400	11423855	–2471545	14053200	11358962	–2694238

CONCLUSIONS

The previous literature on the evaluation of the applications of energy use efficiency has only discussed a one-stage evaluation process and has usually ignored the impact of energy use on economic development. Therefore, the primary purpose of this study is to explore the possible relationship between energy use efficiency and economic efficiency. In addition to the two-stage efficiency measure, this study defines the optimal CO_2 emissions via the modified two-stage CZ model.

Energy consumption is regarded as the input of the first stage while the intermediate output is CO_2 emissions. The inputs of the second stage are the labor force, real capital formation and CO_2 emissions, while the final output is real GDP. The empirical results lead to the following three findings. First, the average values of energy use efficiency are smaller than the average economic efficiency during the three-year period. The results show that the OECD countries are only interested in economic development and have little regard for energy use efficiency. The high performance in terms of energy use efficiency does not ensure high economic efficiency as shown in the cases of Japan, Germany, France, the United Kingdom, Italy, Norway, Sweden and Switzerland. Second, we observe the existence of a tradeoff relationship between energy use efficiency and economic development for the OECD countries. This is evidenced by the energy use efficiency becoming better as the economic efficiency becomes much worse. Then, the differences of the initial CO_2 emissions from the optimal CO_2 emissions as well as the average economic efficiency are found to increase year by year. This result indicates that the OECD countries still discharge too much carbon dioxide. Finally, this research designs a managerial decision-making matrix by the results of energy use and economic efficiencies. The OECD countries are divided into four groups according to the managerial decision-making matrix, and the improvement suggestions are provided to the policy makers of OECD countries.

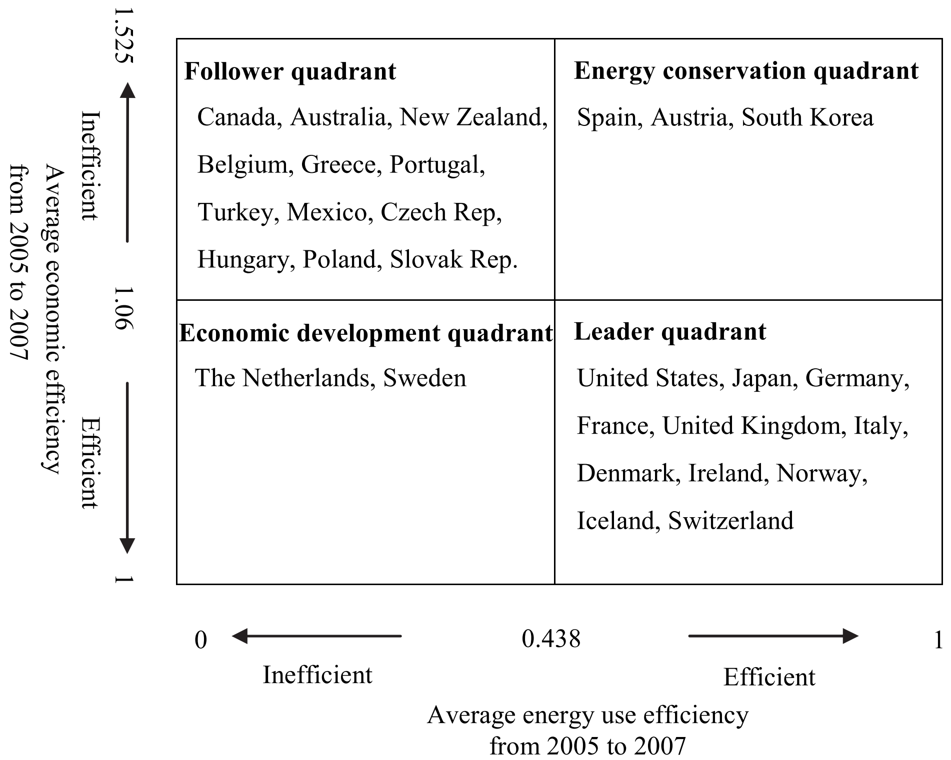

Fig. 3. Managerial decision-making matrix.

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