Sustainability and Environmental Management Capacity in Asian Countries: Efficiency-based Indicator Development

Katsuya Tanaka

Research Center for Sustainability and Environment
Shiga University

1. Introduction

The Social Capacity for Environmental Management (SCEM) is the capacity to manage and solve environmental problems through an endogenous process involving three actors (governments, firms, and citizens) and their interactions (Matsuoka and Kuchiki 2003). Many traditional arguments deal with causal relations between environmental performance (e.g., SO_2 emission) and socioeconomic condition (e.g., GDP per capita). The SCEM approach extends such arguments by integrating the SCEM into a traditional framework. Thus, environmental performance is determined by socioeconomic condition, SCEM, and their interactions. Figure 1 illustrates this relationship.

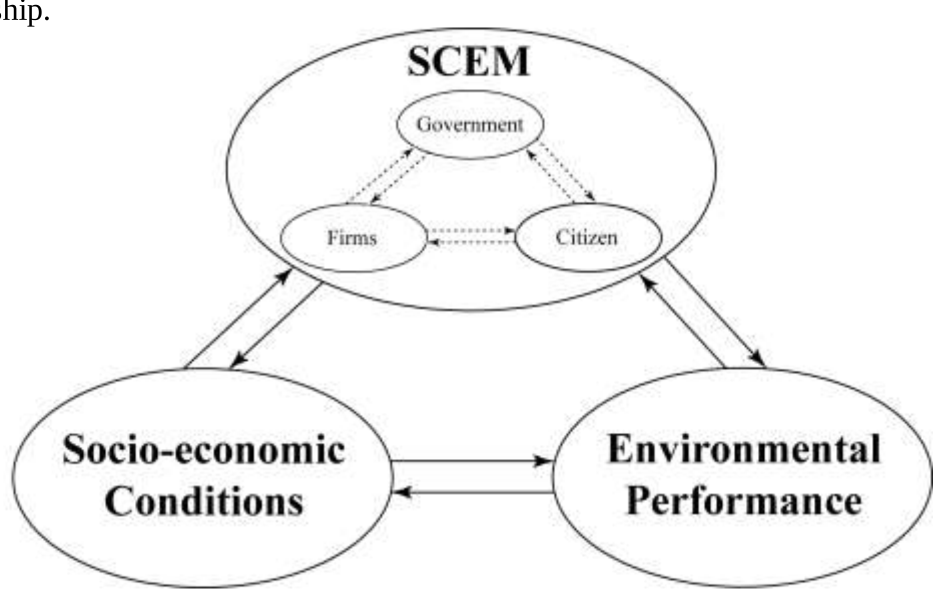

Figure 1. **The SCEM under the Total System**

The capacity development approach has gained greater attention from various environmental perspectives since the 1990s. However, many of the existing relevant studies are limited in terms of either theory or empirics. Some studies are highly conceptual and do not demonstrate the empirical application of those concepts using the existing data. Some other studies present an empirical measurement of capacity development by developing several indicators. However, many such studies provide little relationship between such indicators and environmental performance. In order to obtain a valid measurement of capacity, more statistically sound and reliable indicators need to be developed.

This section proposes another approach toward the elicitation of the causal relationship among environmental performance, socioeconomic condition, and SCEM capacity indicator development. Our approach is different from existing studies in several respects. First, environmental performance is measured in terms of efficiency, not in terms of a direct measure of pollutant emission. Second, a statistical investigation is conducted on the relationship among three major components—environmental performance, the socioeconomic condition, and SCEM. Third, the SCEM indicator is developed using relevant variables and their statistical significance and elasticities. Thus, the indicator we present in this chapter is statistically valid compared to existing indicators.

Existing Indicators

Before presenting the SCEM indicator framework, we summarize and list several major indicators dealing with environmental and natural resources. Overall, there are an extensive number of studies to quantify the capacity of environmental performance and sustainability. Many of these studies either select the relevant indicator variable and evaluate its progress (selection approach) or aggregate the scores obtained from checklists or variables related to the environment of sustainability (aggregation approach). We introduce MDG-7 (Target 9 Indicator) as the selection approach. In addition, we introduce Air Quality Management and Assessment Capabilities and Environmental Sustainability Index (ESI) as aggregation approaches.

MDG-7, Target 9 Indicators

One of the most important innovations of the MDG approach is its ability to make governments more accountable for their performance in improving human well-being. By defining goals and measuring progress in clear, straightforward language, the MDG makes it easy for civil society groups to evaluate the progress toward human development goals and to issue a public "report card" on a government's success or failure.

Unfortunately, the lack of clear, comprehensive targets and indicators for measuring the capacity of ecosystems to provide a sustainable environmental income for the poor means that the "accountability effect" of the MDG approach is not yet applicable to the world's environmental goals. Until the environmental framework of the MDG is mended, the short-run progress toward the other goals is at a risk of being unsustainable. For this reason, it is recommended that MDG-7 (Target 9) be updated.

Air Quality Management and Assessment Capabilities

The United Nations Environmental Programme (UNEP) and the World Health Organization (WHO) propose the aggregation approach of environmental management capacity measurement in their report "Air Quality Management and Assessment Capabilities in 20 Major Cities" (UNEP/WHO 1996). Their approach measures environmental management capacity in 20 major cities by assessing the number of indicators obtained from four primary categories: (1) Air quality measurement capacity, (2) data assessment and availability, (3) emissions estimate, and (4) management enabling capabilities. They prepare a checklist for each category and request each city to provide the current situation in air quality monitoring. The sum of the points of checked items under each category is set at 25 points. Thus, this aggregation approach evaluates the capacity of air quality management from the aggregated score of indicators, which takes a value between 0 and 100.

Environmental Sustainability Index

The ESI benchmarks the ability of nations to protect the environment over the next several decades. In addition, in terms of sustainability vision, the ESI provides the following: (1) A powerful tool for situating environmental decision-making on a firmer analytical footing, (2) an alternative to GDP and the Human Development Index (HDI) for gauging the progress of a country, and (3) a useful mechanism for benchmarking environmental performance (Esty, Marc, Tanja, and Alexander 2005). In order to achieve this goal, the ESI is constructed by integrating 76 data sets—tracking natural resource endowments, past and present pollution levels, environmental management efforts, and the capacity of a society to improve its environmental performance—into 21 indicators of environmental sustainability. The indicators and variables on which they are constructed build on the well-established Pressure-State-Response (PSR) environmental policy model.

These indicators permit comparison across a range of issues that fall into the following five broad categories: (1) environmental systems, (2) reducing environmental stresses, (3) reducing human vulnerability to environmental stresses, (4) societal and institutional capacity to respond to environmental challenges, and (5) global stewardship.

Overall, the ESI, with its emphasis on relative rankings, provides a mechanism for establishing context and for understanding what is possible in terms of policy progress. Indeed, it turns out that comparisons to relevant peer countries are particularly important in goal setting, identifying best practices in both policymaking and technology adoption, and spurring competitive pressure for improved performance.

Outline of This Chapter

This chapter is organized as follows. The next section introduces the manner in which the SCEM indicator is developed. Each of the three steps involved in the development of the SCEM indicator is described in detail. The third section presents two empirical applications. These applications reveal how our framework, presented in section 2, is empirically used with the existing data. Although the first application focuses only on one country (China), the second application compares SCEM development among eight Asian countries using international panel data. The last section summarizes this chapter and draws conclusions from prior chapters. This section also presents some limitations of our approach and the manner in which they are resolved using alternative approaches.

2. Empirical procedures

This study develops the SCEM indicator using the three-step modeling approach. The first step estimates environmental performance by measuring efficiency. We present two different efficiency measures in this section. The first measure is environmental efficiency (EE), which focuses only on the emission of pollutants. The second is balanced growth efficiency (BGE), which estimates the efficiency of sustainable economic development by dealing with both output and pollutant emission. The estimated environmental performance is then used by the second step to identify the impacts of the relationship between environmental performance, the socioeconomic condition, and SCEM. Then, we construct the SCEM indicator using variables and statistical results from the second step. Each of these three steps is described below.

Efficiency is measured either in terms of pollutant emission or both output and pollution. This is done by developing the three-step model. The first step estimates the balanced growth indicator (BGI) for each of the eight Asian countries. Balanced growth is evaluated in terms of GDP and CO_2 emission. This step is empirically carried out by an output-oriented directional data envelopment analysis (DEA). The estimated BGI is then used in the second step. We use the Tobit model to identify the factors affecting BGI. Based on the SCEM framework (figure 1), the three variables representing the environmental management capacities of governments, firms, and citizens are selected and used in the Tobit model. These variables and their elasticities are estimated in the second step and used in the third step to construct the SCEM indicator. In this section, we describe the details pertaining to each of these three steps.

2.1 First Step: Measuring Environmental Performance

We begin by measuring environmental performance in the first step. There are several ways to quantify such performance. For example, in the case of sulfur dioxide (SO_2), environmental performance is typically measured in terms of SO_2 emissions or SO concentrations. Although these measures are common and frequently used, they may underestimate performance in industrial areas and overestimate it in rural areas. In addition, if two different areas produce the same level of SO_2 emission, then environmental performance will be estimated to be the same, even though other factors such as monetary value of industrial output, size of the workforce, and the value of capital are different.

One way to overcome such limitation of conventional performance measurement is to estimate efficiency as an environmental performance measurement. The basic idea behind the efficiency approach is presented in figure 2. In this figure, y is the level of desirable output (e.g., GDP, firm's output) and b is the level of undesirable output (e.g., SO_2 and CO_2 emissions). b can be interpreted as an unavoidable polluting byproduct resulting from the production of desirable output. Thus, in order to produce a desirable output, it is necessary to produce a certain amount of undesirable output at the same time. A production possibility frontier indicates the maximum producible level of desirable output, given the level of undesirable output. Any combination of desirable and undesirable outputs (y,b) is possible under this frontier.

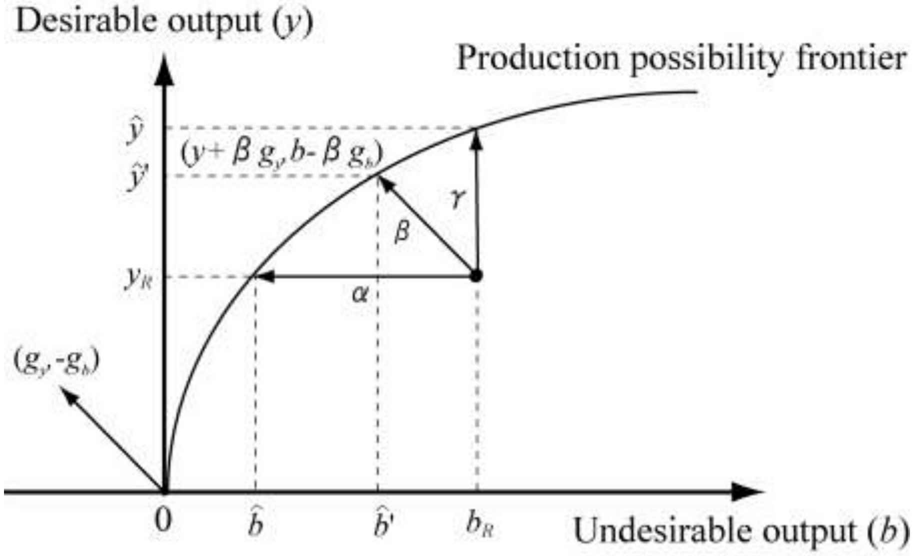

Figure 2. **Directional Distance Function**

Three different types of efficiencies can be measured in terms of the production possibility frontier described above. First, assume that the combination of desirable and undesirable outputs is (y_R, b_R), as shown in figure 2. This combination is inefficient because one can increase the desirable output up to $\hat{y}$ without increasing the undesirable output. This output-oriented efficiency is known as technical efficiency, defined by the distance between the observed level of desirable output (y_R) and the maximum producible level ($\hat{y}$). This is denoted as γ in figure 2.

Second, efficiency can be measured in terms of the undesirable output. We continue to assume the same combination of desirable and undesirable outputs (y_R, b_R). In figure 2, one can decrease the level of undesirable output up to $\hat{b}$ without decreasing the output. We define this input-oriented efficiency as EE. This is illustrated by the difference between the observed level of undesirable output ($\hat{b}$) and the minimum feasible level (b_R) in figure 2.

Third, efficiency can also be measured in terms of both desirable and undesirable outputs, represented as β in figure 2. Given the combination of desirable and undesirable outputs (y_R, b_R), one can simultaneously increase the desirable output up to $\hat{y}'$ and decrease the undesirable output up to $\hat{b}'$. This efficiency is denoted as the balanced growth indicator in Watanabe and Tanaka (2006). In order to be consistent with technical efficiency and EE, we denote the third efficiency as BGE.

Since efficiency is measured in terms of distance between observation and frontier, a small value indicates greater efficiency. The value becomes 0 if observation lies on the frontier curve. We modified this efficiency score such that it is truncated from low to high efficiency. Thus, in our modified efficiency score, 0 indicates the least efficiency and 1 indicates the highest efficiency.

Efficiency can be empirically measured using linear programming software such as GAMS and OnFront. Technical resources for theoretical foundations and linear programming algorithm are presented in the appendix.

2.2 Second Step: The Relationship between SCEM and Environmental Performance

Once environmental performance is estimated in the first step, the next step is to identify the impacts of the relationship among environmental performance, the socioeconomic condition, and SCEM. Specifically, this step evaluates the impacts of the socioeconomic condition and SCEM on environmental performance using the following model:

$$u_{it} = f(G_{it}, F_{it}, C_{it}, X_{it}), \tag{2.1}$$

where u_{it} is environmental performance for unit *i* in period *t*. Environmental performance can be measured by the environmental efficiency or BGE presented in the previous section. The unit indicates an economic decision-making unit, depending on the data. If the data is province-specific aggregated data, the unit will be the province. If the data is a firm-level survey, the unit will be the firm. G_{it}, F_{it}, and C_{it} represent the capacities of governments, firms, and citizens, respectively. Finally, X_{it} is a vector of the socioeconomic condition. In the simplest form, equation (1) can be estimated by the following linear model:

$$u_{it} = \beta_0 + \beta_1 G_{it} + \beta_2 F_{it} + \beta_3 C_{it} + \beta_4 X_{it} + \varepsilon_{it}, \tag{2.2}$$

where β's are parameters to be estimated and ε_{it} is a disturbance term capturing random noise.

Since environmental performance, estimated in the first step, has discrete jump at 0 and 1, i.e., the value always falls between 0 and 1, the parameter estimates of equation (2) using the ordinary least square (OLS) results in baseness and inconsistency (Greene 2003). Thus, it is necessary to consider the censoring of the dependent variable. One of the most commonly used applications for such censored data is the Tobit model (also referred to as censored regression). The Tobit model is given as:

$$u_{it} = \begin{cases} \beta_0 + \beta_1 G_{it} + \beta_2 F_{it} + \beta_3 C_{it} + \beta_4 X_{it} + \varepsilon_{it} & \text{if } 0 < \text{RHS} < 1 \\ 0 & \text{if RHS} \le 0 \\ 1 & \text{if RHS} \ge 1 \end{cases} \tag{2.3}$$

where RHS denotes the right-hand side of equation (2). This model has been widely used in various fields, including economics, and can be estimated using most of the major econometric software such as Eviews, LIMDEP, and STATA.

Once the Tobit model is estimated and the effects of the socioeconomic condition and SCEM are found to be statistically significant, we compare the contributions of these variables to environmental performance by using elasticity. Elasticity is defined as an incremental percentage change in one variable—in this case, environmental performance—due to a 1% increase in another variable. For example, the elasticity of environmental performance with respect to the capacity of a government can be estimated by $\frac{\partial u}{\partial G} \cdot \frac{G}{u}$, where $\frac{\partial u}{\partial G}$ is the coefficient for the capacity of the government, estimated by the Tobit model.

By estimating the elasticity for each of the socioeconomic condition or SCEM variables, we can reveal the degree of contribution to environmental performance among SCEM and socioeconomic conditions. Further, the estimated elasticities are also used in the next step to construct the SCEM indicator. The following section, will discuss this issue in detail.

2.3 Third Step: Development of the SCEM Indicator

Once the environmental management capacity variables of the three actors are estimated and shown to be significant from the Tobit model, these variables and elasticities are used to construct the SCEM indicator. Following Tanaka and Watanabe (2005), the SCEM indicator is calculated by the following weighted average of the capacities of governments, firms, and citizens:

$$SCEM_{it} = \omega_g \tilde{G}_{it} + \omega_f \tilde{F}_{it} + \omega_c \tilde{C}_{it} , \quad (2.4)$$

where $SCEM_{it}$ is the value of the SCEM indicator for country *i* in year *t*. $\tilde{G}_{it}$, $\tilde{F}_{it}$, and $\tilde{C}_{it}$ are the normalized capacities of governments, firms, and citizens, respectively. The capacity of governments is normalized by $\tilde{G}_{it} = G_{it} / \bar{G}_{it}$, where $\bar{G}_{it}$ is the maximum value of G_{it} in the data set. Moreover, similar normalization is performed for firms and citizens. ω_g, ω_f, and ω_c are the "weights" of the three actors. The weights are determined by the given estimated elasticities from the Tobit model. We normalized the weights such that the sum of elasticities take the value of 1 ($\omega_g + \omega_f + \omega_c = 1$), by using the equation $\omega_j = e_j / (e_g + e_f + e_c)$ for $j = G, F, C$. By normalizing all the variables and weights on the right-hand side of equation (4), we obtain the convenient and intuitive indicator of the SCEM taking a value between 0 and 1.

3. Applications of the SCEM Indicator Development

Given the framework of the SCEM indicator development presented in section 2, this section presents two empirical applications. The first application develops the SCEM indicator in terms of CO_2 emissions in eight countries in East and Southeast Asia. This application reveals how the development process and the contributing actors are different among countries. The second application pertains to the domestic scale: SO_2 emissions from industrial sources in China. By focusing only on one country, this application reveals further details in SCEM development.

3.1 Application 1: CO_2 Emissions in Eight Asian Countries

In this example, the empirical procedure developed in the previous section is applied to CO_2 emissions during 1995–2003 in eight Asian countries—China, Indonesia, Japan, Malaysia, the Philippines, South Korea, Thailand, and Malaysia. Environmental performance is measured by BGE (BGE), which is determined by efficiency in terms of both desirable and undesirable outputs. Additional details of BGE are presented in section 2.2.1.

First Step

We first estimate the BGE for the eight Asian countries during 1995–2003 using a directional output distance function. In this framework, each country produces two outputs using three inputs. The two outputs constitute GDP as the desirable output and CO_2 as the undesirable output. Labor, capital, and energy consumption are the three inputs for producing the desirable and undesirable outputs.

The data for labor, capital, and GDP are gathered from World Development Indicators (2005). Data for energy consumption are obtained from Statistics on Energy Balances by the International Energy Agency/Organization for Economic Cooperation and Development (IEA/OECD) (2005a, 2005b). Data for CO_2 emission are obtained from statistics on total CO_2 emissions from the Carbon Dioxide Information Analysis Center (CDIAC) (2005).

Table 1 depicts the estimated BGE in the eight Asian countries during 1995–2003. Overall, the BGE increases by more than 50% in Asia. As expected, Japan is estimated to have the highest BGE score. Although many of the countries exhibit significant increases, the BGE score is low and almost constant for China and Vietnam. This implies that these emerging countries have made little progress toward sustainable development during the estimation period.

***Table 1.* The Estimated Balanced Growth Efficiency in Eight Asian Countries (1995–2003)**

	Balanced growth efficiency								
Year	China	Indonesia	Japan	Malaysia	The Philippines	S. Korea	Thailand	Vietnam	Total
1995	1.00	0.13	0.95	0.12	0.52	0.25	0.13	0.19	0.41
1996	0.09	0.13	0.96	0.13	0.41	0.26	0.12	0.15	0.28
1997	0.08	0.13	0.99	0.13	0.37	0.29	0.13	0.20	0.29
1998	0.09	0.79	1.00	0.30	0.65	1.00	0.71	0.19	0.59
1999	0.10	1.00	0.98	0.81	0.80	0.92	0.73	0.22	0.69
2000	0.10	0.53	0.98	0.20	0.62	0.88	0.47	0.14	0.49
2001	0.10	0.49	1.00	0.66	0.80	0.89	0.40	0.12	0.56
2002	0.09	0.54	1.00	0.68	0.90	0.99	0.42	0.11	0.59
2003	0.09	0.70	1.00	1.00	1.00	1.00	0.36	0.11	0.66
Mean	0.19	0.49	0.98	0.45	0.67	0.72	0.38	0.16	0.51

Second Step

In the second step, given the BGE estimated in the first step, we evaluate the effects of the socioeconomic condition and actor capacities on environmental performance by using a censored regression model. Accordingly, EE for province *i* in year *t* is explained by the following model:

$$\begin{aligned} BGE_{it} &= \beta_0 + \beta_1 GOV_{it} + \beta_2 FIRM_{it} + \beta_3 CITIZEN_{it} \\ &+ \beta_4 GDPPER_{it} + \beta_5 INDONESIA + \beta_6 MALAYSIA \\ &+ \beta_7 THAILAND + \beta_8 D1998 + \beta_9 D1999 \end{aligned}, \qquad (2.5)$$

where the first three variables GOV, FIRM, and CITIZEN are the capacities of governments, firms, and citizens, respectively. GOV is measured by the number of environmental treaties and multilateral agreements per million people. FIRM is represented by ISO 14001 certifications over industry value added. CITIZEN is obtained from the HDI. The socioeconomic indicator is considered to be GDPPER, i.e., gross domestic product per capita. The last two variables are dummies to be constructed from the country and year perspectives. β 's are the parameter coefficients to be estimated. All variables are obtained from international organization publications and databases. Descriptive statistics of the independent variables are summarized in table 2.

***Table 2.* Variables and Descriptive Statistics for the Tobit Model (Application 1)**

Variable	Description	Unit	Mean	Std. Dev.	Min	Max
GOV	Capacity of governments, measured in terms of total environmental treaties and multilateral agreements per million people	number of agreements over million population	1.20	0.98	0.08	3.79
FIRM	Capacity of firms, measured in terms of the number of ISO 14001 per billion dollars in value added	number of certifications over billion constant 2000 US $	2.73	3.03	0.00	11.90
CITIZEN	Capacity of citizens, measured in terms of Human Development Indicator (HDI)	interval between 0 and 1	0.77	0.96	0.56	0.94
GDPPER	Gross domestic product per capita	billion constant 2000 US $ per million population	6.58	11.69	0.30	38.20
INDONESIA	1 if in Indonesia		0.13	0.33	0.00	1.00
MALAYSIA	1 if in Malaysia		0.13	0.33	0.00	1.00
THAILAND	1 if in Thailand		0.13	0.33	0.00	1.00
D1998	1 if in 1998		0.13	0.33	0.00	1.00
D1999	1 if in 1999		0.13	0.33	0.00	1.00

The data for environmental treaties are gathered from the Center for International Earth Science Information Network (CIESIN) and the Environmental Treaties and Resource Indicators (ENTRI) database. The data on multilateral environmental agreements are obtained from Earthtrends Environmental Information searchable databases under the management of the World Resource Institute (WRI), based on their collection from each corresponding organization. The data for ISO certification is adopted from annual ISO surveys (2001–2004) conducted by International Organization for Standardization (ISO). The HDI is collected from annual Human Development Reports (1994–2005) prepared by the United Nations Development Programme (UNDP). Since HDI is not reported for the year 1996, we use the data reported in 1995 for the year 1996 and that reported in 1994 for the year 1995, in the estimation. The denominator variables (population and industry value added) and the socioeconomic background variable—gross domestic product per capita—are obtained from the same sources as in the first stage estimation, i.e., World Development Indicators.

Table 3 depicts the estimated coefficients and elasticities for the Tobit model. The results show that the estimated model fits the data plausibly well. All independent variables are statistically significant at either 1%, 5%, or 10% levels. In addition, the joint null hypothesis is rejected ($\chi^2 = 72.84$). Results indicate that both socioeconomic conditions (GDPPER) and SCEM variables (GOV, FIRM, and CITIZEN) are significant, implying that they affect environmental performance with statistical significance. The results also indicate that the SCEM variables exert greater influence on environmental performance than the socioeconomic condition, implying the importance of social capacity development of environmental management in the eight Asian countries. Among the three capacities, CITIZEN has the largest elasticity and is considerably elastic. GOV and FIRM exhibit nearly the same levels of elasticities.

***Table 3.* The Estimated Coefficients from the Tobit Model (Application 1)**

Independent variable	Coefficient	Std. Error	Elasticity
Intercept	–0.52	0.33	
GOV	0.09 ***	0.02	0.22
FIRM	0.05 ***	0.01	0.24
CITIZEN	0.83 *	0.45	1.26
GDPPER	0.01 ***	0.01	0.16
INDONESIA	0.28 ***	0.09	
MALAYSIA	–0.10	0.09	
THAILAND	–0.18 *	0.09	
D1998	0.21 **	0.08	
D1999	0.28 ***	0.08	
n	72		
χ^2	72.84		

Note: One, two, and three asterisks indicate statistical significance at 1%, 5%, and 10% levels.

Third Step

The third step develops the SCEM indicator based on the results obtained from previous steps and from equation (4). Figure 3 reports the estimated SCEM indicator for the eight Asian countries for the period between 1995 and 2003 and shows a significant increase in the SCEM for all of the eight countries. Japan is estimated to be the highest in the SCEM among these countries. The SCEM in Japan increases from 0.77 to 0.88, accounting for an increase of 15%. The second highest SCEM is observed in Korea. Overall, the ranking of the SCEM indicator is mostly consistent with the degree of economic development among these countries. Although China has one of the lowest SCEM, it exhibits the most rapid increase, which accounts for nearly 40% during the estimation period.

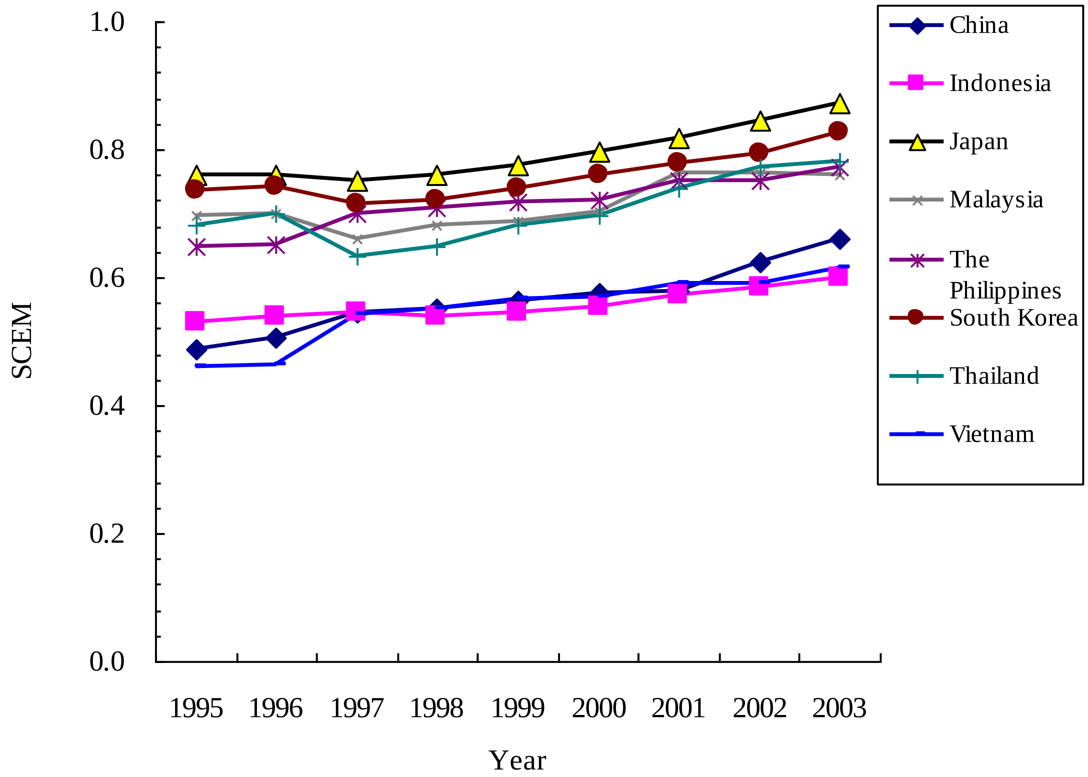

Figure 3. **The Estimated SCEM Indicator in Eight Asian Countries (1995–2003)**

The estimated capacities of governments, firms, and citizens are shown in figures 4, 5, and 6, respectively. These figures reveal the capacity of firms (the number of ISO certifications per billion dollars) as a primary source of SCEM development. As shown in figure 5, firms in most countries enhanced their capacities rather rapidly during the estimation period. Particularly high increases are observed in Thailand and Japan. Although the lowest score is observed in China until 2001, the country increases its capacity rather rapidly after 2002 and keeps pace with other countries. The capacity of citizens (HDI) is almost constant, particularly after 1997. Although its elasticity is relatively large, capacity enhancement is slow in all the eight Asian countries considered in this study. Finally, the capacity of government is observed to be decreasing in all countries except Japan and Malaysia, albeit rather slowly. This reflects the recent stagnation of international agreements pertaining to CO_2 emission reduction and other global environmental issues.

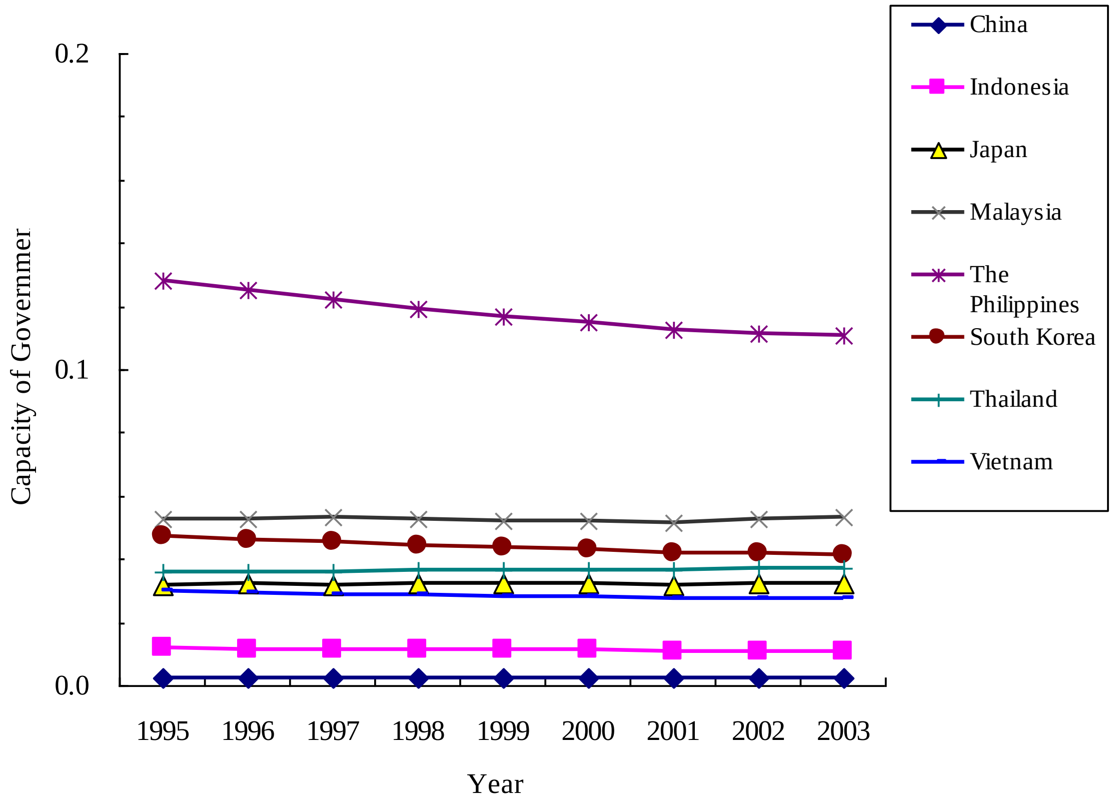

Figure 4. **The Estimated Capacity of Government in Eight Asian Countries (1995–2003)**

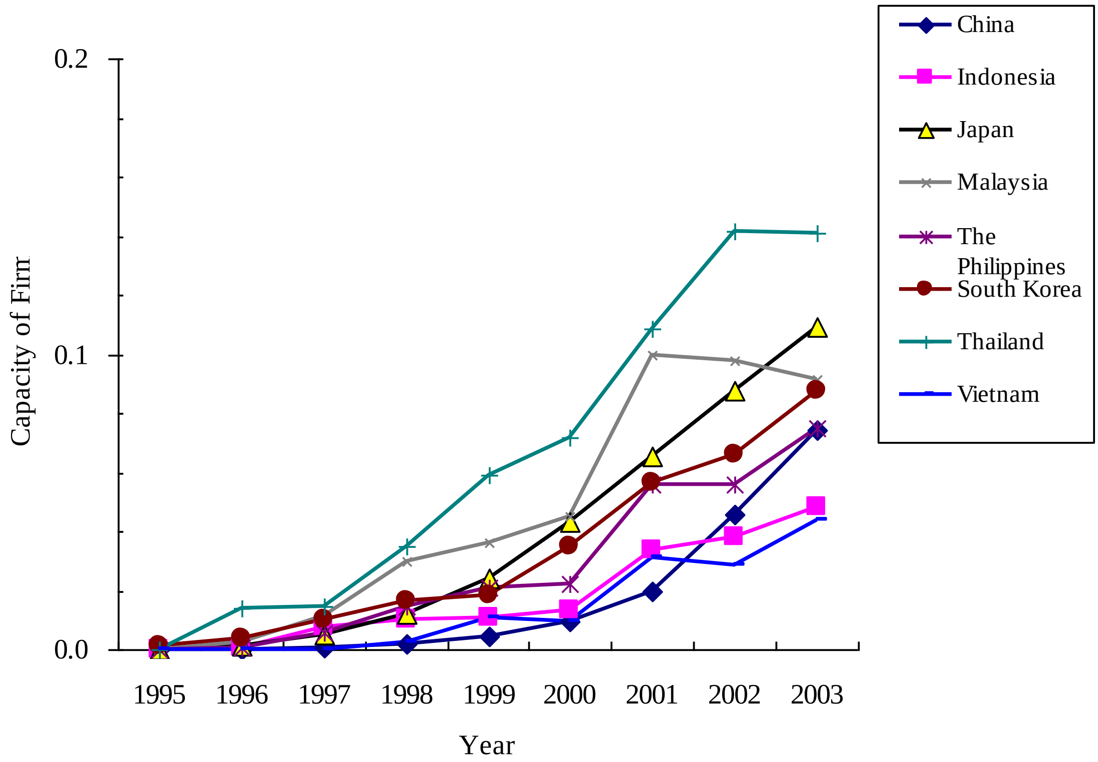

Figure 5. **The Estimated Capacity of Firms in Eight Asian Countries (1995–2003)**

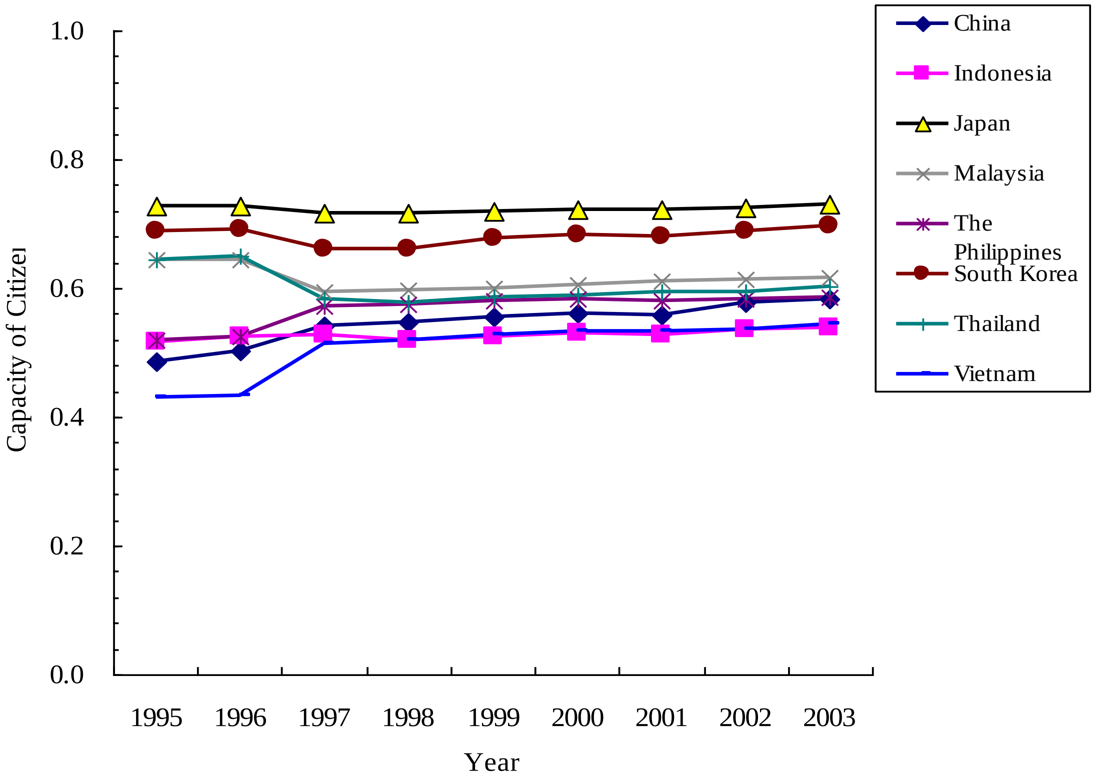

Figure 6. **The Estimated Capacity of Citizen in Eight Asian Countries (1995–2003)**

3.2 Application 2: SO_2 Emissions from Industrial Sectors in China

In this example, the empirical procedures presented in the previous section are applied to SO_2 emissions from industrial sectors (electricity, mining, and manufacturing sectors) in China during the period between 1994 and 2002. Environmental performance is measured by EE in terms of SO_2 emission, i.e., the difference between the minimum feasible level of emission and the observed level of emission, at the given level of GDP. This corresponds to the distance α in figure 2.

First Step

We begin by estimating EE, described above, for 30 provinces in China[1] For this purpose, we set up a province-level aggregated production function consisting of two outputs and three inputs. The outputs include both desirable and undesirable outputs. The desirable output is measured in terms of the gross industrial output value. The undesirable output—pollutants as byproducts of industrial operation—is measured in terms of the level of SO_2 emission from the industrial sectors. With regard to the inputs of the model, we select the size of the labor force, capital, and coal as inputs. Capital is measured in terms of the net value of fixed assets. Labor is measured in terms of the number of staff and workers. Coal is measured in terms of coal consumption as an input material. These variables are obtained from *China Statistical Yearbook*.

Table 4 depicts the estimated EE in China during 1994–2002. The national average of the efficiency score is estimated to be 0.77, with some fluctuation during the estimation period. Specifically, efficiency gradually decreases until the year 2000.

However, the highest efficiency score is achieved in 2002, the last year of our estimation period.

***Table 4.* The Estimated Environmental Efficiency in China (1994–2002)**

Year	Environmental efficiency			
	Coast	Central	West	Nation
1994	0.79	0.80	0.80	0.80
1995	0.71	0.79	0.80	0.76
1996	0.72	0.80	0.80	0.77
1997	0.74	0.81	0.80	0.77
1998	0.69	0.74	0.77	0.73
1999	0.75	0.77	0.77	0.76
2000	0.74	0.78	0.74	0.75
2001	0.79	0.79	0.78	0.79
2002	0.83	0.79	0.78	0.81
Mean	0.75	0.79	0.78	0.77

Second Step

In the second step, using the EE estimated in the first step, we evaluate the effects of the socioeconomic condition and SCEM on EE using the censored regression model. Specifically, EE for province *i* in year *t* is explained by the following model:

$$\begin{aligned} EE_{it} = \beta_0 + \beta_1 GPPC_{it} + \beta_2 IRATIO_{it} + \beta_3 GOV_{it} + \beta_4 FIRM_{it} \\ + \beta_5 CITIZEN_{it} + \beta_6 CENTRAL + \beta_7 WEST + \beta_8 TIME \end{aligned}, \qquad (2.6)$$

where the first two independent variables represent socioeconomic conditions. GPPC denotes gross provincial product per labor and IRATIO represents the ratio of industrial sector. The next three variables GOV, FIRM, and CITIZEN are the capacities of governments, firms, and citizens, respectively. GOV is measured in terms of the number of monitoring stations. FIRM is represented by SO_2 removal rate (ratio of total SO_2 removed to total SO_2 emission). CITIZEN is denoted by the number of environmental disputes. CENTRAL and WEST are dummy variables for provinces in the central and western regions. TIME is a time trend capturing time-varying effects. β's are the parameter coefficients to be estimated. All variables are obtained from the *China Statistical Yearbook* and the *China Environmental Yearbook* between the years 1995 and 2003. Descriptive statistics of the independent variables are summarized in Table 5.

***Table 5.* Variables and Descriptive Statistics for the Tobit Model (Application 2)**

Variable	Description	Unit	Mean	Std. Dev.	Min	Max
GPPC	Gross provincial product per labor, deflated by GDP index	100 million yuan	0.06	0.03	0.02	0.17
IRATIO	Ratio of industrial sector in terms of output value	percentage terms	0.36	0.15	0.08	1.01
GOV	Capacity of government, measured by the number of monitoring station	counts	1.26	0.60	0.00	4.00
FIRM	Capacity of firm, measured by the rate of SO_2 removal (ratio of SO_2 removal and SO_2 emission)	percentage terms	0.21	0.16	0.01	0.68
CITIZEN	Capacity of citizen, measured by the number of cizen groups complained for environmental issues	counts	734.76	798.20	1.00	5530.00
CENTRAL	= 1 if in Central region		0.31	0.46	0.00	1.00
WEST	= 1 if in Western region		0.24	0.43	0.00	1.00
TIME	Time trend (1994 = 1)	year	5.00	2.59	1.00	9.00

Table 6 presents the estimated results. Overall, the model fits the data rather well. All independent variables except CITIZEN are statistically significant at the 1% level. In addition, a chi-square statistic (123.08) strongly rejects the null hypothesis that all coefficients are simultaneously zero. As expected, the signs of the socioeconomic condition (GPPC and IRATIO) and environmental management capacities (GOV, FIRM, and CITIZEN) are shown to be positive. This indicates that both the socioeconomic condition and SCEM are positive inducements for efficiency in SO_2 emissions from the industrial sector in China. The capacity of citizens (CITIZEN) is not significant at any statistical level. This may imply that the citizens' capacity is not well developed to induce an increase in environmental efficiency and a consequent abatement of the SO_2 pollution problem in China.

***Table 6.* The Estimated Coefficients from the Tobit Model (Application 2)**

Independent variable	Coefficient	Std. Error	Elasticity
Intercept	0.21 ***	0.06	
GPPC	4.69 ***	0.53	0.36
IRATIO	0.68 ***	0.11	0.32
GOV	0.08 ***	0.02	0.12
FIRM	0.25 ***	0.07	0.07
CITIZEN	< 0.01	0.00	0.08
CENTRAL	0.16 ***	0.03	
WEST	0.10 ***	0.03	
TIME	–0.03 ***	0.01	
n	190		
χ^2	123.08		

Note: One, two, and three asterisks indicate statistical significance at 1%, 5%, and 10% levels.

Moreover, Table 6 presents the estimated elasticities of the socioeconomic condition and SCEM. Two socioeconomic conditions are relatively elastic: the elasticities of GPPC and IRATIO are estimated to be 0.36 and 0.32, respectively. These indicate that an increase of 1% in GPPC and IRATIO result in an increase in EE by 0.36% and 0.32%, respectively. The elasticities of SCEM variables are relatively small; an increase of 1% in the capacities of governments, firms, and citizens will enhance the EE by 0.12%, 0.07%, and 0.08%, respectively. Among the three actors of the SCEM, the capacity of governments is the most elastic. This indicates that capacity development in governments is the most effective in enhancing efficiency in terms of SO_2 emission from the industrial sectors. The capacity of firms is estimated to have the smallest elasticity among the capacities considered in this study. However, its elasticity is significant whereas that of citizens is not.

Third Step

The third step develops the SCEM indicator based on the results obtained from the first and second steps. Specifically, the SCEM indicator is calculated as follows:

$$SCEM_{it} = \omega_g \tilde{G}_{it} + \omega_f \tilde{F}_{it}, \quad (2.7)$$

where $\tilde{G}_{it}$ and $\tilde{F}_{it}$ are the capacities of governments and firms, respectively, which are normalized such that they take a value between 0 and 1. ω_g and ω_f are the weights of capacities, derived from the elasticities reported in Table 6. These weights are adjusted such that the sum of the weights is 1. This indicator is a modified version of equation (4). The only difference is that the capacity of citizens is not included here due to the insignificance estimated in the Tobit model.

Figure 7 presents the estimated SCEM indicator and observed level of SO_2 emission during 1994–2000. These values are normalized such that they take a value between 0 and 1 for comparison purpose. As the figure shows, the SCEM indicator increases from 0.27 in 1994 to 0.37 in 2002, accounting for a growth of 37%. Thus, environmental management capacity development has been fairly developed during the estimation period. In the same period, SO_2 emission decreased for about 10%. It is modest increase under rapid economic development in the period, and is significantly due to the SCEM development in the period.

Finally, figure 8 illustrates the changes in the capacities of governments and firms during the same period. The figure illustrates the SCEM is fairly increasing during the estimation period. The figure illustrates significant development in the capacity of government. It increases from 0.19 in 1994 to 0.42 in 2002, accounting for an increase of 118%. In contrast, the capacity of governments is estimated to be nearly constant during the estimation period. Thus, although the SCEM is developed for nearly 40% during 1994-2002, such capacity development is mostly due to a rapid enhancement of the capacity of firms. Further development in the SCEM may require enhancing the capacity of government as well as that of firms.

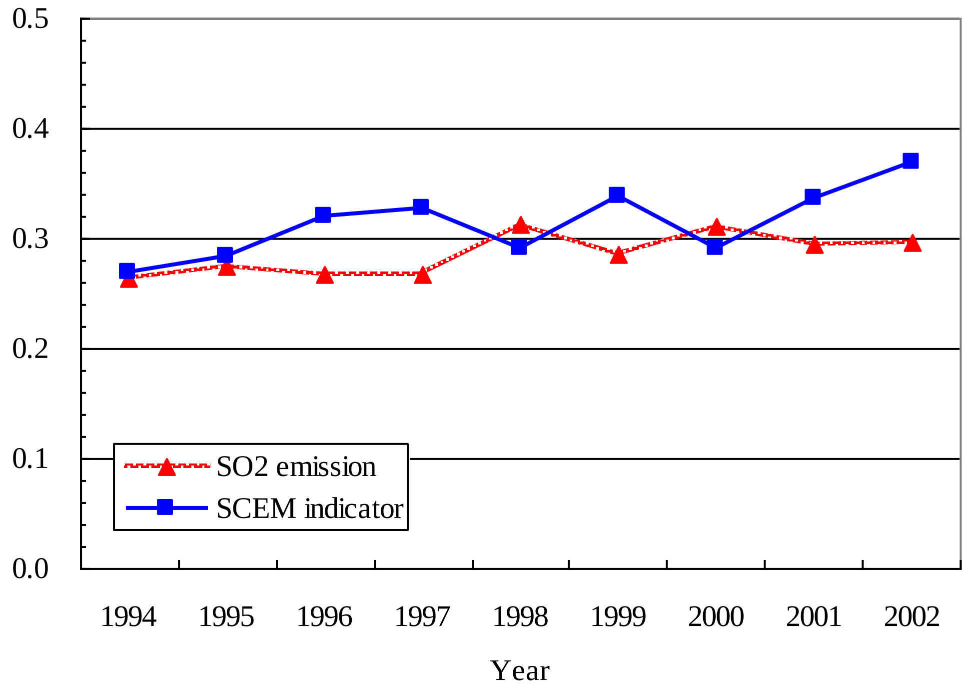

Figure 7. **SO_2 Emissions and SCEM Indicator in China (1994–2002)**

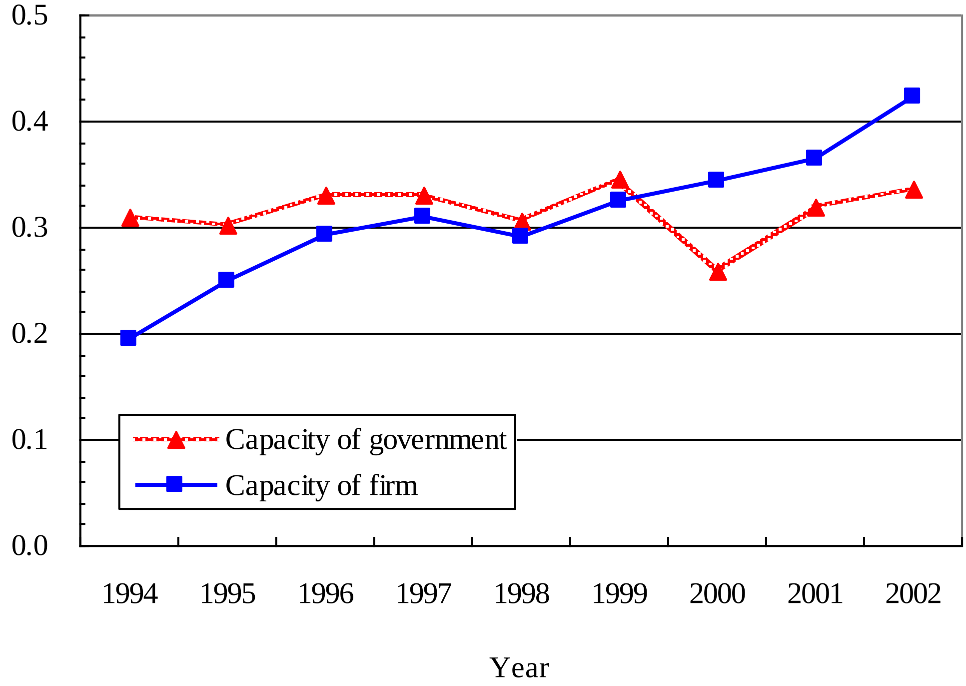

Figure 8. **The Capacities of Government and Firms in China (1994–2002)**

4 Summary and Conclusions

This study develops an indicator of SCEM using the three-step modeling approach. The first step estimates environmental performance by measuring efficiency. We present two different efficiency measures. The first measure is EE, which focuses only on the emission of pollutants. The second is BGE (BGE), which estimates the efficiency of sustainable economic development by dealing with both output and pollutant emission. The estimated environmental performance is then used in the second step to identify the impacts of the relationship between environmental performance, the socioeconomic condition, and SCEM. Then, we construct the SCEM indicator using the variables and statistical results obtained from the second step.

Based on the empirical procedures discussed in section 2.2, we reported two empirical applications. The first application compared the SCEM and its development among eight Asian countries during 1995–2003. We evaluated the environmental performance of each country by the BGE (BGE) and the efficiency measurement in terms of GDP and CO_2 emission. We observed a significant increase in environmental performance in the eight Asian countries. The Tobit model revealed both the SCEM and socioeconomic condition to be a significant source of such performance enhancements. We then constructed the SCEM indicator for the eight Asian countries. The indicator revealed that all eight countries develop the SCEM fairly well. Such a development in the SCEM is mostly due to the capacity enhancement of firms. In contrast, the capacities of governments and citizens remain almost constant during the estimation period.

We also reported another empirical example that focused on industrial SO_2 emission in China during 1994–2002. In this example, environmental performance is defined by EE in terms of SO_2 emissions from the industrial sectors in each of the 30 provinces. The directional distance output function reveals that although the EE decreases marginally during the estimation period, the highest score is observed in the last year of the period of estimation (2002). As observed in the first example, the estimated environmental performance is influenced by both the socioeconomic condition and SCEM. However, the capacity of citizens is estimated not to be significant at any statistical levels. This may imply that the capacity of citizens is not reasonably developed and therefore has no significant influence on the abatement of environmental pollution in China. Finally, we construct the SCEM using the capacities of governments and firms. The capacity of citizens is not included because it is statistically insignificant. Our results reveal that the SCEM is fairly increasing during 1994–2002. Further, they indicate that this is mostly due to a rapid enhancement of the capacity of firms. Although this capacity increases by more than 100%, the capacity of governments is estimated to be nearly constant during the estimation period.

Before concluding this chapter, several limitations need to be identified. First, because the relationship between environmental performance and the SCEM does not need to be linear, a more flexible functional form may be appropriate in the Tobit model. For example, a translog or quadratic form may produce more accurate measures of such a relationship. Further, interactions among governments, firms, and citizens may need to be included as interaction terms in the model. Second, this chapter employed only three variables—governments, firms, and citizens. Although this simplicity significantly facilitates indicator development, it may be fairly simple to investigate each of the three actors for further details. These actors typically consist of the following three factors: (1) policy and measures, (2) organizational resources, and (3) knowledge and technology. However, the more capacity included in the model, the more likely is the model to have multicollinearity, i.e., correlation among independent variables. This may result in biased and inefficient estimates.

Thus, the SCEM indicator can be used as a convenient overview of the SCEM development with readily available data. Further investigation of each actor can be implemented using another approach with factor-specific data for the three actors. The next chapter introduces one such methodology, the actor-factor analysis.

Appendix: Directional Output Distance Function

This appendix presents the technical details involved in the estimation of the directional distance function, derived from Färe and Grosskopf (2004), Watanabe (2004), and Watanabe and Tanaka (2006).

We first denote a vector of inputs by $x = (x_1,..., x_N) \in \Re_+^N$. There are two types of outputs—desirable output (e.g., GDP) and undesirable output (e.g., SO_2 emission)—which are denoted as $y = (y_1,..., y_M) \in \Re_+^M$ and $b = (b_1,..., b_I) \in \Re_+^I$, respectively. The relationship between input and output is represented by an output set:

$$P(x) = \{(y,b) : x \text{ can produce } (y,b)\}, \quad x \in \Re_+^N. \quad \text{(A.1)}$$

The output set is assumed to have the following properties. The first is "null-jointness," which implies that the desirable output cannot be produced without simultaneously producing the undesirable output:

$$(y,b) \in P(x) \text{ and } b = 0, \text{ then } y = 0. \quad \text{(A.2)}$$

The second and third properties relate to the production technology of desirable and undesirable outputs. The second assumption is referred to as the weak disposability of the undesirable output:

$$(y,b) \in P(x) \text{ and } 0 \le \theta \le 1, \text{ then } \theta(y,b) \in P(x). \quad \text{(A.3)}$$

This indicates that it is impossible to reduce the undesirable output without reducing the desirable output. The third assumption is known as the strong disposability of the desirable output:

$$(y,b) \in P(x) \text{ and } y^0 \le y, \text{ then } (y^0,b) \in P(x). \quad \text{(A.4)}$$

This assumption implies that it is possible to reduce the desirable output without reducing the undesirable output. Thus, within this model, there exists an asymmetry in the properties of desirable and undesirable outputs. Figure 2 depicts the output set, $P(x)$, for a case comprising one desirable output and one undesirable output. The output set satisfies the "null-jointness" property as the function passes through the origin. It is possible to reduce the desirable output, i.e., a vertical downward shift in production is possible, although it is not possible to reduce the undesirable output, i.e., a horizontal leftward shift is not possible for observations on the production frontier.

Given the foundations in equations (A.1)–(A.4), the directional output distance function is now defined as follows:

$$\vec{D}_o(x, y, b; g_y, g_b) = \max\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\}. \quad \text{(A.5)}$$

The value of β represents the distance between the observation (y,b) and a point on the production frontier, $(y + \beta g_y, b - \beta g_b)$. A direction vector, $g = (g_y, -g_b)$, determines the direction in which efficiency is measured. The direction vectors for desirable and undesirable outputs are represented by g_y and g_b, respectively. Given the production technology ($P(x)$) and direction vector (g), the directional distance function yields the maximum feasible expansion of the desirable output and the contraction of the undesirable output. If the observation is on the production frontier, then the value of the directional output distance function is zero and the observation is the most efficient. As the value increases, the observation becomes less efficient. Thus, contrary to the distance function, the efficiency of an observation increases as the value of the directional distance function approaches zero. It is possible to measure the efficiency in different directions by changing the value of the direction vector.

The output directional distance function, $\beta^{k'}$, for the k^{th} observation is obtained by solving the following maximization problem:

$$\vec{D}_o(x^{k'}, y^{k'}, b^{k'}; g_y, g_b) = \max \beta^{k'} \quad \text{(A.6)}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} z_k y_{km} \geq y_{k'm} + \beta^{k'} g_{y_m} \qquad m = 1,\ldots, M \quad \text{(A.7)}$$

$$\sum_{k=1}^{K} z_k y_{ki} = b_{k'i} - \beta^{k'} g_{b_i} \qquad i = 1,\ldots, I \quad \text{(A.8)}$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n} \qquad n = 1,\ldots, N \quad \text{(A.9)}$$

$$\sum_{k=1}^{K} z_k = 1 \quad \text{(A.10)}$$

$$z_k \geq 0 \qquad k = 1,\ldots, K, \quad \text{(A.11)}$$

where z_k is the weight of the k^{th} observation. Note that equations (A.7) and (A.8) represent the strong disposability of desirable output and the weak disposability of undesirable output, respectively. Equation (A.10) is omitted if CRS is assumed.

NOTE

1 Tibet is excluded from this analysis due to data limitation.

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