Advances in Management & Applied Economics, vol. 3, no.4, 2013, 105-117
ISSN: 1792-7544 (print version), 1792-7552(online)
Scienpress Ltd, 2013

Public Governance and the Operational and Environmental Efficiencies of EU Countries

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Abstract

In order to decrease the detrimental effects from global warming, the European Union (EU) has started to control CO2 emissions by allocating CO2 emission allowances to 25 member states. In this study we are interested about the effects of CO2 emission allowance on environmental efficiency, operational efficiency, and the unified (operational and environmental) efficiency. We set up a modified RAM (Range-adjusted measure) model and introduce the Truncated regression model. Both of these two models are applied to investigate the relationships among six governance indicators and environmental efficiency, operational efficiency, and unified efficiency. Our results show that greater control of corruption is associated with lower unified efficiency, implying that EU countries are likely to fall into an inefficient regime such as the recent case of the Greek debt crisis. Finally, we emphasize that the modified RAM model in which the input factor is restricted in a fixed amount may be used to model the issue of energy and the environmental. After all, energy storage is limited and energy is always taken as an input factor in the RAM model.

JEL classification numbers: C67, Q56
Keywords: CO2 emission allowance, Range-adjusted measure (RAM)

1 Introduction

Due to the global climate change, the enthusiasm in awareness and concern for environmental protection has been further enhanced. Environmental researchers' interest

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Article Info: *Received :* February 22, 2013. *Revised :* March 24, 2013.
Published online : July 1, 2013

has tremendously increased to formulate and apply modeling technologies in environmental issues. The data envelopment analysis (DEA) is one of the most popular managerial approaches to estimate the performance of various decision making units (DMU).

Traditional DEA models such as the CCR model proposed by Charnes et al. (1978) or the BCC model proposed by Banker et al. (1984) only consider the desirable (good) outputs. However, the production activities of DMU often include desirable outputs and undesirable (bad) outputs such as CO2. Hence, an application of DEA in environmental studies has to separate the outputs into desirable outputs and the undesirable outputs. The reason undesirable outputs are not appropriate to be analyzed by the traditional DEA model is that the reduction of undesirable outputs is likely to be costly.

There are two methods generally to incorporate undesirable outputs into the DEA model. One method proposed by Seiford and Zhu (2002) uses data translation to utilize the traditional DEA model. The other method takes the original data in the weak disposability reference technology proposed by Färe et al. (1989). The concept of weak disposability reference technology in the DEA framework is also called the environmental DEA technology (2004).

In the environmental DEA framework, the measurement of the efficiency score mainly consist of oriented measures of inputs, desirable outputs, and undesirable outputs. We introduce here two kinds of efficiency measures that have been widely used in the environmental DEA framework. The most well-known efficiency measure in DEA models is the radial efficiency measure, which proportionally adjusts inputs, desirable outputs, and undesirable outputs for optimizing the environmental performance of DMU. The literature in the environmental field that applies the radial efficiency measure includes Tyteca (1996, 1997) and Färe et al. (2004), etc. The slack-based efficiency measure proposed by Tone (2001) is constructed from the slacks in inputs and outputs. The advantage of the slack-based efficiency measure is that it can identify all the economic inefficiencies and can discriminate operational efficiency and environmental efficiency. The concept of a slack-based efficiency measure is an additive measure called the Tone's measure (2006). We list some DEA methodologies applied in previous literature on the environment and energy, such as Sueyoshi and Goto (2010a, 2010b, 2011a, 2011b, 2011c, 2012a, 2012b, 2012c) and Sueyoshi et al. (2010).

In this paper, environmental efficiency, operational efficiency, and unified efficiency (operational and environmental), as measured by Tone's measure, are functions of certain governance variables such as rule of law, control of corruption, or government effectiveness. In our RAM (Range-adjusted measure) model, we take the CO2 emission allowance as the input factor, GDP as a desirable output, and CO2 emission as an undesirable output. It is crucial to note that the input factor, i.e., CO2 emission allowance, is restricted in a fixed amount. This idea is different from Gomes and Lins (2008) and Hu and Fang (2010) in which the output factor is restricted.

The issue of CO2 emission allowance in the European Union (EU) depends on Directive 2003/87/EC in which each EU member provides its own National Allowance Plan (NAP) to the European Commission and then the European Commission refers to the principles of grandfathering and benchmarking to confirm a legal amount of CO2 emission. Following the principle of grandfathering, the European Commission confirms a legal amount of CO2 emission by a historical record of CO2 emission. Benchmarking means that the issue of the legal amount of CO2 emission depends on an established standard on products and industries. Westner and Madlener (2012) point out that the allocation mechanism of CO2 emission allowances is strongly affected the combination of heat and power (CHP) generation. They use a discounted cash-flow model to show that the allocation principles of CO2 emission allowance may cause an inefficient situation where highly efficient CHP plants are gradually replaced by separate power and heat generation in boilers respectively fossil-fueled condensing plants. Sijm et al. (2007) use the criteria of environmental effectiveness, economic efficiency, equity, and industrial competitiveness and so on to compare the principles of grandfathering and benchmarking. A distinguishing characteristic in this study is to use CO2 emission allowance as an input, and as per past literature, we respectively use GDP and CO2 emission as a desirable output and an undesirable output to study the allocation problem for CO2 emission allowance. This is shown in Table 1. The analytical result shows that Germany is the only state in the EU to attain 100% in unified efficiency.

The issue about the public governance in the environmental field is more and more important. In 2006, China government establishes the industrial environmental management system including the Best Available Techniques (BAT) determination method to be as the pollutants gross control policy. Liu and Wen (2012) use DEA model to argue BAT for improving the decision-making ability of policymakers and plant owners. Our paper also investigates the relationships between public governance and operational efficiency, environmental efficiency, and unified efficiency. The determinants of public governance used in this study include the six governance indicators developed by Kaufmann et al. (2008). The six governance indicators are the rule of law, control of corruption, government effectiveness, regulatory quality, voice and accountability, and political stability. We find that greater control of corruption is associated with lower unified efficiency. This finding is consistent with the 'grease the wheels hypothesis', which argues that corruption may raise efficiency in an ineffective bureaucratic country (Huntington, 1968). This result also implies that the EU experiences an ineffective bureaucratic regime.

The remainder of this paper is organized as follows. Section 2 introduces the methodology including the RAM model and the Truncated regression model. Section 3 describes the empirical analysis results. Some concluding remarks are in Section 4.

Table 1: A Comparison on the Estimation of Environmental Performance

Literature	Output		Input	Objective
	Desirable output	Undesirable output		
Scheel (2001)	GDP	Amount of waste	Labor	EU
Zofio and Prieto (2001)	GDP	CO2 emission	Labor, Capital	OECD
Kumar and Khanna (2002)	GDP	CO2 emission	Population, energy consumption	Cross-country
Gomes and Lins (2008)	Population, GDP, energy consumption		CO2 emission	Countries in Kyoto Protocol
Sebastián and Gutiérrez (2008)	GDP	CO2 emission, energy consumption	Population	Countries in Kyoto Protocol
This study	GDP	CO2 emission	CO2 emission allowance	EU

2 Methods and Materials

We now set up a modified RAM model and introduce the Truncated regression model. Both of these two models are applied in our study.

2.1 Model Set-up

We simultaneously consider both desirable and undesirable outputs and the restricted input factor such as CO2 emission allowance in the DEA model. Thus, this study modifies the RAM model proposed by Sueyoshi and Goto (2011b) to unify both operational and environmental performances. The seminal RAM model can be seen in Cooper et al. (2000).

There are n DMUs in our model. Each DMU uses m kinds of inputs to produce s kinds of desirable outputs and h kinds of undesirable outputs. We define x_{ij} as the ith input for the jth DMU; g_{rj} as the rth desirable (good) output for the jth DMU; and b_{fj} as the fth undesirable (bad) output for the jth DMU, where $j = 1,\ldots, n$; $i = 1,\ldots, m$; $r = 1,\ldots, s$; and $f = 1,\ldots, h$.

We take the kth DMU as an example. The ranges in the RAM model are specified as follows: $\Omega_i^x = 1 / [(m + h + s)(\overline{x}_i - \underline{x}_i)]$; $\Omega_r^g = 1 / [(m + h + s)(\overline{g}_r - \underline{g}_r)]$; $\Omega_f^b = 1/ [(m + h + s)(\overline{b}_f - \underline{b}_f)]$, where $\overline{x}_i = \max\{x_i\}$; $\underline{x}_i = \min\{x_i\}$; $\overline{g}_r = \max\{g_r\}$; $\underline{g}_r = \min\{g_r\}$; $\overline{b}_f = \max\{b_f\}$; $\underline{b}_f = \min\{b_f\}$. We modify the RAM model provided by Sueyoshi and Goto (2011b) to become that the input factors being limited, which in this study is a limited CO2 emission allowance. Our RAM model suggests that the performance of the specific kth DMU by the following:

$$Max \ \sum_{i=1}^{m}\Omega_i^x q_i^{xg} + \sum_{r=1}^{s}\Omega_r^g q_r^g + \sum_{i=1}^{m}\Omega_i^x q_i^{xb} + \sum_{f=1}^{h}\Omega_f^b q_f^b$$

s.t.

$$\sum_{j=1}^{n}(1+u_j^g)x_{ij} + q_i^{xg} - x_{ik} = \overline{Z}_i$$

$$\sum_{j=1}^{n} g_{rj}u_j^g - q_r^g = g_{rk}$$

$$\sum_{j=1}^{n} u_j^g = 1$$

$$\sum_{j=1}^{n}(1+u_j^b)x_{ij} + q_i^{xb} - x_{ik} = \overline{Z}_i$$

$$\sum_{j=1}^{n} b_{fj}u_j^b - q_f^b = b_{fk}$$

$$\sum_{j=1}^{n} u_j^b = 1$$

$u_j^g \geq 0$
$u_j^b \geq 0$
$q_i^{xg} \geq 0$
$q_i^{xb} \geq 0$
$q_r^g \geq 0$
$q_f^b \geq 0,$ (1)

where u_j^g and u_j^b are the respective weights of the *j*th DMU used for connecting the desirable output and the undesirable output by a convex combination; q_i^{xg} and q_i^{xb} are slack variables related to *i*th inputs for the desirable outputs and the undesirable outputs, respectively; q_r^g and q_f^b are also slack variables related the *r*th desirable output and *f*th undesirable output; $\overline{Z}_i$ represents the *i*th input factor limited in a fixed amount.

We modify the model proposed by Sueyoshi and Goto (2011b) as Category I by including a restriction on the amount of input in Equation (1). The terms $(1 + u^g_j)$ and $(1 + u^b_j)$ in Eq. (1) mean that the efficiency score of the DMU is decided by both the weight and the amount of original input factor since our model considers the scenario that the amount of the input factor is restricted.

Our model in the mathematical structure includes two efficiency frontiers for the operational and environmental performances, as visually described in Figure 1 in which we take the case of one input, one desirable output, and one undesirable output. The solution of our model can be solved by means of linear programming. The overall efficiency score (ϕ) in our modified model is measured by:

$$\phi = 1 - [\sum_{i=1}^{m} \Omega_i^x q_i^{xg*} + \sum_{r=1}^{s} \Omega_r^g q_r^{g*} + \sum_{i=1}^{m} \Omega_i^x q_i^{xb*} + \sum_{f=1}^{h} \Omega_f^b q_f^{b*}]. \quad (2)$$

Equation (2) indicates that the overall efficiency score is obtained by subtracting the level of inefficiency from 1. The term $\sum_{i=1}^{m} \Omega_i^x q_i^{xg*} + \sum_{r=1}^{s} \Omega_r^g q_r^{g*}$ in Equation (2) is called the level of inefficiency caused by operation (ICO); and the term $\sum_{i=1}^{m} \Omega_i^x q_i^{xb*} + \sum_{f=1}^{h} \Omega_f^b q_f^{b*}$ in Equation (2) is called the level of inefficiency caused by the environment (ICE).

2.2 Truncated Regression Model

To test the relationships between public governance and efficiency empirically, we specify the truncated regression model as follows:

$$\text{Efficiency score} = \alpha_0 + \sum_{\gamma=1}^{\ell} \alpha_\gamma \text{ (governance variable)}_\gamma + \varepsilon. \quad (3)$$

The parameter α_0 represents the constant term, the parameter α_γ represents γth governance variable's coefficient, and the parameter ε is the error term. The total number of governance variables is ℓ in Eq. (3). The reason that we use the Truncated regression model instead of the Tobit (1958) regression model is a suggestion by Simar and Wilson (2007) who conclude that the estimated confidence interval in the Tobit regression model is more sensible than that in the Truncated regression model in their Monte Carlo experiments.

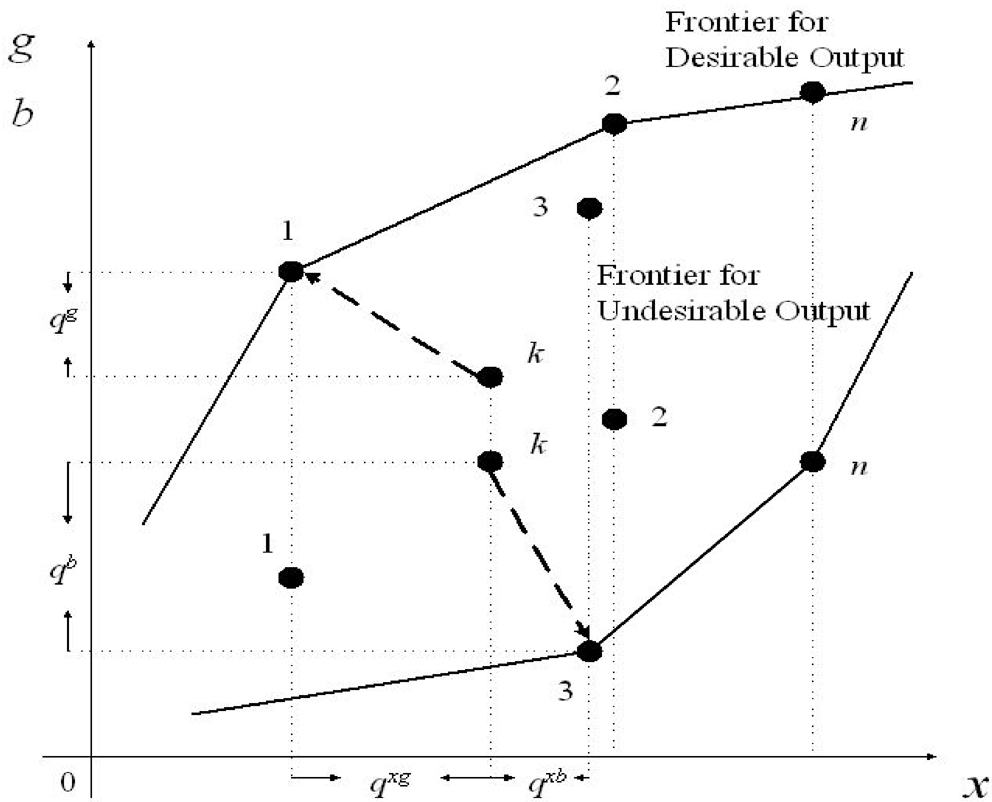

Figure 1: Visual Structure of Operational Efficiency and Environmental Efficiency

2.3 Data Description

To analyze how the CO2 emission allowance affects the operational efficiency and the environmental efficiency, we apply the proposed RAM model to 25 member states in the EU. The dataset is shown in Table 2, which consists of one input (i.e., CO2 emission allowance), one desirable output (i.e., gross domestic product; GDP), and one undesirable output (i.e., CO2 emissions). We refer to the 2007 data published by the Community Independent Transaction Log (CITL) for the CO2 emission allowance (in ton^3 of equivalent carbon) and the World Bank Database for GDP (in thousand USD) and for the CO2 emissions (in ton^3 of equivalent carbon).

Table 2: Dataset of 25 Member States in the EU in 2007

		Desirable output	Undesirable output	Input
Country	Country Code	GDP (Thousand USD)	CO2 Emissions (ton^3)	CO2 Emission Allowance (ton^3)
Austria	AUT	372291310	68674352	32729289
Belgium	BEL	458619727	102951072	60428821

Cyprus	CYP	21835946	8192704	5899493
Czech Republic	CZE	174214944	124861792	96919971
Denmark	DNK	310721017	49954976	27902895
Estonia	EST	21383915	20456112	21343525
Finland	FIN	245952168	64123664	44620371
France	FRA	2594012356	371452656	149775970
Germany	DEU	3329145213	787291008	497302479
Greece	GRC	309916788	98037648	71162432
Hungary	HUN	138757192	56425600	30236166
Iceland	ISL	20428032	2337632	19240229
Italy	ITA	2116201720	456054416	203255077
Latvia	LVA	28765687	7818976	4035018
Lithuania	LTU	39103973	15267888	10318307
Luxembourg	LUX	51278198	10834448	3229321
Malta	MLT	7547856	2722352	3048394
Netherlands	NLD	778311558	173102016	86476714
Poland	POL	425321394	317119200	237542720
Portugal	PRT	230944736	58063408	36908808
Slovak Republic	SVK	84241815	36955104	30486829
Slovenia	SVN	47314863	15095680	8245914
Spain	ESP	1440836639	358965744	159739872
Sweden	SWE	462512854	49207520	22846480
United Kingdom	GBR	2799040362	539175920	215875184
Total		16508700263	3795141888	2079570279

Data Source: CITL and World Bank WDI Database

3 Results and Discussion

Table 3 shows that the input and output variables have positive correlation coefficients that represent that the choice of the input variable and the output variables satisfying the principle of isotonicity in the DEA method. In other words, the more CO2 emission allowance there is, the higher the GDP and the more CO2 emissions there will be.

Table 3: Correlation Coefficient

	GDP	CO2 Emissions	CO2 Emission Allowance
GDP	1.000000	0.948177	0.847431
CO2 Emissions	0.948177	1.000000	0.961574
CO2 Emission Allowance	0.847431	0.961574	1.000000

The dataset of governance variables is from Kaufmann et al. (2008), who provide six governance indicators, including the rule of law (Rol), control of corruption (Coc), government effectiveness (Ge), regulatory quality (Rq), voice and accountability (Vaa), and political stability (Ps). 'Rule of law' measures the quality of contract enforcement of the agent such as police or courts. 'Control of corruption' measures the reverse direction of private gains from corruption. 'Government effectiveness' measures the quality of public departments including the civil service, policy formulation and implementation, and the credibility of the government's commitment. 'Regulatory quality' measures the ability of the government to formulate and implement policies for promoting private sector development. 'Voice and accountability' refers to the rights of a country's citizens, including the right to participate in selecting their government, freedom of expression, freedom of association and so on. 'Political stability' measures the likelihood that the government faces a crisis, which refers to government power that will be destabilized or overthrown by possibly violent means. The range for the six governance indicators is from about 0 to 2.5, with higher values corresponding to better governance outcomes.

3.1 Efficiency and Inefficiency Analysis

Table 4 summarizes unified efficiency scores of 25 member states in the EU and represents the level of inefficiency caused by operation and by the environment. Germany is the only state in the EU to attain 100% in unified efficiency. Germany's ICO and ICE are zero, implying that the GDP and the CO2 emission of Germany are located on the frontiers of the desirable output and the undesirable output such as DMU *n* in Figure 1. Malta exhibits the second highest level of unified efficiency score at 99.9%, only marginally below Germany. Malta's ICO is zero, but its ICE is not zero. This implies that the GDP of Malta is located on the frontier of the desirable output, but the CO2 emission of Malta is not located on the frontier of the undesirable output such as DMU 2 in Figure 1. The lowest level of unified efficiency score is in Poland, which only has 72.3% in unified efficiency. Poland's ICO is not zero, but its ICE is zero. This implies that the GDP of Poland is not located on the frontier of the desirable output, but its CO2 emission is located on the frontier of the undesirable output such as DMU 3 in Figure 1. Italy is one of the nations in the G8 (Great Eight) and is also one of the Annex I nations in the Kyoto Protocol. However, Italy's ICO and ICE are not equal to zero, implying that the GDP and the CO2 emissions of Italy are not located on the frontiers of the desirable output and the undesirable output such as DMU *k* in Figure 1.

Table 4: Efficiency Scores of 25 Member States in the EU

Country	Country Code	Unified Efficiency	Level of Inefficiency Caused by Operation (ICO)	Level of Inefficiency Caused by Environment (ICE)
Austria	AUT	0.9524	0.0257	0.0219
Belgium	BEL	0.9170	0.0637	0.0193
Cyprus	CYP	0.9797	0.0086	0.0117
Czech Republic	CZE	0.8413	0.1538	0.0049

Denmark	DNK	0.9598	0.0238	0.0164
Estonia	EST	0.9518	0.0411	0.0071
Finland	FIN	0.9298	0.0584	0.0118
France	FRA	0.9177	0.0000	0.0823
Germany	DEU	1.0000	0.0000	0.0000
Greece	GRC	0.8935	0.0967	0.0098
Hungary	HUN	0.9372	0.0450	0.0178
Iceland	ISL	0.9632	0.0368	0.0000
Italy	ITA	0.8339	0.0840	0.0821
Latvia	LVA	0.9832	0.0040	0.0128
Lithuania	LTU	0.9718	0.0161	0.0121
Luxembourg	LUX	0.9852	0.0000	0.0148
Malta	MLT	0.9889	0.0000	0.0111
Netherlands	NLD	0.8900	0.0755	0.0345
Poland	POL	0.7232	0.2768	0.0000
Portugal	PRT	0.9389	0.0470	0.0141
Slovak Republic	SVK	0.9406	0.0508	0.0086
Slovenia	SVN	0.9757	0.0110	0.0133
Spain	ESP	0.8073	0.1224	0.0703
Sweden	SWE	0.9805	0.0000	0.0195
United Kingdom	GBR	0.8911	0.0000	0.1089

In Table 5 we find some countries attaining 100% in operational efficiency, some attaining 100% in environmental efficiency, but only Germany attained 100% in the unified efficiency under regime of CO2 emission allowance. However, the number of countries that reach 100% in environmental efficiency is less than the number of countries that reach 100% in operational efficiency. This result may point out that EU members emphasize development in the economic field more than in the environmental field. Table 5 exhibits the detailed results.

Table 5: EU States with 100% Unified, Operational, and Environmental Efficiency

Efficiency	100% in Unified Efficiency	100% in Operational Efficiency	100% in Environmental Efficiency
Country	Germany	France Germany Luxembourg Malta Sweden United Kingdom	Germany Iceland Poland

3.2 Truncated Regression Analysis

We are now interested in the relationships between public governance and operational efficiency, environmental efficiency, unified efficiency. Based on the truncated regression model, we use the operational efficiency score (OES), the environmental efficiency score (EES), and the unified efficiency score (UES) as the dependent variables, six governance indicators as the independent variables, and obtain three Truncated regression models as follows:

$$OES=0.713+0.052*Rol-0.082*Coc+0.024*Ge+0.059*Rq+0.114*Vaa+0.036*Ps \quad (4)$$
$$(p < 0.01^{***})$$

$$EES=0.973-0.014*Rol-0.022*Coc+0.037*Ge-0.006*Rq-0.036*Vaa+0.059*Ps \quad (5)$$
$$(p < 0.01^{***}) \qquad (p < 0.01^{***})$$

$$UES=0.685-0.038*Rol-0.104*Coc+0.061*Ge+0.054*Rq+0.079*Vaa+0.095*Ps \quad (6)$$
$$(p < 0.01^{***}) \qquad (p < 0.05^{**}) \qquad (p < 0.01^{***})$$

The meanings of all independent variables are shown in Section 3.1. The numbers in the parenthesis of Eqs. (4), (5), and (6) are the p-values. Some coefficients of the governance variables in Eqs. (4), (5), and (6) are significant under the 95% and 99% confidence levels. We summarize the influences of six governance indicators on the operational efficiency, environmental efficiency, and unified efficiency scores as follows.

Table 6: An Analysis on the Truncated Regression

	Rol	Coc	Ge	Rq	Vaa	Ps
Operational efficiency score (OES)	N	N	N	N	N	N
Environmental efficiency score (EES)	N	N	N	N	N	+
Unified efficiency score (UES)	N	–	N	N	N	+

Note: "+" represents a significant positive effect; "–" represents a significant negative effect; "N" represents an insignificant effect.

Eq. (4) shows that all governance variables are insignificant. In other words, an increase in any governance variable does not cause an increase in operational efficiency. A reasonable explanation of the above results is that the EU is a ripe economic and political organization. Hence, the issues of economy and politics in EU are independent of each other. In other words, the political troubles of the EU only have an insignificant influence on economic activities. However, Eq. (5) shows there is positive relationship between political stability and environmental efficiency, meaning that a political disturbance has a significant influence on environmental issues. Although the EU has a robust integration in economy and political regimes, it cannot integrate environmental troubles very well. This result illustrates that the EU has a weaker integration for environmental troubles than that for economic ones, and the finding in Eq. (5) is different with the argument that only when the regime faces a serious crisis does efficiency improvement become possible (Binswanger and Deininger, 1997).

Eqs. (4) and (5) show that the control of corruption does not have a significant effect on operational efficiency and environmental efficiency, but a surprising result in Eq. (6) is that a higher control of corruption leads to a low unified efficiency. This result is consistent with the well-known 'grease the wheels hypothesis' that argues corruption may raise efficiency in an ineffective bureaucratic country (Huntington, 1968). The finding illustrates that the EU is likely to fall into an inefficient situation such as the case of the Greek debt crisis.

4 Conclusion

In the production process, desirable outputs and undesirable outputs always co-exist. One contribution of the DEA model in environmental studies is to suggest that the output factor should be separated into desirable and undesirable outputs. We have employed herein a modified RAM model in which the input factor is restricted to a fixed amount in order to treat the issue of the undesirable output. We then use the truncated regression model to investigate the relationships between the governance variables and operational efficiency, environmental efficiency, and unified efficiency.

The empirical results show that Germany is the only state in the EU to attain 100% in operational efficiency, environmental efficiency, and unified efficiency. On the other hand, the number of EU members that reach 100% in environmental efficiency is less than the number of EU members that reach 100% in operational efficiency. This result may means that EU members emphasize development in the economic field more than in the environmental field.

Since we are interested in the relationships between public governance and operational efficiency, environmental efficiency, and unified efficiency, we establish three truncated regression models by using the six governance indicators as independent variables and using operational efficiency, environmental efficiency, and unified efficiency as dependent variables. We conclude that there is an insignificant relationship between operational efficiency and the six governance indicators. This result implies that the political factors do not affect economic results in the EU. However, political stability has a significantly positive affect on environmental efficiency. In other words, the argument by Binswanger and Deininger (2008) that political stability may not be beneficial to efficiency, because some countries may reach efficiency only when they face a serious crisis, does not exist in our case. This result illustrates that many environmental protection issues in the EU are always interfered by political factors. If such factors are removed, then there will be an environmental efficiency improvement in the EU. A most surprising finding is that a higher control of corruption leads to a lower unified efficiency. This result shows that the EU is likely to fall into an inefficient situation such as the recent Greek debt crisis.

Finally, we emphasize that the modified RAM model in which the input factor is restricted in a fixed amount may be used to model the issue of energy and the environmental. After all, energy storage is limited and energy is always taken as an input factor in the DEA model.

ACKNOWLEDGEMENTS: The first author (Ming-Chung Chang) appreciates financial support from Taiwan's National Science Council (NSC 101-2410-H-424 -012).

References

[1] R.D. Banker, A. Charnes and W.W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis, *Management Science*, **30**, (1984), 1078-1092.

[2] H. Binswanger and K. Deininger, Explaining agricultural and agrarian policies in developing countries, *Journal of Economic Literature*, **35**, (1997), 1958-2005.

[3] A. Charnes, W.W. Cooper and E. Rhodes, Measuring the efficiency of decision making units, *European Journal of Operational Research*, **2**, (1978), 429-444.

[4] W.W. Cooper, K.S. Park and J.T. Pastor, RAM: A range adjusted measure of efficiency, *Journal of Productivity Analysis*, **11**, (2000), 5-42.

[5] W.W. Cooper, L.M. Seiford and T. Tone, Introduction to Data Envelopment Analysis and Its Uses: With DEA-Slover Software and References, Springer, New York, United States, (2006).

[6] R. Färe, S. Grosskopf, C.A.K. Lovell and C. Pasurka, Multilateral productivity comparisons when some outputs are undesirable: A nonparametric approach, *The Review of Economics and Statistics*, **71**, (1989), 90-98.

[7] R. Färe and S. Grosskopf, Modeling undesirable factors in efficiency evaluation: comment, *European Journal of Operational Research*, **157**, (2004), 242-245.

[8] R. Färe, S. Grosskopf and F. Hernandez-Sancho, Environmental performance: An index number approach, *Resource and Energy Economics*, **26**, (2004), 343-352.

[9] E.G. Gomes and M.E.P. Lins, Modeling undesirable outputs with zero sum gains data envelopment analysis models, *Journal of the Operational Research Socity*, **59**, (2008), 616-623.

[10] J.L Hu and C.Y. Fang, Do market share and efficiency matter for each other? An application of the zero-sum gains data envelopment analysis, *Journal of the Operational Research Society*, **61**, (2010), 647-657.

[11] S.P. Huntington, Political Order in Changing Societies, New Haven, CT: Yale University Press, (1968).

[12] D. Kaufmann, A. Kraay and M. Mastruzzi, Governance matters VII: Aggregate and individual governance indicators for 1996-2007, Working paper, Washington, DC: World Bank, (2008).

[13] S. Kumar and M. Khanna, Productivity growth and CO2 abatement: A cross-country analysis using the distance function approach. International Conference on Climate Change and Environmental Policy, University of Illinois, (2002); http://www.ace.uiuc.edu/pERE/conference/papers

[14] X. Liu and Z. Wen, Best available techniques and pollution control: A case study on China's thermal power industry, *Journal of Cleaner Production*, **23**, (2012), 113-121.

[15] H. Scheel, Undesirable outputs in efficiency valuation, *European Journal of Operational Research*, **132**, (2001), 400-410.

[16] L. Sebastián and E. Gutiérrez, Non-parametric frontier approach to modelling the relationships among population, GDP, energy consumption and CO2 emissions, *Ecological Economics*, **66**, (2008), 687-699.

[17] L.M. Seiford and J. Zhu, Modeling undesirable factors in efficiency evaluation, *European Journal of Operational Research*, **142**, (2002), 16-20.

[18] J.P.M. Sijm, M.M. Berk, M.G.J. den Elzen and R.A. van den Wijngaart, Options for post-2012 EU burden sharing and EU ETS allocation, Energy Research Center of

the Netherlands and Netherlands Environmental Assessment Agency, (2007).
[19] L. Simar and P.W. Wilson, Estimation and inference in two-stage, semi-parametric models of production processes, *Journal of Econometrics,* **136**, (2007), 31-64.
[20] T. Sueyoshi and M. Goto, Measurement of a linkage among environmental, operational and financial performance in Japanese manufacturing firms: A use of data envelopment analysis with strong complementary slackness condition, *European Journal of Operational Research*, **207**, (2010a), 1742-1753.
[21] T. Sueyoshi, M. Goto and T. Ueno, Performance analysis of US coal-fired power plants by measuring three DEA efficiencies, *Energy Policy*, **38**, (2010), 1675-1688.
[22] T. Sueyoshi and M. Goto, Should the US clean air act include CO2 emission control? Examination by data envelopment analysis, *Energy Policy*, **38**, (2010b), 5902-5911.
[23] T. Sueyoshi and M. Goto, DEA approach for unified efficiency measurement: Assessment of Japanese fossil fuel power generation, *Energy Economics*, **33**, (2011a), 292-303.
[24] T. Sueyoshi and M. Goto, Methodological comparison between two unified (operational and environmental) efficiency measurements for environmental assessment, *European Journal of Operational Research*, **210**, (2011b), 684-693.
[25] T. Sueyoshi and M. Goto, Measurement of returns to scale and damages to scale for DEA-based operational and environmental assessment: How to manage desirable (good) and undesirable (bad) outputs?, *European Journal of Operational Research*, **211**, (2011c), 76-89.
[26] T. Sueyoshi and M. Goto, Returns to scale and damages to scale under natural and managerial disposability: Strategy, efficiency and competitiveness of petroleum industry, *Energy Economics*, **34**, (2012a), 645-662.
[27] T. Sueyoshi and M. Goto, Data envelopment analysis for environmental assessment: Comparison between public and private ownership in petroleum industry, *European Journal of Operational Research*, **216**, (2012b), 668-678.
[28] T. Sueyoshi and M. Goto, Environmental assessment by DEA radial measurement: U.S. coal-fired power plants in ISO (Independent System Operator) and RTO (Regional Transmission Organization), *Energy Economics*, **34**, (2012c), 663-676.
[29] J. Tobin, Estimation of relationships for limited dependent variables, *Econometrica*, **26**, (1958), 24-36.
[30] K. Tone, A slacks-based measure of efficiency in data envelopment analysis, *European Journal of Operational Research*, **130**, (2001), 498-509.
[31] D. Tyteca, On the measurement of the environmental performance of firms – A literature review and a productive efficiency perspective, *Journal of Environmental Management*, **46**, (1996), 281-308.
[32] D. Tyteca, Linear programming models for the measurement of environmental performance of firms – Concepts and empirical results, *Journal of Productivity Analysis*, **8**, (1997), 183-197.
[33] G. Westner and R. Madlener, The impact of modified EU ETS allocation principles on the economics of CHP-based district heating systems, *Journal of Cleaner Production*, **20**, (2012), 47-60.
[34] J.L. Zofio and A.M. Prieto, Environmental efficiency and regulatory standards: The case of CO2 emissions from OECD industries, *Resource and Energy Economics*, **23**, (2001), 63-83.