Economic development and emission intensity in Asian countries : A DEA approach

Economic development and emission intensity in Asian countries: A DEA approach

Masayuki Shimizu *

Abstract: Several Asian countries have achieved rapid economic development, but their development has lead to more rapid environmental pollution. Under these circumstances, this study evaluates the environmental performance of six Asian countries measured by emission intensity index, using a non-parametric Data Envelopment Analysis approach with time-series data for the period 1970−2008. The empirical results are as follows. First, China is the best performer while Thailand is the worst. Second, the six Asian countries improved their production efficiency but deteriorated the environmental efficiency through the 1970s to the 2000s. Third, the environmental performance measured by emission intensity index remained almost unchanged because the improvement of production efficiency offset the deterioration in environmental efficiency.

Key words: DEA approach; economic development; emission intensity index; SO_2, NO_X, CO_2 emissions.

JEL codes: O44, Q53, Q56

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I. Introduction

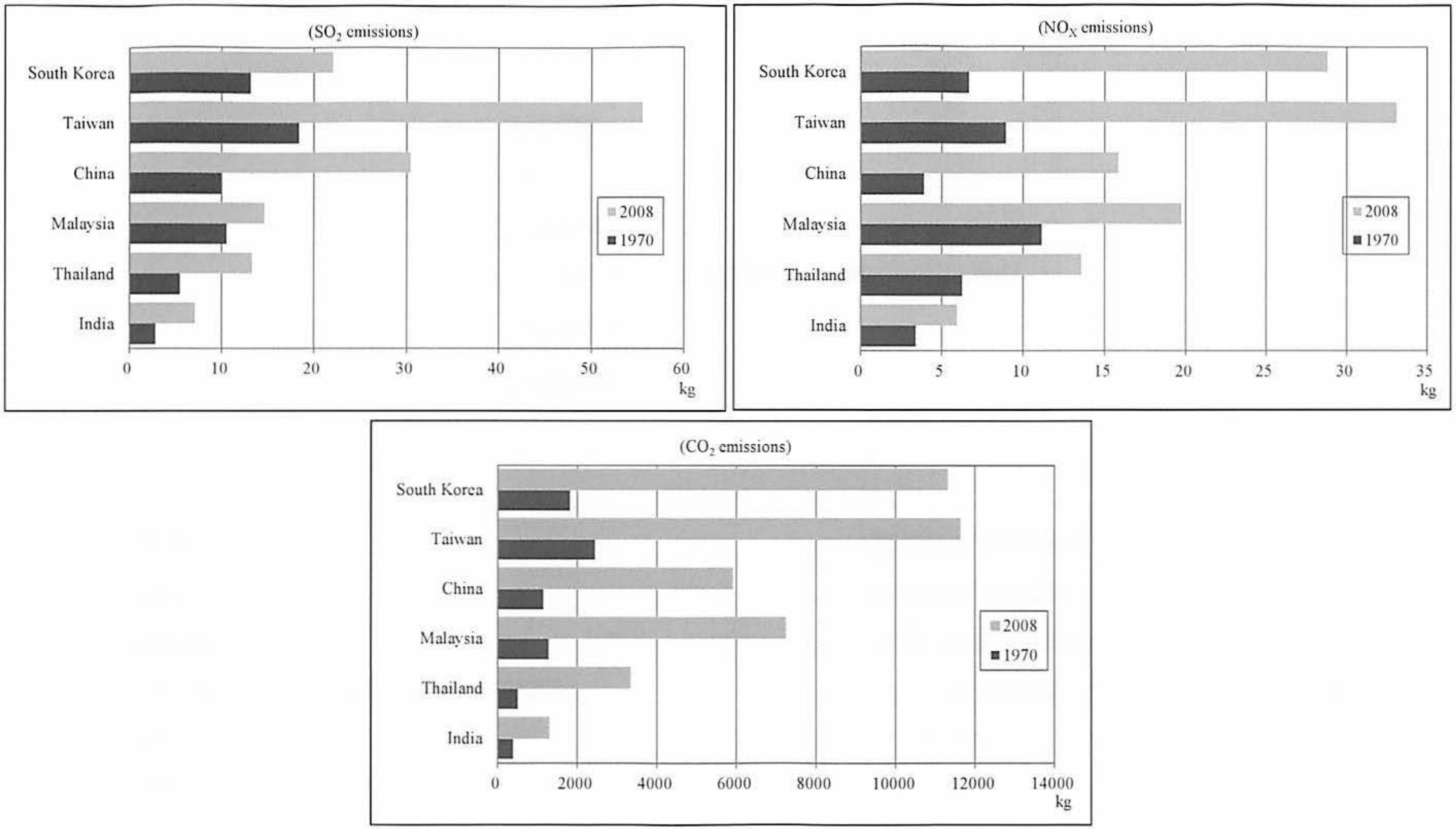
Several Asian countries have achieved rapid economic development and are growing faster than other developing countries. This phenomenon, known as the "East Asian Economic Miracle," was mainly led by the high economic growth of eight Asian economies: Japan, Hong Kong, South Korea, Singapore, Taiwan, Indonesia, Malaysia, and Thailand (World Bank, 1993). However, the rapid growth of the economy led to more rapid environmental pollution and environment constraints limited the growth and inflicted damage on people's lives (World Bank, 1992, 2009). Environmental pollution is a serious problem in Asian countries, increasing every year.

This paper analyzes the per capita sulfur dioxide (SO_2), nitrogen oxide (NO_X), and carbon dioxide (CO_2) emissions of South Korea, Taiwan, China, Malaysia, Thailand, and India in 1970 and 2008, as shown in Figure 1. Per capita emissions typically indicate the pollution level of a country and represent the real impact on the environment. A comparison of the 1970 and 2008 emission levels shows the latter much larger than the former in all Asian countries. Thus, the Asian environment has rapidly worsened with economic development. The highest pollution levels are found in South Korea and Taiwan, which have already become developed countries. China, Malaysia, and Thailand have also raised their pollution levels. However, a comparison of the pollution levels of these countries with that in India shows the disparity in pollution levels between Asian countries widening.

However, given that environmental pollution is a result of economic activity, the relationship between pollution emission and economic activity needs to be examined. Figure 2 shows the six Asian countries' emission intensities of SO_2, NO_X, and CO_2 for 1970 and 2008. Emission intensity is expressed as the pollution emitted per unit real Gross Domestic Product (GDP); this is a better indicator of environmental performance. From Figure 2, the emission intensities of these pollutants have declined sharply, except for that of CO_2 in Malaysia, Thailand, and India. Thus, the environmental performance of Asian countries, especially of China, has improved considerably.

Some previous studies analyzed the environmental performance of countries using different approaches, very often not simple indicators such as the above emission intensity. One such non-parametric approach is the Data Envelopment Analysis (DEA) method; this method is advantageous in that it does not specify the functional forms in estimation techniques but simultaneously accounts for multiple pollutions, instead of focusing on a single pollution. This study aims to evaluate the environmental performance of the above Asian countries by using this non-parametric DEA approach with time-series data from 1970 to 2008.

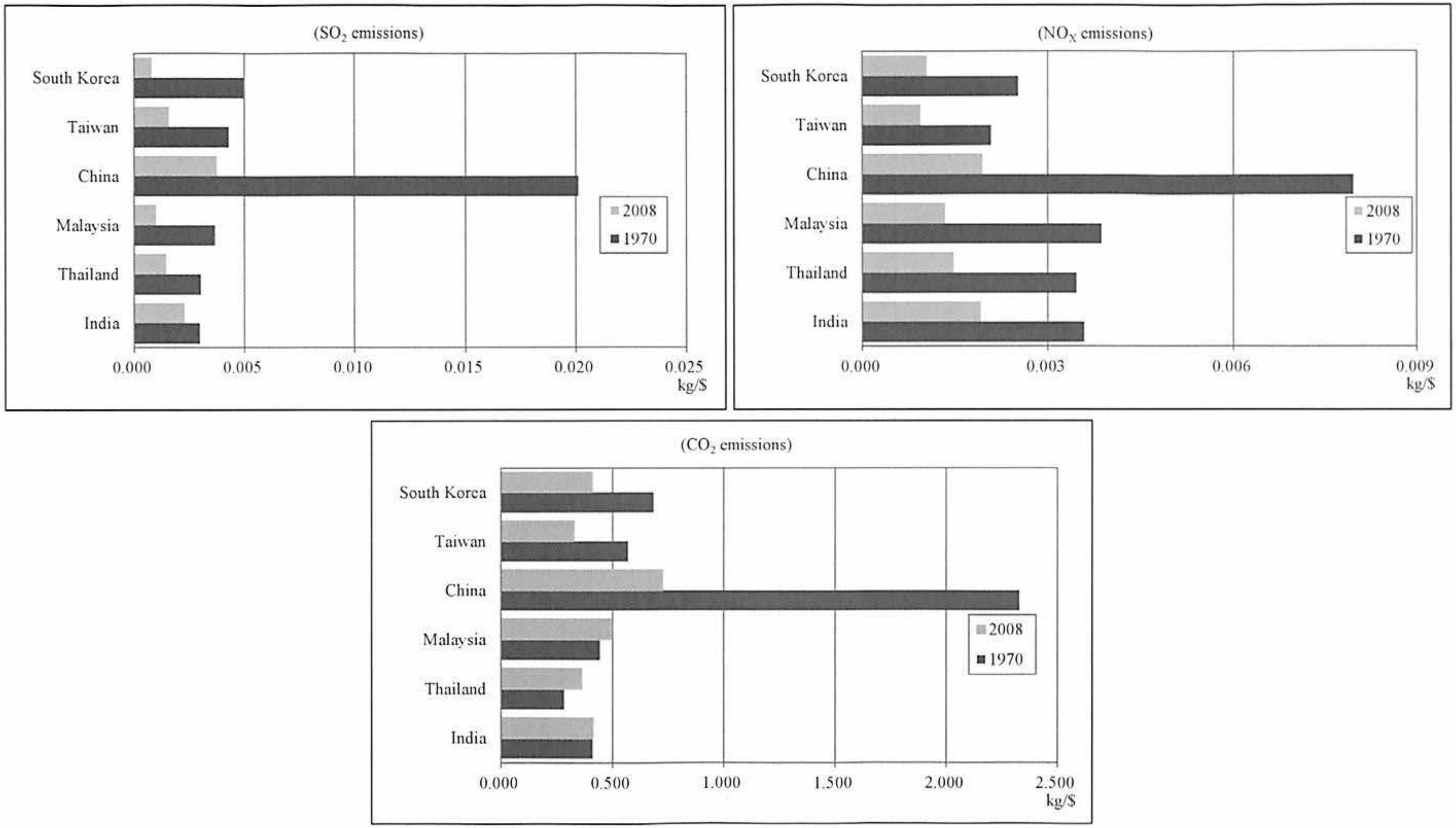
Figure 1. Per capita emissions of SO_2, NO_X, and CO_2 in six Asian countries for 1970 and 2008



Source: Author's calculations based on the EC-JRC/PBL. (2011). Emission Database for Global Atmospheric Research (version 4.2) and Feenstra et al. (2015). Penn World Table (version 8.1).

Note: The figure gives the ratio of total emissions and population.

Figure 2. Emission intensities of SO_2, NO_X, and CO_2 in six Asian countries for 1970 and 2008



Source: Author's calculations based on EC-JRC/PBL. (2011). Emission Database for Global Atmospheric Research (version 4.2) and Feenstra et al. (2015). Penn World Table (version 8.1).

Note: The figure gives the ratio of total emissions and real GDP at 2005 constant prices.

In a pioneering work, Färe et al. (1989) developed an environmental performance indicator using a non-parametric DEA approach. They explicitly assumed that an economically productive activity leads to desirable outputs such as value-added and collaterally undesirable outputs such as environmental pollution in a joint production. Furthermore, they assumed that pollution abatement is a pollution reduction cost, in an assumption of weak disposability. Thus, their work reflected a practical situation in the process of production.

Since then, many environmental performance indicators based on Färe et al. (1989) have been proposed; for example, see Färe et al. (1996), Tyteca (1997), Chung et al. (1997), Hernandez-Sancho et al. (2000), and Färe and Grosskopf (2003). Basically, these studies used a cross-section analysis. However, Färe and Grosskopf (2003) applied time-series analysis. This work uses time-series data and follows the method applied by Zaim (2004), which is a slightly modified version of the environmental performance index developed by Färe and Grosskopf (2003). Färe and Grosskopf's (2003) environmental performance index was constructed as the ratio between the desirable output and undesirable output quantity indices, as with the Hicks-Moorsteen productivity index. Zaim (2004) took the reciprocal of the environmental performance index as the emission intensity index in time-series analysis.[1]

Färe and Grosskopf (2003) estimated the time-series environmental performance index, simultaneously accounting for CO_2 emissions and solid particulate matter in 24 OECD countries for the period 1971－1990. They found that Iceland, Sweden, and France showed high performance levels whereas Mexico, Turkey, and Greece showed low performance levels.[2] Further, Shimizu (2014) estimated the time-series emission intensity index based on Zaim (2004), simultaneously accounting for carbon (CO_2) and sulfur emissions in Japan, the United States, and the United Kingdom for the long-run period 1890－1992. The study found that the emission intensity indices of these three countries were at their highest level before the Second World War but then tended to decline remarkably. Japan showed the highest performance among the three countries.[3]

As mentioned above, previous empirical studies focused solely on the developed countries. This paper uses a non-parametric DEA approach to estimate the emission intensity index as a measure of environmental performance for South Korea, Taiwan, China, Malaysia, Thailand, and India. This work simultaneously accounts for the emissions of SO_2, NO_X, and CO_2 and applies country-level time-series data for the period 1970－2008. The paper analyzes the emission intensity indices of the six Asian countries and provides future policy guidelines to sustain a desirable relationship between economic development and environmental performance for policy makers. The rest of the paper is organized as follows: Section II presents the estimation model for the emission intensity index. Section III describes the data used in the study. Section IV reports the empirical results. Finally, Section V summarizes the

[1] Zaim (2004) estimated the emission intensity index of the U.S. manufacturing sectors by state using both the time-series and cross-section analyses for the period 1972－1986.

[2] Färe et al. (2004) applied cross-section analysis on the data of 17 OECD countries for 1990. Thus, the cross-section environmental performance index, which includes simultaneous emissions of sulfur oxides (SO_X), NO_X, and CO_2, showed that France and Sweden are the best performers. Likewise, Yörük and Zaim (2006) estimated the index for CO_2 and water pollutant (WP) emissions in 27 OECD countries for the period 1983－1998. They indicated that Poland, Hungary, and Luxembourg are the best performers.

[3] In addition to the study, Yörük and Zaim (2008) estimated the cross-section emission intensity index for 28 OECD countries for the period 1983－1998. Their indices simultaneously accounted for CO_2 and NO_X emissions, CO_2 and WP emissions, and NO_X and WP emissions. They confirmed that Poland is the best performer.

conclusions of this work and proposes policy implications.

II. Model

Following Zaim (2004), which is based on Färe and Grosskopf (2003), this study considers the time-series emissions intensity indices of six Asian countries to measure their environmental performance. Assume that the production technology $T = \{(x, y, b)$: x can produce $(y, b)\}$, where the vector of production factors (inputs) is $x = (x_1, \cdots, x_N) \in R^N_+$, the vector of desirable outputs is $y = (y_1, ..., y_M) \in R^M_+$, and the vector of undesirable outputs is $b = (b_1, ..., b_J) \in R^J_+$. Since the technology is assumed to satisfy joint production, the null-jointness condition holds in the production process as follows:

$$\text{if } (x, y, b) \in T \text{ and } b = 0, \text{ then } y = 0,$$

where undesirable outputs are not emitted and desirable outputs are not necessarily produced. This technology is assumed to satisfy weak disposability as follows:

$$\text{if } (x, y, b) \in T \text{ and } 0 \leq \theta \leq 1, \text{ then } (x_n, \theta y, \theta b) \in T.$$

Thus, if the undesirable outputs are reduced, the desirable ones too must be reduced simultaneously at the same rate. Therefore, the pollution reduction cost can be measured by the decreased production of desirable outputs. In addition to the two technology properties, this study imposes closedness and convexity in the technology.

To construct the quantity indices of both desirable and undesirable outputs, the output distance function D_y on the desirable outputs and the input distance function D_b on the undesirable ones are defined, respectively, as follows:

$$D_y(x, y, b) = \inf \{ \theta : (x, y/\theta, b) \in T\}.$$
$$D_b(x, y, b) = \sup \{ \lambda : (x, y, b/\lambda) \in T\}.$$

The output distance function D_y represents the desirable outputs that can be increased when the undesirable outputs and factor inputs are kept constant, and the input distance function D_b reflects the undesirable outputs that can be reduced when the desirable outputs and factor inputs are kept constant. The output and input distance functions are homogeneous of degree +1 in both the desirable and undesirable outputs.

Using the two distance functions, this study constructs the quantity indices of desirable outputs Q_y and undesirable outputs Q_b as follows:

$$Q_y(x^o, b^o, y^k, y^l) = \frac{D_y(x^o, y^k, b^o)}{D_y(x^o, y^l, b^o)}$$

$$Q_b(x^o,y^o,b^k,b^l)=\frac{D_b(x^o,y^o,b^k)}{D_b(x^o,y^o,b^l)}$$

The two quantity indices satisfy certain properties such as homogeneity, time reversal, transitivity, and dimensionality (Färe and Grosskopf, 2003). The quantity index of desirable outputs Q_y indicates whether the desirable outputs' production efficiency for observation k improves compared to that for observation l, which holds the inputs and undesirable outputs in observation o. Similarly, the quantity index of undesirable outputs Q_b indicates whether the environmental efficiency of undesirable outputs for observation k improves compared to that for observation l, which holds the inputs and desirable outputs in observation o.

Using the two quantity indices, Zaim (2004) derives the emission intensity index EI as follows:

$$EI^{k,l}(x^o,y^o,b^o,y^k,y^l,b^k,b^l)=\frac{Q_b(x^o,y^o,b^k,b^l)}{Q_y(x^o,b^o,y^k,y^l)}$$

Therefore, to improve environmental performance, the emission intensity index EI must become smaller.

This paper computes both the output and input distance functions using the DEA approach. Let the $k=(1,\cdots,K)$ index be represented by the year in the sample. For each year $k'=1,\cdots,K$ in each studied country, the paper solves the output and input distance functions using two linear programming problems as follows:

$$\left(D_y\left(x^o,y^{k'},b^o\right)\right)^{-1}=\max\theta$$

st

$$\sum_{k=1}^{K} z_k y_m^k \geq \theta y_m^{k'} \quad m=1,\ldots,M$$

$$\sum_{k=1}^{K} z_k b_j^k = b_j^o \quad j=1,\ldots,J$$

$$\sum_{k=1}^{K} z_k x_n^k \leq x_n^o \quad n=1,\ldots,N$$

$$z_k \geq 0 \qquad k=1,\ldots,K,$$

$$\left(D_b\left(x^o,y^o,b^{k'}\right)\right)^{-1}= \min \lambda$$

st

$$\sum_{k=1}^{K} z_k y_m^k \geq y_m^o \quad m=1, ..., M$$

$$\sum_{k=1}^{K} z_k b_j^k = \lambda\, b_j^k \quad j=1, ..., J$$

$$\sum_{k=1}^{K} z_k x_n^k \leq x_n^o \quad n=1, ..., N$$

$$z_k \geq 0 \qquad k=1, ..., K$$

The strict equality on undesirable output constraints is assumed to impose weak disposability, but the null jointness is assumed as follows:

$$\sum_{k=1}^{K} b_j^k > 0 \qquad j=1, ..., J$$

$$\sum_{j=1}^{J} b_j^k > 0 \qquad k=1, ..., K.$$

This work estimates the emission intensity index with time-series data. However, some previous studies have shown that linear programming is a problem with infeasible solution. To avoid this problem, this study sets a hypothetical year as reference to reflect the minimum desirable outputs as well as maximum undesirable outputs and inputs, referring to Färe et al. (2004). Thus, this paper assumes that observation l is observation o, which refers to the above hypothetical year. The study obtains the emission intensity index by comparing the selected year with the hypothetical reference year.

III. Data

To estimate the emission intensity index, this study applied country-level time-series data of six Asian countries for the period 1970－2008. The data are obtained from two databases, the Penn World Table (PWT 8.1) of Feenstra et al. (2015) and the Emission Database for Global Atmospheric Research (EDGAR v4.2) of the European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL) (2011). This work considered one desirable output, three undesirable outputs, and two inputs. The details of the time-series data used are explained below. The descriptive statistics of the variables are summarized in Table 1.

- Desirable output: real GDP at 2005 prices by PWT 8.1.

- Undesirable outputs: SO_2, NO_X, and CO_2 emissions based on EDGAR v4.2. These emissions arise from fuel combustion, industrial processes, product use, and agriculture.

- Inputs: real capital stock at 2005 prices by PWT 8.1. Labor is quality-adjusted and estimated by multiplying the human capital per person index by the number of persons engaged. The data on human capital per person index and number of persons engaged are derived from PWT 8.1.

Table 1. Descriptive statistics of variables

	GDP (millions 2005US$)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	548443	358337	2849158	166680	284457	1440427
Std. dev.	392225	235588	2785728	110955	177800	903340
Min	83158	62578	394344	31403	66945	525547
Max	1315581	811248	10611006	404758	626716	3703562
	Labor (quality-adjusted)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	49	22	1242	17	56	509
Std. dev.	17	7	439	8	18	198
Min	20	9	545	6	29	225
Max	77	33	1959	32	91	884
	Capital stock (millions 2005US$)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	1570258	670647	8172844	456558	982840	2794611
Std. dev.	1429448	563071	7923435	362644	669780	1769507
Min	136275	55890	1229130	55355	163794	1003497
Max	4637753	1787364	30813352	1192412	2121024	7771351
	SO_2 emissions (Gg)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	1150	791	18261	271	639	3919
Std. dev.	440	361	7419	90	327	1984
Min	413	268	7938	112	198	1555
Max	2009	1370	39698	416	1178	8493
	NO_X emissions (Gg)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	955	479	9094	333	580	3742
Std. dev.	577	253	4539	155	271	1594
Min	208	130	3139	99	196	1856
Max	1884	884	20690	569	953	7105
	CO_2 emissions (Gg)					
	South Korea	Taiwan	China	Malaysia	Thailand	India
Mean	272456	139080	2814848	72307	103391	670913
Std. dev.	165551	82095	1715987	56434	76014	389463
Min	57052	35706	919109	13983	19082	216498
Max	539674	279622	7709318	198916	226989	1530495

IV. Empirical results

Table 2 and Figure 3 report the estimation results of the time-series emission intensity index based on the desirable and undesirable output quantity indices in South Korea, Taiwan, China, Malaysia, Thailand,

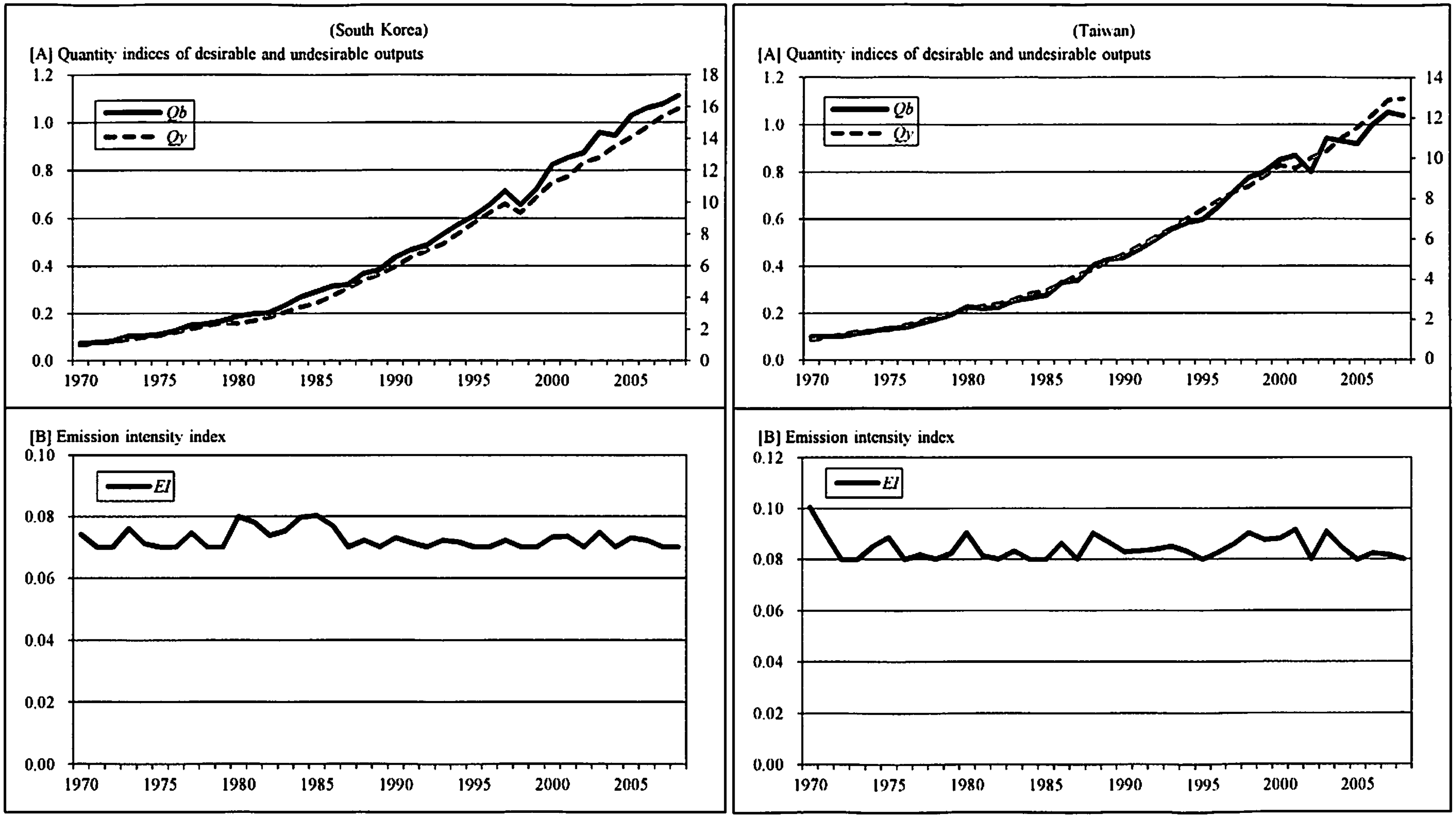
and India for the period 1970−2008. These indices simultaneously account for SO_2, NO_X, and CO_2 emissions. In Table 2, these indices of each country calculate the geometric mean for the 1970s (1970−1979), 1980s (1980−1989), 1990s (1990−1999), and 2000s (2000−2008). Figure 3 shows the long-run changes in these indices for the six Asian countries from 1970 to 2008.

Table 2 shows that the quantity index of undesirable outputs is highest in Thailand among the six Asian countries from the 1970s to the 2000s. However, the quantity index of desirable outputs is gradually increasing in all countries, with the index of China particularly high in the 2000s. Thus, the emission intensity index is the lowest in China and highest in Thailand. This indicates that China is the best performer whereas Thailand is the worst.

Table 2. Geometric means of emission intensity index

	South Korea		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	0.1108	1.5484	0.0716
1980–1989	0.2686	3.5564	0.0755
1990–1999	0.5761	8.1108	0.0710
2000–2008	0.9655	13.4403	0.0718
	Taiwan		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	0.1306	1.5445	0.0846
1980–1989	0.2886	3.4468	0.0837
1990–1999	0.5989	7.0979	0.0844
2000–2008	0.9302	11.0410	0.0842
	China		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	0.0598	1.2767	0.0468
1980–1989	0.1076	2.8038	0.0384
1990–1999	0.2836	7.2464	0.0391
2000–2008	0.6700	17.5608	0.0382
	Malaysia		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	0.1286	1.6075	0.0800
1980–1989	0.2494	3.1242	0.0798
1990–1999	0.5167	6.3088	0.0819
2000–2008	0.8133	10.4065	0.0782
	Thailand		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	1.3925	1.3226	1.0528
1980–1989	2.5790	2.5272	1.0205
1990–1999	5.7286	5.4686	1.0475
2000–2008	8.4185	7.8346	1.0745
	India		
	Quantity index of undesirable outputs	Quantity index of desirable outputs	Emission intensity index
1970–1979	0.1650	1.1232	0.1469
1980–1989	0.2806	1.7115	0.1639
1990–1999	0.5288	2.9535	0.1790
2000–2008	0.7893	5.2671	0.1499

Figure 3. Long-run changes in emission intensity index of the Asian countries for 1970–2008



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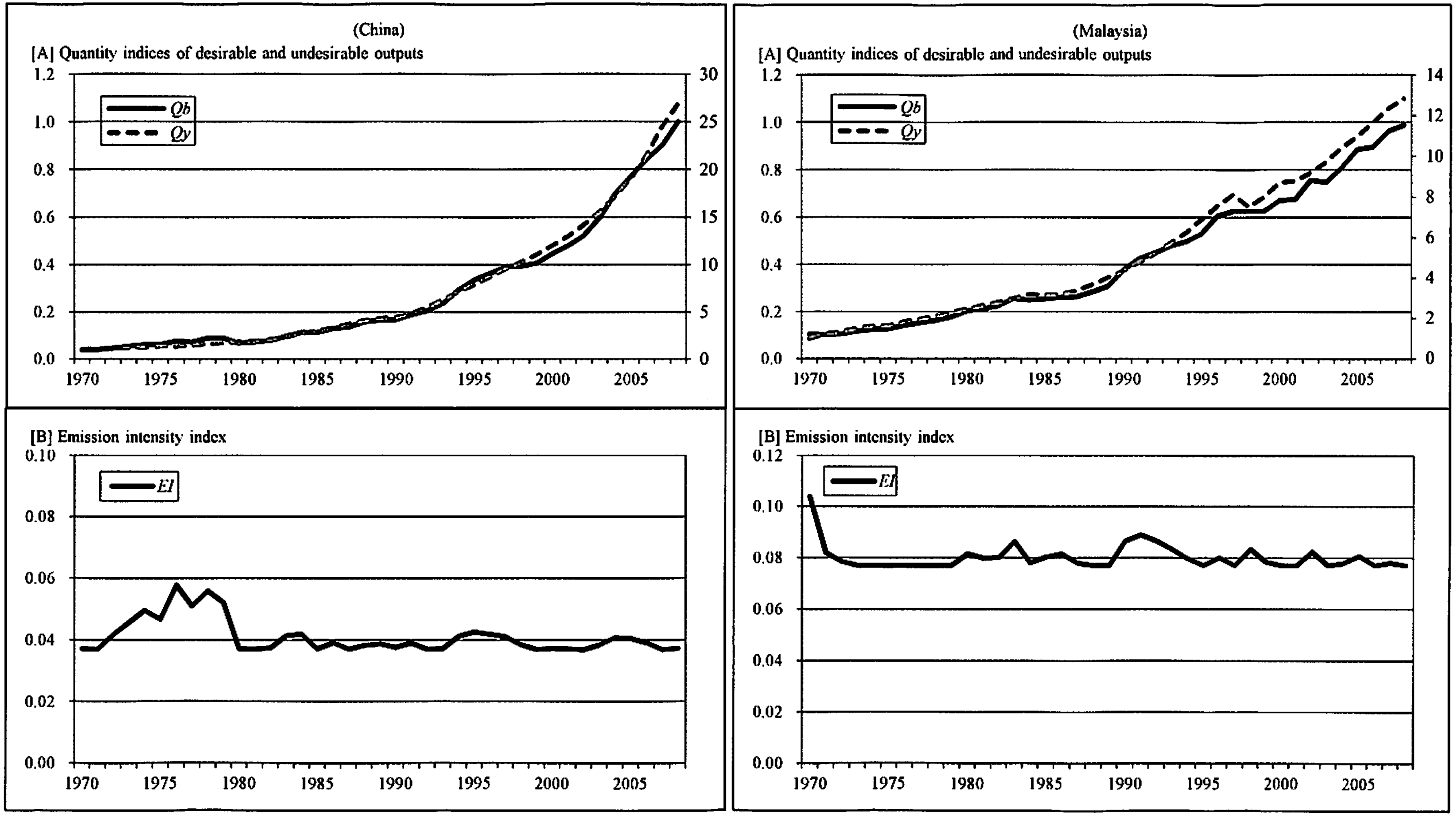

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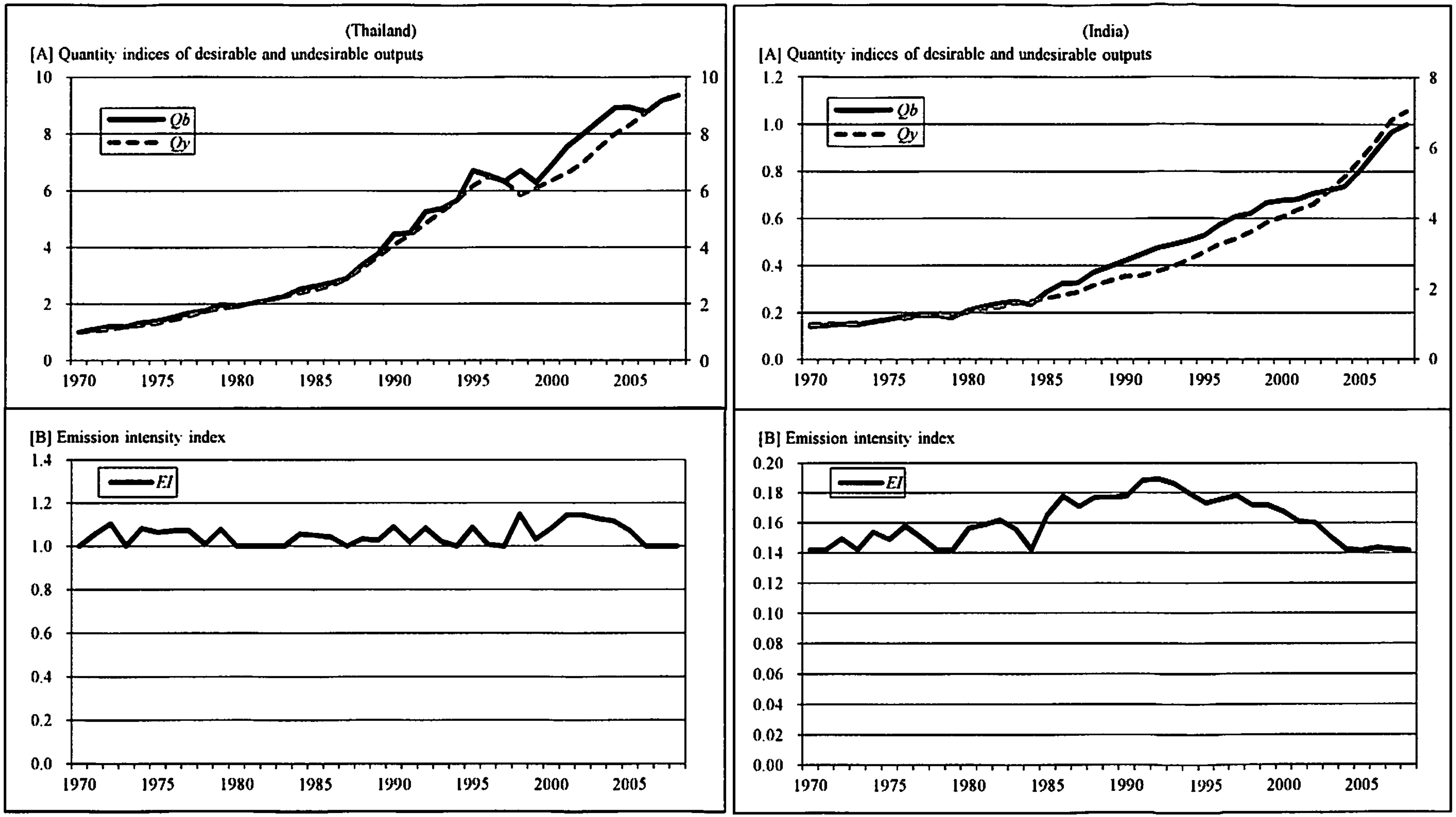


Note: The left axis shows the quantity index of undesirable outputs, whereas the right axis shows the quantity index of desirable outputs.

Figure 3 shows that the quantity index of undesirable outputs has increased steadily since the 1970s for all the six Asian countries. This means that these countries emitted far more undesirable outputs compared to the reference year, indicating the Asian environment gradually worsened since the 1970s. However, the quantity index of desirable outputs for all these countries shows a dramatic increase, indicating that that these countries efficiently produced more desirable outputs compared to the reference year, thus promoting economic growth.

Figure 3 shows the emission intensity index for each country from 1970 to 2008 based on both desirable and undesirable quantity indices. South Korea and Thailand do not show a clearly increasing or decreasing trend. Likewise, the indices of Taiwan and Malaysia declined in the early 1970s but then stayed almost unchanged. Thus, the environmental performance of these four countries shows no large improvement since the 1970s. However, this is not the case for simple emission intensity.

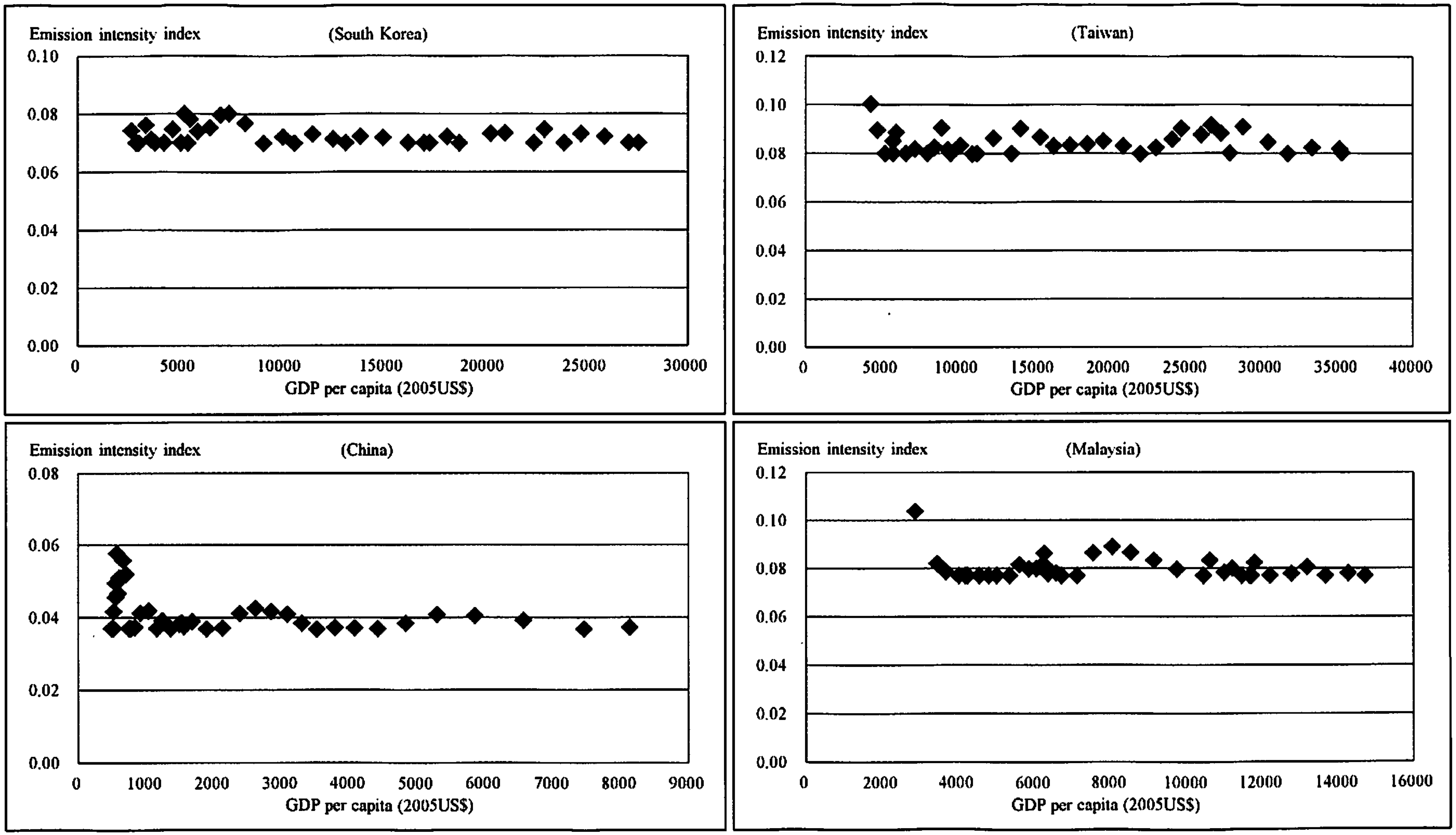
However, the indices of China and India increased before they launched their economic reforms, which was started in 1979 and 1991, respectively. After the economic reforms, the Chinese index declined slightly and then leveled off, but the Indian index shows a decreasing trend. Thus, the environmental performance of China and India has moved from declining to improving trends.

V. Conclusions

This study tried to evaluate the environmental performance of Asian countries using the non-parametric DEA approach. The results have shown a high performance level for China but a low performance level for Thailand. Furthermore, the study has confirmed that the examined six Asian countries have improved their production efficiency from the 1970s to the 2000s, although their environmental efficiency deteriorated during the period. Thus, the improvement of production efficiency has been offset by the deterioration of environmental efficiency. Hence, the emission intensity index has stayed almost unchanged for South Korea, Taiwan, China, Malaysia, and Thailand. Although the index has shown decreasing trends for India, there is a possibility that it would stabilize over time as in China. Figure 4 shows the relationships between emission intensity index and economic development measured by GDP per capita. The emission intensity index tends to stabilize with income growth. Thus, the six Asian countries have a strong incentive to promote production efficiency without increasing environmental efficiency. This result suggests that these countries prioritize the promotion of economic growth rather than the reduction of environmental pollution.

However, this paper reserves certain tasks for the future. Since the study analyzed the emission intensity index relating to only waste gas emissions, it would be worthwhile in a future research to examine the emission intensity index for other environmental pollutants such as wastewater and solid waste. Furthermore, this work considered only six Asian countries and did not study the other developing countries. A future research should clarify whether the findings of this study would apply to other developing countries as well and help understand the generality of changes in environmental performance.

Figure 4. Relationships between emission intensity index and per capita GDP in Asian countries, 1970–2008



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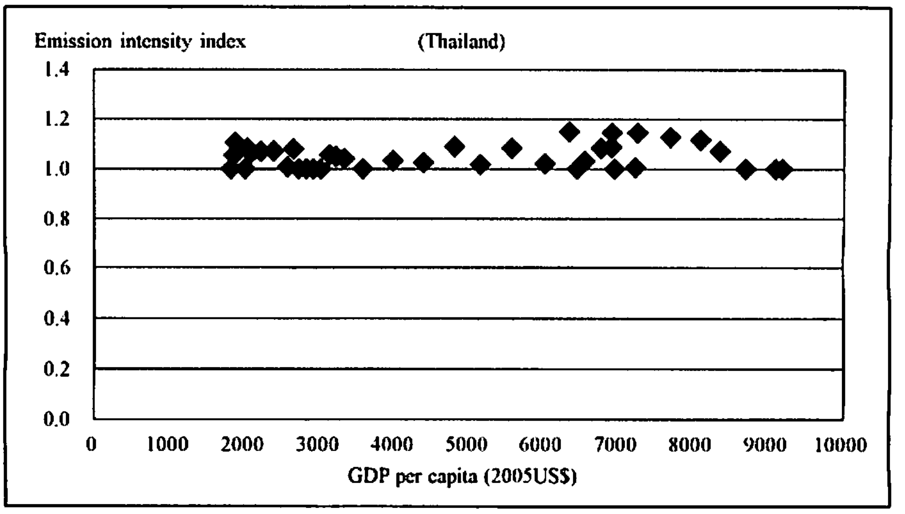

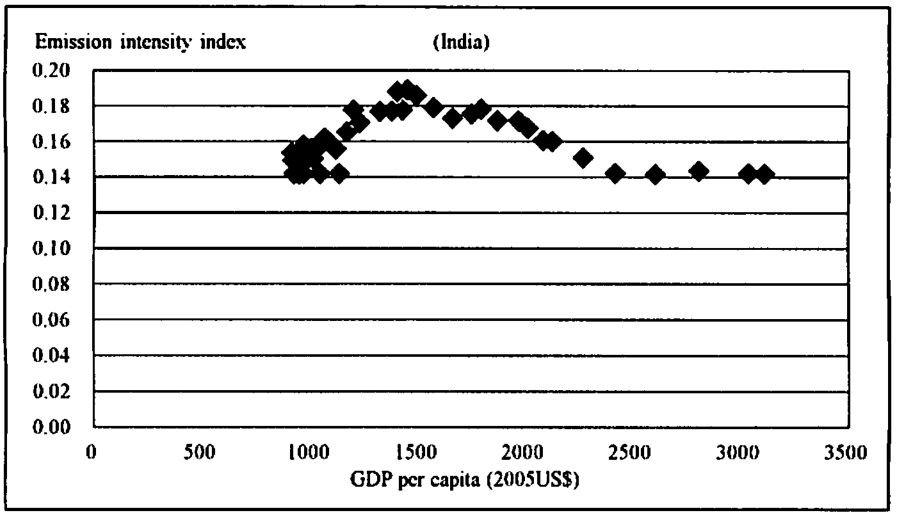

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