Efficiency at Energy Industry : A Comparison of Energy Consumption Efficiency among Asian Pacific Countries

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Abstract

This paper proposes a scheme to estimate the technical efficiency of energy consumption and production and shadow prices of CO_2 emission in country-level at Asia Pacific countries by Data Envelopment Analysis (DEA). The result of technical efficiency estimation shows that there exists an heterogeneity and a substantial opportunity for improvement in technical efficiency at energy consumption and production across countries, specially in the CO_2 emission, which implies that more pollutant are spread in air. Each country will have the different willingness to pay for the additional CO_2 emission right and this result enables us to predict the competition in international CO_2 emission right market.

1. Introduction

The possibility of regulatory control of particular inputs or outputs of industries is an important concern in most sectors of current economy. In the case where a private good technology interacts with public or quasi-public inputs or outputs, it is often in the social interest to control that interaction to achieve social goals that deviate from the industry's private goals. In the case of energy industry, the environmental impacts of the use of fossil fuels to generate energy for industries or individuals are an important case where applications may contribute to good objectives such as generating electricity while generating pollutants such as CO_2 emissions. In this paper, explored is the utility of nonparametric approaches such as Data Envelopment Analysis (DEA) to estimate the social cost of regulatory changes in input utilization.

Farrell (1957) initially claimed that evaluation of efficiency is useful for decision making units (DMUs) because it provides information on how much a DMU can decrease input without decreasing output (with keeping current output). Equivalently, technically inefficient DMUs can be brought towards efficiency by cutting down overused inputs. Trucks (DMUs) can al-

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so reduce the overused inputs (Bad performance) and truck owners evaluate their trucks reasonably through the evaluation of technical efficiency. As the approach to evaluate the technical efficiency, Data Envelopment Analysis (DEA) is employed in this paper because it does not require the assumption of the functional specification between input factors and output factors and also includes multiple outputs unlike stochastic frontier model (SFM). Data for empirical analysis in this paper come from a survey to truck drivers.

As past work has shown, where firms are inefficient in their use of polluting inputs, the private costs of regulation may be much smaller that implied by similar reduction in use by firms that are efficient in their current use of those inputs, see e.g. Piot-Petite *et al.* (1998) The approaches in this paper are to develop estimates of shadow prices that are conditioned on the possibility of inefficient use of the regulated input and to calculate the relevant social cost of additional use of the regulated input among Asian Pacific countries.

The utility of DEA for estimation of the impacts of regulation has been explored in a stream of past literature. Haynes *et al.* (1994) used DEA to examine whether pollution prevention is successful or not. They did not use the shadow prices but use only the efficiency values. They tried to find the opportunity of improvement in polluting input use. Coggins and Swinton (1996) and Swinston (1998) provides estimates of the shadow price of SO_2 abatement using the output distance function approach for coal-burning electric plants. He estimated the radial efficiency of each firm, measured the relative distance of each firm from efficient frontier, and calculated the shadow prices of each firm. The shadow price means the marginal value of the electricity foregone as resources go to reducing SO_2 emissions by one unit. In other point of view, the allowance of one unit from current amount has the value of the shadow price-that is, a firm is willing to pay the shadow price for the allowance of one unit. Lee and Kang (2002) made a replica of Swinton paper for Korean electricity plants.

The approach of this paper is quite different from the above papers in that this paper focuses on the consumption of energy as well as the production of it and on the energy consumption and production of countries rather than power plants and employs DEA directly to estimate the shadow price of the regulated input. Thus, this paper will be the first paper which tries to evaluate technical efficiency at the energy consumption and production of the country level and to calculate the social cost generated through energy production and consumption.

2. Theoretical Backgrounds

Shadow prices are values that are used largely following the Linear Programming (LP). The notion of a shadow price emerges from elementary microeconomic theory as the marginal value of relaxing a constraint faced by a DMU. The value of the marginal change in the constraint is measured by the DMU's objective that states the value to the DMU of the productivity of the constrained control variable. Within the context of a regulated DMU, regulation might place a constraint on the use of a polluting input. In this case, the impact of that constraint on the DMU is the discrete change in the DMU's objective induced by the discrete change from current use to the use of regulated input. In a traditional profit maximization problem where the firm manages a vector of outputs (y) by applying a vector of variable inputs (x) and use of the regulated input (z), the unregulated DMU would proceed with a production plan (y^*, x^*, z^*) that maximizes profits ($\pi^* = \pi(y^*, x^*, z^*)$). In contrast, when z is regulated such that $z < z_g$, the DMU's maximum profits are $\pi_g = \pi(y^*, x^*, z_g)$ where $\pi_g < \pi^*$ and $R = \pi^* - \pi_g$ is the regulation cost to the DMU. In the short-run, where z^* represents optimal use and where technical efficiency exists, $R > 0$. Where the DMU is technologically inefficient in its use of z, e.g. using a production plan (y^*, x^*, z') where $z' > z^*$, then $\pi' = \pi(y^*, x^*, z') > \pi^*$ and the possibility $\pi' < \pi_g$ is admitted. In this case, as Piot-Petit, *et al.*, noted, a free lunch occurs as a result of regulation.

A similar logic is applied for marginal regulatory adjustments in use of a regulated input. In general, the change in profits can be measured as $d\pi = \frac{d\pi}{dz}dz$ where the change in z is measured from the initial level. However, when the DMU is inefficient, $\frac{d\pi}{dz}dz$ must be measured by $\pi' - \pi_g$ whereas when the firm is efficient, it is $\frac{d\pi}{dz}dz = -R = \pi^* - \pi_g = \mu$, which is interpreted as the shadow price of the marginal regulatory constraint on z.

In order to estimate the shadow price of the regulated input through DEA, it should be noted that the implications for the measurement of technical efficiency were recognized by Farrell (1957) and Charnes *et al.* (1978). The input based measures of Farrell can be defined for a set of N firms ($n = 1, \cdots, N$), a vector of variable inputs (x) into a vector of outputs (y). The production possibilities set for a DMU which is evaluated firm can be written as the following piece-wise linear technology:

$$P = \left\{ (y_{n0},\ x_{n0}) | x_{n0} \geq \sum_{n=1}^{N} z_n x_n,\ y_{n0} \leq \sum_{n=1}^{N} z_n y_n,\ \sum_{n=1}^{N} z_n = 1,\ z \in R_+^N \right\} \tag{1}$$

where $z = (z_1, \cdots\cdots, z_N)$ is the intensity vector with elements indicate the intensity with which each DMU's production plan is taken into account in the construction of the technology frontier (Cooper *et al.*, 2000). From equation (1), input-oriented technical efficiency is defined for the DMU (n_0) as follows.

Objective function (RTE)

$$\underset{\lambda_{n_0}, z_n}{Min}\, \lambda_{n_0}$$

Subject to,

$$\sum_{n=1}^{N} z_n x_{n,i} \le x_{n_0,i}\lambda_{n_0},\ i = 1,\ 2,\ \cdots,\ I\text{: Variable inputs} \tag{2}$$

$$y_{n_0,j} \le \sum_{n=1}^{N} z_n y_{n,j},\ j = 1,\ 2,\ \cdots,\ J\text{: Outputs}$$

$$\sum_{n=1}^{N} z_n = 1\text{: Variable returns to scale}$$

Objective function (NRTE)

$$\underset{\lambda_{n_0,i}, z_n}{Min} \sum_{i=1}^{I} \lambda_{n_0,i}$$

Subject to,

$$\sum_{n=1}^{N} z_n x_{n,i} \le x_{n_0,i}\lambda_{n_0,i},\ i = 1,\ 2,\ \cdots,\ I\text{: Variable inputs} \tag{3}$$

$$y_{n_0,j} \le \sum_{n=1}^{N} z_n y_{n,j},\ j = 1,\ 2,\ \cdots,\ J\text{: Outputs}$$

$$\sum_{n=1}^{N} z_n = 1\text{: Variable returns to scale}$$

Output-oriented technical efficiency is defined for the DMU (n_0) as follows.

Objective function (RTE)

$$\underset{\lambda_{n_0}, z_n}{Max}\, \lambda_{n_0}$$

Subject to,

$$\sum_{n=1}^{N} z_n x_{n,i} \le x_{n_0,i},\ i = 1,\ 2,\ \cdots,\ I\text{: Variable inputs} \tag{4}$$

$$y_{n_0,j}\lambda_{n_0} \le \sum_{n=1}^{N} z_n y_{n,j},\ j = 1,\ 2,\ \cdots,\ J\text{: Outputs}$$

$$\sum_{n=1}^{N} z_n = 1\text{: Variable returns to scale}$$

Objective function (NRTE)

$$\underset{\lambda_{n_0,i}, z_n}{Max} \sum_{i=1}^{I} \lambda_{n_0,i}$$

Subject to,

$$\sum_{n=1}^{N} z_n x_{n,i} \le x_{n_0,i}, \; i = 1,\ 2,\ \cdots,\ I\text{: Variable inputs} \tag{5}$$

$$y_{n_0,j}\lambda_{n_0,j} \le \sum_{n=1}^{N} z_n y_{n,j}, \; j = 1,\ 2,\ \cdots,\ J\text{: Outputs}$$

$$\sum_{n=1}^{N} z_n = 1\text{: Variable returns to scale}$$

The above equations illustrate the DEA models developed by Banker *et al.* (1984), assuming the variable returns to scale (VRS) and strong disposability. Input-oriented efficiency gives us the information on how much of inputs can be reduced by, keeping current output level while output-oriented efficiency gives us the information on how much of outputs can be reduced by, keeping current input level.

It is possible to obtain the shadow price of the regulated input by tallying the shadow price information for the regulated input after running the above DEA formulations. However, since the shadow prices from them are expressed by efficiency score rather than by monetary value or utility, they could not be interpreted as the ‘real’ shadow price of the regulated input which indicates the social cost of the input. Nonetheless, they are important because they are used to calculate the ‘real’ shadow prices.

Following the paper of LePetit *et al.* (1998), a method of calculating the ‘real’ shadow price of the regulated input in monetary value is presented. It is possible to write the technical efficiency measure in terms of input-output subvector distance function: $d_n(x_n,\ y_n) = \frac{1}{\lambda_n(x_n,\ y_n)}$, where $\lambda_n(x_n,\ y_n)$ is the radial technical efficiency measure of each firm. From this, the ratio of shadow prices between input factor and output factor is computed as:

$$\frac{p_{x_i}}{p_{y_k}} = \frac{\partial d_n(x,y)/\partial x_i = \textit{shadow price of input}}{\partial d_n(x,y)/\partial y_j = \textit{shadow price of output}}$$

, where p_{xi} is the ‘real’ shadow price of i^{th} input and p_{yj} is the ‘real’ shadow price of j^{th} output. In other words, the ratio of ‘real’ shadow prices of i^{th} input and to the ‘real’ shadow price of j^{th} output factor is equal to that of shadow prices estimated by DEA. Therefore, if it is assumed that the price of j^{th} output is known and known to equal its ‘real’ shadow price, then calculate calculate the ‘real’ shadow price of i^{th} input.

3. Data and Empirical Issues

The data on the 2004 energy production and consumption in Asia Pacific countries were collected from ‘2007 Overseas Electric Power Industry Statistics’ prepared by Korea Electric Power Corporation. The size of sample is 35 that are located in Asia and Pacific area.

The model for efficiency evaluation is specified with four output categories (electricity consumption, petroleum consumption, natural gas consumption, and coal consumption) and three input factors (CO_2 emission, Total energy production, and net energy export). Output factors indicate how much energy elements have been consumed in each country and input factors indicate how much energy has been produced. Therefore, the mail points are to examine how much energy was produced and how much CO_2 was emitted to consume how much energy elements and to calculate how much the reduction of CO_2 emission costs socially.

Table 1 illustrates the summary of data for all samples.

Table 1. Summary of data for sample

Variables	N	Min	Max	Mean	Standard Deviation
CO_2 emission (Mega tons)	35	3.66	5799.97	580.89	1257.97
Energy production (Mtoe)	35	0.00	1641.04	250.19	429.81
Net export (Mtoe)	35	-714.51	521.00	-11.58	216.69
Electricity consumption (Tera Wh)	35	0.94	3920.61	342.25	747.80
Petroleum consumption (Mtoe)	35	3.30	937.60	79.45	164.62
Natural gas consumption (Mtoe)	35	0.00	582.00	55.34	127.03
Coal consumption (Mtoe)	35	0.00	956.90	68.92	185.77

4. Results and Discussion

Both input-oriented and output-oriented technical efficiency for 35 countries has been evaluated. The interpretation of input-oriented technical efficiency is that keeping current consumption of energy elements (electricity, petroleum, natural gas, and coal) can reduce energy production, total export, and CO_2 emission by the ratio of (1-technial efficiency score). The interpretation of output-oriented technical efficiency is that keeping current energy production, total export, and CO_2 emission can increase the consumption of energy elements (electricity, petroleum, natural gas, and coal) by the ratio of (technical efficiency score-1).

The summary of technical efficiency evaluation in Table 2 and Table 3 shows the heterogeneity in efficiency of energy consumption and production across countries, substantial opportunity for improvement, and, as the result, the possibility for reduction of CO_2 emission. The heterogeneity is shown by the results that the ranges of input-oriented efficiency are 52.11% (1-0.4789) and those of output-oriented efficiency is 138.37% (2.3837-1) These results imply that countries are producing more energy than what they consume and emit more CO_2 than what they need and reversely they should consume more energy under current energy production

For improvement opportunity, countries will be able to improve their input-oriented efficiency by 8.73%, 40.78%, and 74.29% averagely for CO_2 emission, energy production, and net export, respectively. Countries will also be able to improve their output-oriented efficiency by 16.58%, 72.32%, 43.36%, and 118.19% averagely for electricity consumption, petroleum consumption, natural gas consumption, and coal consumption, respectively.

Table 2. Summary of results from radial technical efficiency evaluation

	Input-oriented radial	**Output-oriented radial**
Average efficiency	0.8968	1.1477
# of efficient centers	19	19
% of efficient centers	54.29%	54.29%
Min. (Max) efficiency	0.4789	2.3837

Table 3. Summary of results from nonradial technical efficiency evaluation

	CO_2 emission	Energy production	Net export	Electricity consumption	Petroleum consumption	Natural gas consumption	Coal consumption
Average efficiency	0.9127	0.5922	0.2571	1.1658	1.7232	1.4336	2.1819
# of efficient centers	20	16	9	27	20	26	20
% of efficient centers	57.14%	45.71%	25.71 %	77.14%	57.14%	74.29%	57.14%
Minimum efficiency	0.4789	0.3541	0.0000	27.31%	63.21%	39.81%	20.50%

Table 4 shows the result of calculating the shadow price of CO_2 emission for each country with respect to the electricity price. Among 35 countries, since 2004 electricity price of only 18 is available, the below table has the shadow price information for them. ‘NA’ indicates the case that the shadow price of electricity consumption is zero. The values in the table indicate the marginal cost when CO_2 emission is reduced. In other words, they indicate the willingness of each country to pay for the right of the one more ton of CO_2 emission. As shown in Table 4, country 29, 20, 1 and 3 have large willingness to additional emission right. They consist of Turkey, Japan, Former USSR, and Chinese Taipei. In addition, United States, Ecuador, and Korea etc. have the large willingness to pay. This result enables us to predict a tough competition to get more CO_2 emission rights at cheaper price and emphasizes the importance of the information on the willingness of other countries.

Table 4. The result of 'real' shadow price estimation for CO_2 emission

ID	Electricity Price (US cent/kWh)	Shadow Price for CO_2 emission (USD/ton)			
		Input-oriented Radial	Output-oriented Radial	Input-oriented Nonradial	Output-oriented Nonradial
1	12	NA	NA	NA	610.2
2	12	NA	117.6	NA	0.00
3	8	101.1	86.9	20.8	468.5
5	9	NA	NA	NA	154.9
6	9	NA	NA	1.8	229.4
8	5	66.1	115.5	140.4	115.3
9	9	135.4	91.9	264.9	113.9
13	4	57.2	57.2	51.1	71.7
14	13	150.2	159.8	15.9	290.1
15	10	110.3	109.8	2830.2	283.9
18	4	45.3	45.3	NA	174.3
20	20	0.0	154.9	NA	920.1
22	9	83.2	83.2	52.4	118.0
23	3	NA	NA	NA	72.4
25	7	304.6	63.7	27.7	87.2
26	8	98.7	98.7	84.0	174.8
29	11	NA	NA	NA	5216.2
32	11	132.6	132.6	5783.7	199.4
34	8	114.1	141.7	NA	202.5

5. Conclusion

This paper deals with topic how to evaluate the performance of Asian Pacific countries at ensergy consumption and production. Main contribution of this paper is to estimate the technical efficiency and willingness to pay for additional CO_2 emission right for country level not firm level. Technical efficiency based on production function of energy production and consumption was chosen as the performance measure and DEA was implemented in order to estimate technical efficiency. As the result, it was possible to confirm some meaningful findings and get some important intuition.

Asia Pacific countries show the substantial heterogeneity in technical efficiency. While some countries are efficient, others are inefficient by considerable amount. Also, the scale and type of inefficiency is different among countries. More important thing is that each country has the heterogeneous willingness to pay for the additional CO_2 emission right.

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