Original Research

Efficiency and Governance of Power Corporations: A China and Taiwan Analysis

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Abstract

Every country's power generation sector is highly controlled by the government since it is closely related to the country's economic development and environmental protection. This study discusses the efficiency of power corporations and investigates the relationship between public governance and the electricity power industry's efficiency in China and Taiwan. We find that:

(i) Only half of the six power corporations in China and Taiwan belonged to Green Enterprises in 2010

(ii) The production efficiency and environmental efficiency in Taiwan's electrical power industry have always been superior to those in China's electrical power industry

(iii) In 2010, the SO_2 emissions of all of China's five power corporations were either close to or equal to optimal SO_2 emissions; however, the SO_2 emissions of Taiwan's TPC departed from the optimal SO_2 emissions

(iv) Finally, we conclude that a good quality of public governance is helpful for improving the efficiency of China's electrical power industry.

Keywords: efficiency, power corporation, public governance

Introduction

The process of power generation entails a large amount of capital, labor, and powerful government support [1, 2]. Such power generation also emits large quantities of greenhouse gases and pollutants such as carbon dioxide (CO_2) and sulfur dioxide (SO_2), causing an environmental side effect. CO_2 is the main reason for global warming, and SO_2 is the main factor underlying the formation of acid rain, which damages streams, lakes, and the growth of plants and forests. SO_2 is an irritant to the eyes, nose and throat, and even the cause of the killer smog in Donora, PA, in 1948 and London, England, in 1952 [3, 4]. SO_2 has in fact increased human mortality [5]. It is estimated that of the amount of SO_2 in the atmosphere, more than 70% is from anthropogenic sources, half of which are due to fossil-fuel combustion [6]. The main source of SO_2 in China is power plants, with the amount of SO_2 having rapidly increased from 10.6Tg in 2000 to 18.6Tg in 2006 [7]. In order to reduce greenhouse gases and pollutants in the atmosphere, it is necessary to increase efficiency in the generation, transportation, allocation, and consumption of electricity [8].

Research on the issue of electricity and CO_2 concludes that the best choice for reducing CO_2 is using renewable resources to generate electricity [9]. Some recent papers focus on the issue of electricity, SO_2, and CO_2 [10, 11]. Sozen et al. [10] use data envelopment analysis (DEA) to analyze the operational and environmental performances of 15 coal-fired power plants in Turkey; Sueyoshi et al. [11] study the influence of the clean air act (CAA) in the US on the operational and environmental efficiency of coal-fired power plants. The results show that CAA not only promotes environmental protection efficiency, but also helps out in technical efficiency.

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Many studies related to the efficiency of power plants use DEA as an analytical tool. Park and Lesourd [12] estimate the efficiency of coal-fired power plants in South Korea using the BCC (Banker, Charnes, and Cooper) model proposed by Banker et al. [13]. They take the efficiency value of a coal-fired power plant as a dependent variable to establish an econometric model for finding which factors affect the efficiency of power plants. Lam and Shiu [14] use the DEA approach to estimate the efficiency of thermal power generation in China. They engage in two-stage Tobit regression analysis to find the factors that impact the efficiency of thermal power generation. They conclude that the government's policy such as reasonable peak-load pricing or effectual demand side management is helpful in increasing the technical efficiency of thermal power generation. Since the key role of economic development is power generation [15, 16], some studies use the DEA approach to analyze the efficiency of the electricity power industry, including Abbott [17], Cooper et al. [18], Sarica and Or [19], Simar and Wilson [20], Barros and Peypoch [21], Liu et al. [16], and Sueyoshi and Goto [22].

Few studies have investigated the relationship between public governance and the efficiency of the electrical power industry. However, some studies have observed the existence of a relationship between public governance and agricultural production efficiency. For instance, the World Development Report 2008 published by the World Bank [23] mentions that public governance is a fundamental characteristic of agricultural development that plays a key role in improving agricultural performance. Since agriculture and the electrical power industry hold the same position in a country's development, it is reasonable to assume that good governance quality fosters the efficient development of the electrical power industry. Lio and Hu [24] investigated the relationship between public governance indicators and agricultural efficiency. They concluded that the improvement in the institutional framework can enhance the poor countries' agricultural efficiency. Besides, a number of scholars are also concerned with the relationship between public governance and macroeconomic performance such as Adkins et al. [25] and Méon and Weill [26].

The power generation process creates desirable outputs such as electricity and undesirable outputs such as SO_2. If a power plant generates a large amount of electricity, then it has high operational efficiency; on the contrary, if the power plant emits a huge quantity of SO_2, then it has low environmental efficiency. Sueyoshi and Goto [22] draw a distinction between operational efficiency and environmental efficiency in relation to the efficiency frontier. Operational efficiency is estimated by desirable outputs, and environmental efficiency is estimated by undesirable outputs. The concept that outputs may be separated into desirable outputs and undesirable outputs is similar to that of Zhou and Ang [27] who set up the inputs as energy inputs and non-energy inputs. Besides, they discuss the issues of energy efficiency and environmental efficiency under a DEA framework. The idea of total-factor energy efficiency was originally proposed by Hu and Wang [28], who took 29 administrative regions in China as an example to compare the regional energy efficiency among western China, central China, and eastern China. The idea of total-factor energy efficiency has been comprehensively applied to different objectives such as 17 APEC economies by Hu and Kao [29], 47 prefectures in Japan by Honma and Hu [30], and 27 regions in China by Lee et al. [31].

This study introduces the production efficiency assessment model, the environmental efficiency assessment model, and the overall efficiency assessment model to estimate the efficiency of power corporations in China and Taiwan. Through the production efficiency assessment model, we can calculate the efficient desirable output increment given the undesirable output. Similarly, we can calculate the potential pollution reduction given the desirable output in the environmental efficiency assessment model. We simultaneously consider production efficiency and environmental efficiency by applying the overall efficiency assessment model. In addition, we investigate the relationship between public governance and the efficiency of power corporations in China and Taiwan. The main contribution of this study is that it establishes a model that is used to calculate the total desirable output increment ratio and the total potential pollution reduction ratio. This study concludes that:

(i) In 2010 only half of the six power corporations in China and Taiwan belonged to Green Enterprises that have higher production efficiency and environmental efficiency

(ii) The electricity power industry in Taiwan has always had higher production efficiency and environmental efficiency than China's electrical power industry

(iii) In 2010 the SO_2 emissions of all five power corporations in China were either close to or equal to the optimal SO_2 emissions; however, the SO_2 emissions of TPC in Taiwan have departed from the optimal SO_2 emissions

(iv) Good public governance quality is helpful for improving the efficiency of China's electrical power industry.

Methodology

We introduce in this section the production efficiency assessment model, the environmental efficiency assessment model, and the overall efficiency assessment model to estimate the DMU's production efficiency, environmental efficiency, and overall efficiency, respectively.

Assessment of Production Efficiency

We examine whether a given decision-making unit (DMU) labeled k is or is not efficient in its production process, and simultaneously consider the desirable output and undesirable output. The number of DMUs is n. Each DMU uses m kinds of inputs to produce s kinds of desirable outputs and h kinds of undesirable outputs. Define x_{ij} as the ith input for the jth DMU; g_{rj} is the rth desirable (good) output for the jth DMU; and b_{fj} is the fth undesirable (bad) output for the jth DMU, where $j = 1,\ldots, n$; $i = 1,\ldots, m$, $r = 1,\ldots, s$, $f = 1,\ldots, h$.

The production efficiency assessment model is specified as follows:

$$\begin{aligned}
&Max\ \phi\\
&\text{s.t.}\\
&\sum_{j=1}^{n} u_j x_{ij} \le x_{ik}\\
&\sum_{j=1}^{n} u_j g_{rj} \ge g_{rk}(1+\phi)\\
&\sum_{j=1}^{n} u_j b_{fj} = b_{fk}\\
&u_j \ge 0\\
&\phi \ge 0
\end{aligned} \tag{1}$$

...where u_j is the weight of the jth DMU used for connecting the input, the desirable output, and the undesirable output by a linear combination of each DMU.

In Equation (1), the equality characteristic of the undesirable output constraint is due to its being weakly disposable. The model in Equation (1) uses a directional distance function approach to solve for an optimal ϕ^* value, which stands for the distance from the location of the kth DMU, i.e., (x_{ik}, g_{rk}, b_{fk}) to the efficient frontier. Thus, an optimal ϕ^* value is defined as production inefficiency, and the larger ϕ^* is, the greater the inefficiency.

To achieve production efficiency, we calculate the total desirable output increment (TDOI). The desirable output constraint in Equation (1) can be rewritten as $\sum_{j=1}^{n} u_j g_{rj} - \phi g_{rk} \ge g_{rk}$. Let $\varepsilon_{rk}^{g} = \phi g_{rk} \ge 0$ be the desirable output increment of the kth DMU with respect to the rth desirable output. Thus, the TDOI of the kth DMU is $\sum_{r=1}^{s} \varepsilon_{rk}^{g}$, and the TDOI ratio (TDOIR) of the kth DMU is:

$$TDOIR_k = \frac{\sum_{r=1}^{s} \varepsilon_{rk}^{g}}{\sum_{r=1}^{s} g_{rk}} = \frac{\phi \sum_{r=1}^{s} g_{rk}}{\sum_{r=1}^{s} g_{rk}} = \phi \tag{2}$$

The denominator of Equation (2) stands for the total amount of desirable output, such as the sum of 110v power, 220v power, and so on; the numerator of Equation (2) stands for the potential increment for each desirable output. We take two kinds of desirable output, such as 110v power and 220v power, as an example. The sum of the desirable output for 110v power and 220v power is 100 units, including 60 units for 110v power and 40 units for 220v power. If TDOIR is 10%, then 110v power and 220v power should increase output by 6 units and 4 units, respectively. Hence, the optimal total amount of desirable output for 110v power and 220v power is 110 units, including 66 units for 110v power and 44 units for 220v power. Equations (1) and (2) were provided by Chang [32] who also uses them to estimate production efficiency.

Since the minimal value of $\sum_{r=1}^{s} \varepsilon_{rk}^{g}$ is zero, the value of $TDOIR_k$ is between zero and unity. We therefore define the total production efficiency (TPE) index as:

$$TPE_k = 1 - TDOIR_k = 1 - \phi \tag{3}$$

...where TPE_k is the TPE of the kth DMU. A zero TDOIR value indicates a DMU on the frontier with the best total production efficiency reaching as high as unity among all DMUs. Higher TDOIR represents lower production efficiency.

Assessment of Environmental Efficiency

The environmental efficiency assessment model is as follows:

$$\begin{aligned}
&Max\ \eta\\
&\text{s.t.}\\
&\sum_{j=1}^{n} u_j x_{ij} \le x_{ik}\\
&\sum_{j=1}^{n} u_j g_{rj} \ge g_{rk}\\
&\sum_{j=1}^{n} u_j b_{fj} = b_{fk}(1-\eta)\\
&u_j \ge 0\\
&\eta \ge 0
\end{aligned} \tag{4}$$

The undesirable output constraint in Equation (4) can be rewritten as $\sum_{j=1}^{n} u_j b_{fj} + \eta b_{fk} = b_{fk}$. Let $\varepsilon_{fk}^{b} = \eta b_{fk} \ge 0$ be the potential pollution reduction of the kth DMU with respect to the fth undesirable output, and the total potential pollution reduction (TPPR) of the kth DMU is $\sum_{f=1}^{h} \varepsilon_{fk}^{b}$.

The formulation of the total potential pollution reduction ratio (TPPRR) of the kth DMU is:

$$TPPRR_k = \frac{\sum_{f=1}^{h} \varepsilon_{fk}^{b}}{\sum_{f=1}^{h} b_{fk}} = \frac{\eta \sum_{f=1}^{h} b_{fk}}{\sum_{f=1}^{h} b_{fk}} = \eta \tag{5}$$

The denominator of Equation (5) stands for the total amount of pollution, such as the sum of CO_2, SO_2, NO_x and so on; the numerator of Equation (5) stands for the potential reduction for each kind of pollution. We take three kinds of pollution, say, CO_2, SO_2, and NO_x, as an example. The sum of the emissions of CO_2, SO_2, and NO_x is 100 units, including 50 units for CO_2, 30 units for SO_2, and 20 units for NO_x. If TPPRR is 20%, then CO_2, SO_2, and NO_x should reduce emissions by 10 units, 6 units, and 4 units, respectively. Hence, the optimal total amount of emissions for CO_2, SO_2, and NO_x is 80 units, including 40 units for CO_2, 24 units for SO_2, and 16 units for NO_x. An optimal η^* value is defined as inefficient, and the larger η^* is, the greater the inefficiency. Equations (4) and (5) were provided by Chang [32] in which he uses $1 - \eta^*$ to estimate energy efficiency; here we use $1 - \eta^*$ to assess environmental efficiency. Since the minimal value of $\sum_{f=1}^{h} \varepsilon_{fk}^{b}$ is zero, the value of TPPRR is between zero and unity.

We can now define the total environmental efficiency (TEE) index as:

$$TEE_k = 1 - TPPRR_k = 1 - \eta \tag{6}$$

...where TEE_k is the total environmental efficiency of the kth DMU. A zero TPPRR means that no pollution reduction exists. A value of TPPRR larger than zero means that the quantity of pollution emissions is too large. Higher TPPRR represents lower environmental efficiency.

Assessment of Overall Efficiency

The efficiency value that simultaneously considers production efficiency and environmental efficiency is referred to as overall efficiency. The overall efficiency assessment model is:

$$\begin{aligned}
&Max\ \lambda \\
&\text{s.t.} \\
&\sum_{j=1}^{n} u_j x_{ij} \le x_{ik} \\
&\sum_{j=1}^{n} u_j g_{rj} \ge g_{rk}(1+\lambda) \\
&\sum_{j=1}^{n} u_j b_{fj} = b_{fk}(1-\lambda) \\
&u_j \ge 0 \\
&\lambda \ge 0
\end{aligned} \tag{7}$$

The desirable output constraint in Equation (7) can be rewritten as $\sum_{j=1}^{n} u_j g_{rj} - \lambda g_{rk} \ge g_{rk}$. Let $\varepsilon_{rk}^{g'} = \lambda g_{rk} \ge 0$ be the desirable output increment of the kth DMU with respect to the rth desirable output. The undesirable output constraint in Equation (7) can be rewritten as $\sum_{j=1}^{n} u_j b_{fj} + \lambda b_{fk} = b_{fk}$. Let $\varepsilon_{fk}^{b'} = \lambda b_{fk} \ge 0$ be the potential pollution reduction of the kth DMU with respect to the fth undesirable output.

We define the total slack of the kth DMU as:

$$\varepsilon_k^{'} = (\sum_{r=1}^{s} \varepsilon_{rk}^{g'} + \sum_{f=1}^{h} \varepsilon_{fk}^{b'}) = \lambda(\sum_{r=1}^{s} g_{rk} + \sum_{f=1}^{h} b_{fk}).$$

Parameter λ stands for the distance from the location of the DMU to the efficient frontier. A zero λ means that there is no slack from the location of the DMU to the efficient frontier. A value of λ greater than zero means that the distance between the DMU's location and the efficient frontier is large. The higher λ represents lower environmental efficiency. We therefore define the overall efficiency (OE) index as:

$$OE_k = 1 - \lambda \tag{8}$$

...where OE_k is the overall efficiency of the kth DMU.

Truncated Regression Model

We specify the truncated regression model to empirically test the relationship between public governance and efficiency as follows:

$$\text{Efficiency score} = a_0 + \sum_{t=1}^{\lambda} a_t\,(\text{governance variable})_t + e \tag{9}$$

...where parameter a_0 stands for the constant term, parameter a_t represents the tth governance variable's coefficient, and parameter e is the error term. The total number of governance variables is t in Equation (9). The reason we apply the truncated regression model in this paper instead of the Tobit regression model [33] is due to a suggestion by Simar and Wilson [20], who performed Monte Carlo experiments and concluded that the estimated confidence interval in the Tobit regression model is more sensible than that in the truncated regression model.

Empirical Analysis

Data Description

We use the DEA approach to analyze production efficiency, environmental efficiency, overall efficiency, and the relationship between public governance and the electrical power industry in China and Taiwan. The data on the six power corporations from 2005 to 2010 include one input and three outputs, in which the desirable output has two terms and the undesirable output has one term. The monetary input and outputs such as total assets and total sales are deflated to 2005 values. All input and output variables in this study are originally proposed by Sueyoshi and Goto [22] except that:

(i) We chose SO_2 as the undesirable output instead of CO_2, as proposed by Sueyoshi and Goto [22]

(ii) We eliminate one of the input variables proposed by Sueyoshi and Goto [22], i.e., labor cost.

The reason we do not use labor cost as an input factor is because of a negative correlation coefficient between total assets and labor cost. The result means that these two input variables are substitute factors. In addition, a negative correlation coefficient between the labor cost and all output

Table 1. Correlation coefficient matrix.

	Input variable	Desirable output variable		Undesirable output variable
	Total assets	Total sales	Number of customers	SO_2
Total assets	1	0.705	0.344	-0.224
Total sales	0.705	1	0.715	-0.034
Number of customers	0.344	0.715	1	-0.011
SO_2	-0.224	-0.034	-0.011	1

variables violates the principle of isotonicity in the DEA model. Hence, we choose one of them.

Our data sources are power company statistical yearbooks and the websites of each power company. The six DMUs in this study include five of China's power corporations and one Taiwan power corporation. China's power corporations are China Power Investment Corporation (CPIC), China Guodian Corporation (CGC), China Huadian Corporation (CHC), China Huaneng Group (CHG), and China Datang Corporation (CDC); the only Taiwan power corporation is the Taiwan Power Company (TPC).

Table 1 shows that the correlation coefficients between the input and desirable output variables are positive, which indicates that the input and the desirable output variables satisfy the principle of isotonicity from the DEA method. However, the correlation coefficients between SO_2 and total assets, total sales, and the number of customers are negative, which implies that when there are more inputs and desirable outputs, the SO_2 emissions are lower. This result illustrates that the power corporation not only inputs a lot of equipment to reduce SO_2 emissions, but places emphasis on producing the more desirable output and the less undesirable output. The production mode of power corporations in China and Taiwan fits the world trend of environmental protection.

Production Efficiency (PE) and Environmental Efficiency (EE)

Production efficiency, environmental efficiency, and overall efficiency for the six power companies are presented in Table 2. As Fig. 1 shows, the horizontal coordinate represents production efficiency and the vertical coordinate stands for environmental efficiency. Considering the technological change in production efficiency and environmental efficiency, this study uses the average values of production efficiency and environmental efficiency as two boundary lines within which their adjustment follows the different years. The two boundary lines are applied to separate the six power companies into four company types, which can be used to view the power company's status quo, as outlined below.

(1) Green enterprise: A green enterprise has the characteristic of high production efficiency and high environmental efficiency and is the most popular company type. We propose the label "Green Enterprise" for a power company belonging to quadrant I.

(2) Green-improved enterprise: The characteristics of this enterprise are high environmental efficiency but low production efficiency. This kind of enterprise makes efforts to improve its environmental efficiency by sacrificing its production efficiency. A green-improved enterprise has a trade-off relationship between production efficiency and environmental efficiency. We propose "green-improved enterprise" as the label for a power company in quadrant II.

(3) Weak enterprise: A weak enterprise has low production efficiency and low environmental efficiency. We propose the label "weak enterprise" for a power company belonging to quadrant III.

(4) Production-improved enterprise: A production-improved enterprise has the characteristic of high production efficiency but low environmental efficiency, which we show in quadrant IV. A production-improved enterprise only emphasizes production efficiency but ignores environmental efficiency.

The historical focus of the development of power companies should be from a weak enterprise to a production-improved enterprise; and then from a production-improved enterprise to a green-improved enterprise. The final target of the company is to become a green enterprise.

We present the average values of production and environmental efficiency for each year (2005 avg., 2006 avg., 2007 avg., 2008 avg., 2009 avg., 2010 avg.) in Fig. 1 in which the path of average production and environmental efficiency from 2005 to 2010 shows that the average production efficiency continuously decreases after 2006, and the average environmental efficiency continuously decreases after 2008. This result implies that the average production efficiency and average environmental efficiency of six power companies were regressive from 2008 to 2010. We investigate the reasons for the regression in production efficiency after 2006 and the regression in environmental efficiency after 2008 in relation to the financial crisis from 2007 to 2008 and the rapid economic growth after the financial crisis. More specifically, the financial crisis caused total sales to decrease in 2007 and 2008, and then also resulted in low production efficiency. However, the global economy experienced rapid growth after the financial crisis. Due to the increment in investment in total assets being larger than that in total sales and the number of cus-

Table 2. Production efficiency, environmental efficiency, and overall efficiency.

	DMU	2005	2006	2007	2008	2009	2010	Average
Production efficiency	CPIC	0.619	0.657	0.629	0.611	0.629	0.466	0.602
	CGC	1	1	0.934	0.617	0.449	0.361	0.727
	CHC	1	1	1	0.619	0.352	0.084	0.676
	CHG	1	1	1	1	1	1	1
	CDC	1	1	1	1	1	1	1
	TPC	1	1	1	1	1	0.890	0.982
	Average	0.937	0.943	0.927	0.808	0.738	0.634	0.831
Environmental efficiency	DMU	2005	2006	2007	2008	2009	2010	Average
	CPIC	0.486	0.678	0.501	0.478	0.483	0.423	0.508
	CGC	1	0.472	0.376	0.376	0.261	0.274	0.460
	CHC	0.262	0.311	0.300	0.368	0.228	0.169	0.273
	CHG	0.560	0.597	1	1	1	1	0.860
	CDC	1	1	1	1	1	1	1
	TPC	1	1	1	1	1	0.790	0.965
	Average	0.718	0.676	0.696	0.704	0.662	0.609	0.678
Overall efficiency	DMU	2005	2006	2007	2008	2009	2010	Average
	CPIC	0.654	0.817	0.742	0.743	0.729	0.616	0.717
	CGC	1	1	0.880	0.719	0.676	0.660	0.823
	CHC	0.683	1	1	0.702	0.632	0.538	0.759
	CHG	0.909	1	1	1	1	1	0.985
	CDC	1	1	1	1	1	1	1
	TPC	1	1	1	1	1	0.928	0.988
	Average	0.874	0.970	0.937	0.861	0.840	0.790	0.879

tomers, production efficiency started to decrease in 2009 and 2010. The reasons for the ongoing regression in environmental efficiency from 2008 to 2010 were also related to the financial crisis and the rapid economic expansion after the crisis. The increment in investment in total assets was larger than the reduction in SO_2 emissions in 2008 during the crisis; however, this phenomenon was more and more obvious during the 2009 and 2010 economic expansion period. This was the cause of the ongoing regression in environmental efficiency from 2008 to 2010.

The average values of production efficiency and environmental efficiency separate the plane into the four quadrants. According to the classification in Fig. 1, CPIC always belongs to the weak enterprise category, except in 2006; CGC is a green enterprise in 2005 and a production-improved enterprise in the next two years. Finally, CGC becomes a weak enterprise in the last three years. CHC is a production-improved enterprise in the first three years, and then it becomes a weak enterprise in the last three years. CHG is a production-improved enterprise in 2005 and 2006, and then it becomes a green enterprise from 2007 to 2010. CDC and TPC are always green enterprises during the data time span. In addition, we see that three of the six power companies are weak enterprises while, the others are Green Enterprises in 2010. The three weak enterprises in 2010 are CPIC, CGC, and CHC, all of which are power companies in China. Originally, CGC was a green enterprise in 2005, but then it turned into a production-improved enterprise in 2006 and 2007. Finally, CGC regressed to become a weak enterprise in 2008 and 2010. CHG is a progressive enterprise. Originally, CHG was a production-improved enterprise in 2005 and 2006, and then it improved to become a green enterprise from 2007 to 2010. CDC has always remained a green enterprise during the data time span, hence it is the most outstanding enterprise among the six power companies. Although TPC was a green enterprise from 2005 to 2010, its production efficiency and environmental efficiency worsened in 2010.

We next examine the production efficiency and environmental efficiency of the six power companies in China

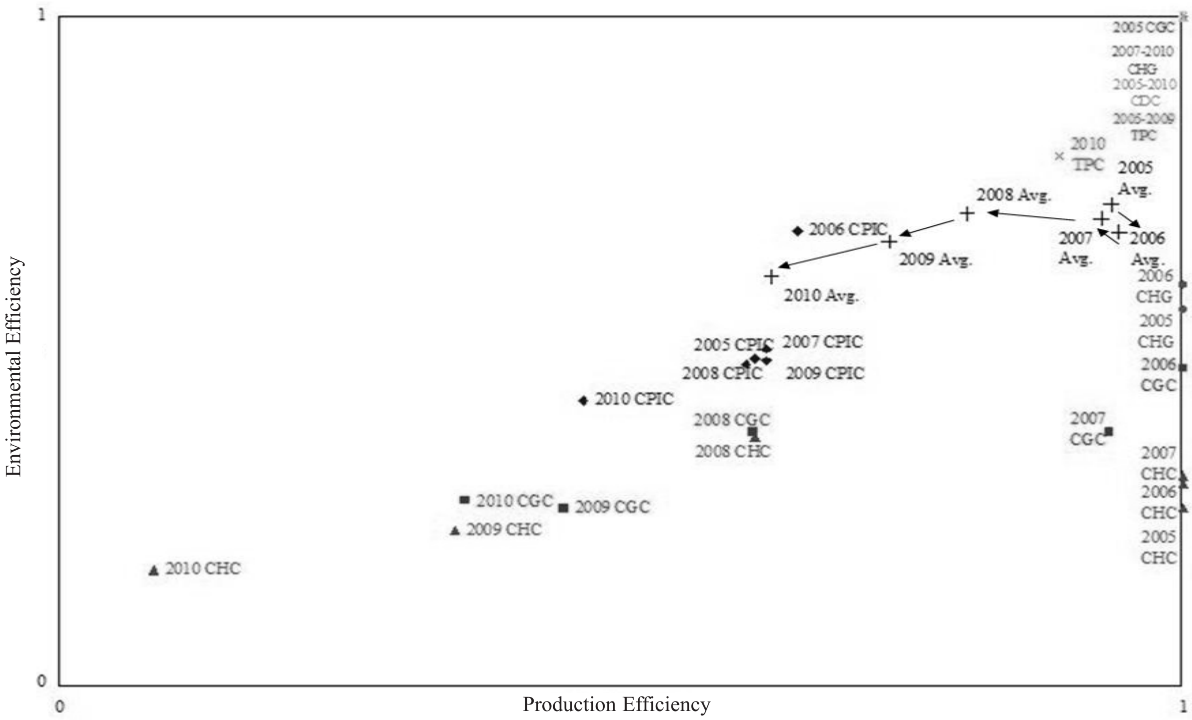

Fig. 1. The historical locus of development of power companies.

and Taiwan. Fig. 2 shows that the average production efficiency of the power companies in China is always lower than that of the one power company in Taiwan. Moreover, the average production efficiency of the power companies in China deteriorates from 2006 to 2010. Although the environmental efficiency of TPC in Taiwan is always superior to the average environmental efficiency of China's power corporations, the environmental efficiency of TPC declines sharply in 2010. In addition, TPC has the best production efficiency and environmental efficiency from 2005 to 2009, but TPC's environmental efficiency is inferior to its production efficiency in 2010. Since Taiwan's electricity power market only has one company, and there are five power corporations in China's electricity power market, Taiwan's electricity power market is a monopoly and China's electricity power market is an oligopoly. Generally speaking, the efficiency in a more competitive market should be superior to that in a less competitive market. However, we here find an interesting result in that the efficiency in the monopolistic electricity power market in Taiwan is superior to that in the oligopolistic electricity power market in China. Because of the different political regimes in China and Taiwan, we suspect that this interesting result may be related to public governance. An analysis of public governance and electricity power market efficiency is presented in subsection IV.

Reduction in SO_2 Emissions

The potential reduction in the amount of SO_2 emissions is defined as the difference between real SO_2 emissions and optimal SO_2 emissions. Through Equation (5) we calculate the potential reduction in the amount of SO_2 emissions and show the results in Table 3. We use Fig. 3 here to present the results in Table 3. Based on the definition of the potential reduction in the amount of SO_2 emissions, the potential reduction is smaller when the locus is close or equal to the horizontal coordinate. Hence, CDC reaches the optimal SO_2 emissions level during the data time span; on the contrary, CHC should reduce its high SO_2 emissions from 2005 to 2010. In addition, CHG has the most significant

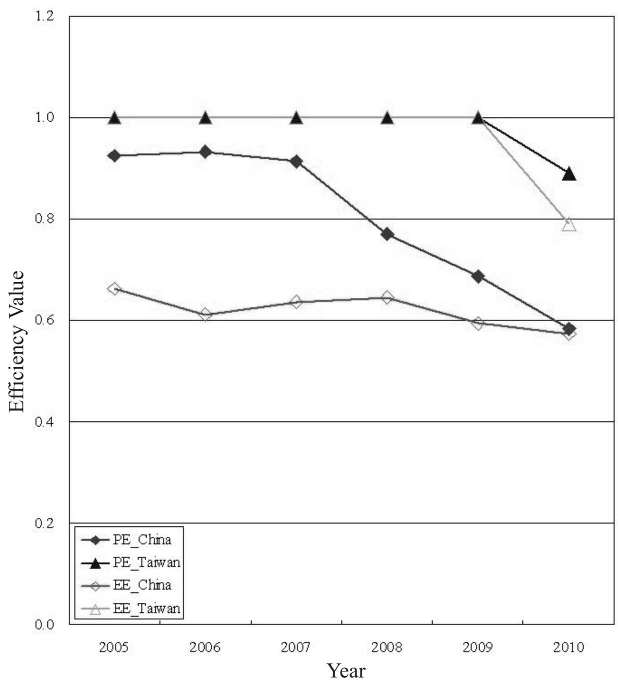

Fig. 2. Comparison of the production and environmental efficiencies of the power corporations in China and Taiwan.

Table 3. The potential reduction in SO_2 (10,000 tons).

DMU	2005	2006	2007	2008	2009	2010
CPIC	4.266	1.996	2.630	2.323	1.913	1.714
CGC	0.000	6.352	7.082	6.983	8.173	6.897
CHC	12.421	10.769	9.261	7.167	8.531	7.545
CHG	6.952	4.635	0.000	0.000	0.000	0.000
CDC	0.000	0.000	0.000	0.000	0.000	0.000
TPC	0.000	0.000	0.000	0.000	0.000	0.588
Summary	23.639	23.752	18.973	16.472	18.617	16.744
China	23.639	23.752	18.973	16.472	18.617	16.156
Taiwan	0.000	0.000	0.000	0.000	0.000	0.588

improvement in SO_2 emissions reduction after 2007. In 2010, the SO_2 emissions of all five power corporations in China were close or equal to the optimal SO_2 emissions; however, the SO_2 emissions of only one power corporation in Taiwan depart from the optimal SO_2 emissions. It is interesting for us to find out what causes SO_2 emissions to decline for all China's power corporations in 2010. We suspect the reason to be that China's government revised the "Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution" in 1995. According to the revised law, China's government has set up an area to monitor acid rain and sulfur emissions in order to reach a target so that the area polluted by acid rain and sulfur is no more extended; in addition, the sulfur emissions in this area are reduced by 10% based on the emissions level in 2000. Hence, the SO_2 emissions reduction in China's electricity power industry exhibits excellent performance.

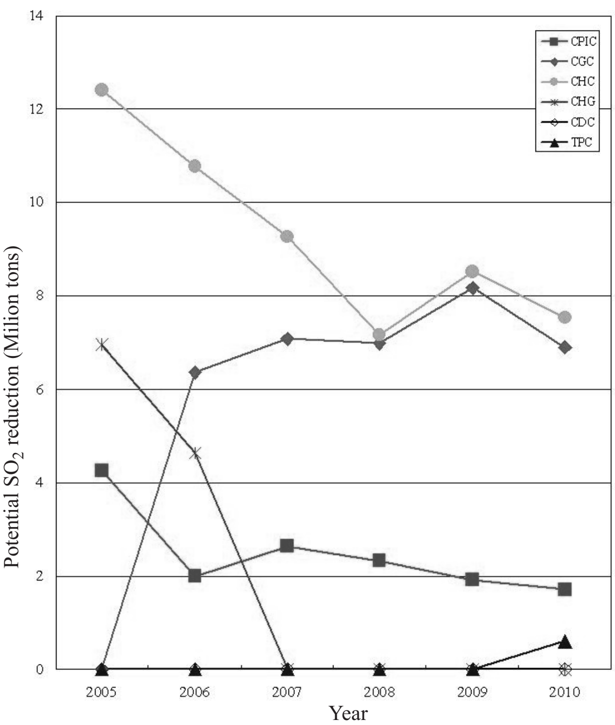

Fig. 3. The potential emissions reduction amount of SO_2.

Public Governance and Efficiency in the Electrical Power Industry

The past literature by Lio and Hu [24] discusses the issue of governance and agricultural production efficiency. Since our research sample includes five power companies in China and one power company in Taiwan in covering the electrical power industry in China and Taiwan, we would now like to examine the relationships between public governance and production efficiency, environmental efficiency, and overall efficiency of China's and Taiwan's electrical power industries. We use the production efficiency score (PES), the environmental efficiency score (EES), and the overall efficiency score (OES) as the efficiency variables and follow Kaufmann et al. [34] in using "control of corruption" (Coc) and "government effectiveness" (Ge) as the governance variables. Hwang and Akdede [35] also use these two measurements to examine whether the quality of governance affects public sector efficiency. The range for the two governance indicators lies between -2.5 and 2.5, where the higher score corresponds to better governance outcomes. Aside from the measures of Coc and Ge, Kaufmann et al. [36] compile data on "voice and accountability," "political instability and violence," "regulatory quality," and the "rule of law." Since Kaufmann et al. [36] point out that these four measurements are highly correlated with each other, we choose Coc and Ge as public governance variables. Table 4 presents the definitions of the two public governance indicators.

Fig. 4 presents the 3D results for three kinds of efficiency scores and two governance variables as follows:

Fig. 4 shows that the combinations of (PES, Coc, Ge), (EES Coc, Ge), and (OES, Coc, Ge) in Taiwan's electrical power industry are concentrated in the upper-left corner, while the same combinations in China's industry are con-

Table 4. Definitions of governance indicators.

Governance indicator	Symbol	Definition
Control of corruption	Coc	The reverse direction of private gains from corruption.
Government effectiveness	Ge	The quality of public departments, including the civil service, policy formulation and implementation, and the credibility of the government's commitment.

centrated in the lower-right corner. Moreover, the combinations in Taiwan have a higher concentration rate than those in China. Hence, Taiwan and China obviously belong to different systems for the combinations of (PES, Coc, Ge), (EES Coc, Ge), and (OES, Coc, Ge). Since Taiwan is always superior to China in PES, EES, OES, Coc, and Ge during the data time span, Taiwan could be a model for China.

Since the electrical power companies in Taiwan and China belong to government enterprises, the public governance variables influence a power company's performance. Through an analysis of the 3D figure, Taiwan has a higher concentration rate in the combinations of (PES, Coc, Ge), (EES Coc, Ge), and (OES, Coc, Ge), and hence improvement in Coc and Ge have limited impacts on PES, EES, and OES in Taiwan's electrical power industry. This result shows that Taiwan has complete regulations with respect to the industry for both production and environmental protection, and the government seriously adheres to these regulations. However, a low concentration rate in the combinations of (PES, Coc, Ge), (EES Coc, Ge), and (OES, Coc, Ge) in China implies that if China has higher levels of Coc and Ge, then the PES, EES, and OES in China's industry will show significant improvement. On average, the Ge performances are better than the Coc performances in China, meaning that China has complete regulations with respect to the industry in both production and environmental protection, but the government does not seriously adhere to them.

Policy Implication

Based on the results of the above analysis, we find that high-quality public governance has a significantly positive influence on China's electrical power industry. In China, the production efficiency and environmental efficiency in the industry can be enhanced through good public governance. However, public governance has an insignificant influence on Taiwan's industry. Generally speaking, the environmental efficiency of the power corporations in China is inferior to that in Taiwan. Hence, China can improve its industry's environmental efficiency through effective public governance, and then lead China's power corporations to become green enterprises that are characterized by high production efficiency and environmental efficiency. When the power corporation becomes a Green Enterprise, it is implied that its SO_2 emissions are reduced to the optimal emissions level. Fig. 5 shows the process chart of public governance in order to achieve the targeted reduction in SO_2 emissions.

Conclusions

There are two main highlights of this study. One is that we create three models to estimate the DMU's production efficiency, environmental efficiency, and overall efficiency, and calculate the total desirable output increment ratio and the total potential pollution reduction ratio. The other highlight is that we use public governance variables to examine whether the quality of public governance affects the efficiency in the industry where we take China and Taiwan as examples. The data period extends from 2005 to 2010.

Our first contribution is to divide the six power corporations in China and Taiwan into four corporation types. We find that three of the six power corporations are green enterprises, and the other three are weak enterprises in 2010. Moreover, we draw the evolution locus of technological

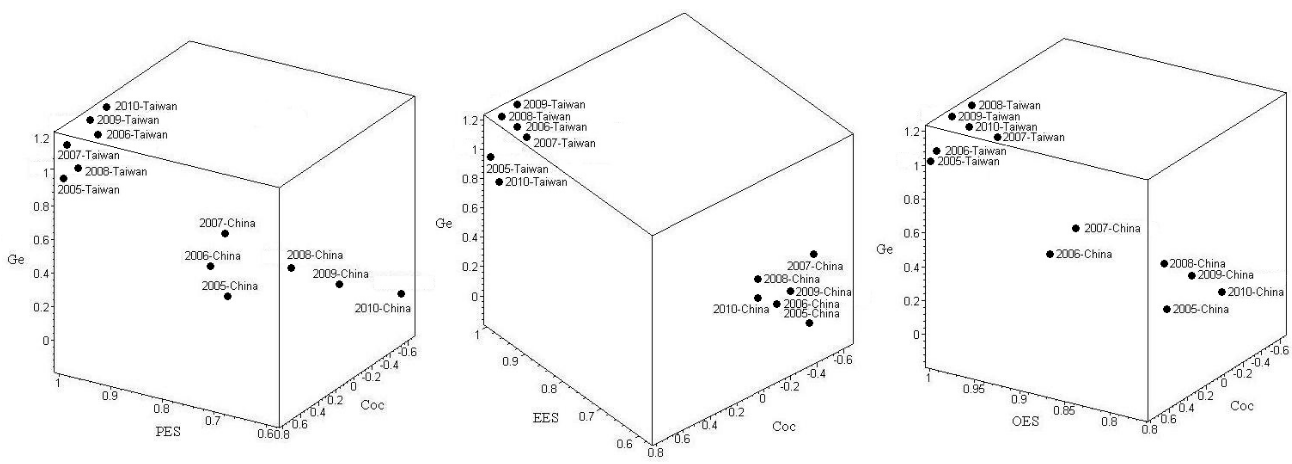

Fig. 4. Estimated results for power company efficiency.

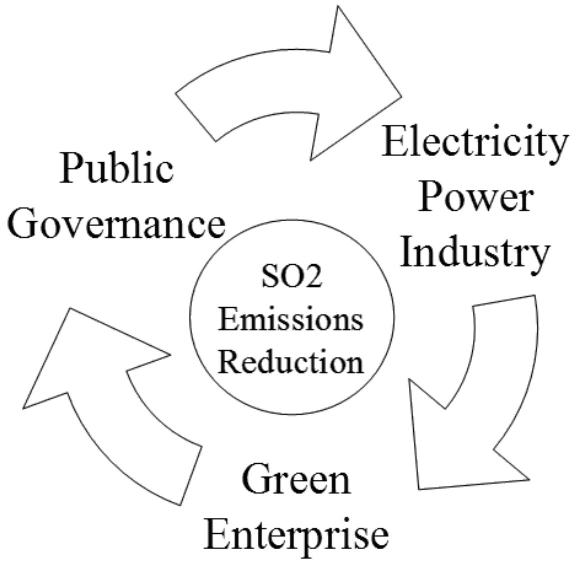

Fig. 5. The process chart of public governance.

change in production efficiency and environmental efficiency for the six power corporations from 2005 to 2010. Our second contribution is to compare the production efficiency and environmental efficiency of the six power corporations from 2005 to 2010. We find that the production efficiency and environmental efficiency in Taiwan's industry are always superior to those in China's. Our third contribution is to calculate the potential emissions reduction of SO_2 for six power corporations. We find that the SO_2 emissions of all five power corporations in China are either close to or equal to the optimal SO_2 emissions in 2010; however, the SO_2 emissions of TPC in Taiwan depart from the optimal SO_2 emissions in 2010. Our final contribution is to establish the relationships between public governance and electrical power industry efficiency. The public governance indicators in this study are "control of corruption" and "government effectiveness." We conclude that production efficiency, environmental efficiency, and overall efficiency in China's electricity power industry will increase when "control of corruption" improves. However, "government effectiveness" has a statistically insignificant impact on these three kinds of efficiency in China's electrical power industry. On the other hand, both "control of corruption" and "government effectiveness" have a statistically insignificant impact on the three kinds of efficiency in Taiwan's electrical power industry. These results are due to there being complete regulations in China that are not seriously implemented. On the contrary, Taiwan has complete regulations and has seriously implemented them. Hence, we conclude that the improvement in public governance quality is helpful to promoting the efficiency of China's industry.

The power sector in every country is highly controlled by the government since the power industry is not only related to the country's economic development, but is also highly related to its environmental protection. Hence, we studied production efficiency, environmental efficiency, and overall efficiency of six power corporations in China and Taiwan. We also take China and Taiwan as examples to examine the relationship between public governance and the efficiency of the electrical power industry.

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