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Multi-country Comparative Analysis Based on the Environmental Efficiency

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Foreword

While environment becoming a hot issue, there have been broad discussions about relationship between economic growth and environmental degradation. In modern society, policy-maker can't make a plan an economic and environmental polity without considering environmental condition. Therefore, if we considering environmental condition, we need to study how changes occurred for economic growth at this point.

The studies that were published about relationship between economic growth and environmental degradation mainly have focused on developing indicators such as Sustainable Development Indicators or studying Environmental Kuznets Curve about relationship economic growth and environmental quality. But the relationship between economic growth and environment differ in national competitive power and pollution level of main industry. Also, as we know in indexation work about Sustainable Development, though a various indicator systems have been developed up to now, there is no the standardized indicator system that can be connected with both economic growth and environmental quality.

Product efficiency or improvement of productivity considering an environmental factor is one of the important indicators that measure the national competitive power. Thus, measurement of product efficiency and productivity considering and environmental factor needs at this point.

Therefore, this study estimates efficiency and output loss including environmental regulation by using Environmental Efficiency Index, and forecasts each country's environmental efficiency level though multi-country comparative analysis.

Environmental Efficiency Index, when authorities have a decision-making about economic or environmental policies, will provide an critical information with human activity, and will play a key role in understanding the national environment condition. Also, it will be used in estimating and promoting the national development for sustainable future.

This study will be important fundamental material in research about economic growth considering environmental factors. Based on the analysis of Environmental Efficiency Index by each nation, environmental efficiency by industry of each nation could be estimated for the future. Also, study about Environmental Kuznets Curve between Environmental

Efficiency Index and economic growth will be a meaningful research.

Finally, I would like to thanks to Dr. Young Keun CHUNG and Mr. Jun LEE of KEI for their efforts. My special thanks goes to Dr. Sang Mok KANG in Pusan University for their excellent contribution to this study.

The views expressed herein are those of the authors and not necessarily those of the Korea Environment Institute.

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Abstract

Growing demands for environmental quality force the policy-makers to consider the environmental impacts of their choices in the formation of economic policies. The objective of this study is to evaluate each country's sustainability, by using the multi-country comparative analysis based on the Environmental Efficiency Index (EI). Product efficiency or improvement of productivity considering an environmental factor is one of the important indicators that measure the national competitive power. These new indicators can provide critical information to the government in the implementation of industrial and regulation policies.

This study estimates efficiency and an output loss including environmental regulation, and analyzes the Environmental Efficiency Index empirically, then forecasts each country's sustainability level through multi-country comparative analysis.

Environmental efficiency index can be constructed by comparing the production processes under alternative assumptions of disposability, by using a hyperbolic measure of productive efficiency. A hyperbolic measure of productive efficiency is a method that can increase production and at the same time, decrease pollutants simultaneously. This measure regards a product unit that achieved more output and less pollutant at the same time as the high efficiency level. It is a measure of productive efficiency that anticipates a simultaneous success of the growth and environment and corresponds to the concept of sustainable development.

To estimate environmental efficiency level of each country including an environmental regulation, the technology efficiency of production was divided into two classes-Strong disposability and Weak disposability.

Strong disposability means that a producer can produce a product only by considering the cost about output without additional cost that is caused by a regulation and restriction. On the other hand, weak disposability means that a producer considers an additional pollutant treatment cost with production cost. This analysis of efficiency shows how the environmental factor or the change of output affects productivity respectively.

To develop an environmental efficiency index, we used cross-section data on all countries to solve the linear programming problems for each country. The solutions determine the efficiency for each country for a given year, with respect to two OECD multi-output production frontiers

constructed under alternative disposability assumptions for the undesirable output. The ratio of the two efficiency scores gives an index of the environmental efficiency for a given years. This computation is repeated for each year from 1985 to 1999 in order to analyze the development of environmental efficiency over time.

The results indicate that the Environmental Efficiency Index of OECD countries gradually show a downward trend. In the model that includes all kinds of pollutants, the analysis of the efficiency scores indicates that the efficiency in the latter half of the 1990's is lower than the efficiency in the latter half of the 1980's. In terms of the treatment of pollutants, Japan, Germany and France are countries that have a considerable burden in getting rid of pollutants. In particular, Japan is a country that would assume the largest share due to this transformation. In case of Korea for estimation of environmental efficiency index, the result shows that Korea displayed excellent environmental efficiency, but in the latter half of the 1990's (Ⅲ period), the environmental efficiency of Korea became slightly worse. During the same period, Korea had a burden in dealing with NOx just like the other OECD countries.

The results of this study reveal that as far as the environmental regulations or the pollutant treatment costs are concerned, environmental efficiency in Korea is not so bad compared with the other countries. However, there are some points to be improved about environmental efficiency.

Therefore, the manufacturing industry or the pollution industries need to transform into environmentally friendly production process, and be concerned about the treatment of NOx particularly. For the sustainable and environmentally friendly economic growth, under the basis of this study, the level of pollutant emissions was refrained strongly. And it is necessary to study the case of countries that shows the high environmental efficiency in same condition as compared with our country.

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Chapter 1. Introduction

1. Backgrounds and Objective of Study

In recent year, the relationship between economic growth and environmental pollution has been focus of many studies. Growing demands for environmental quality forces policy-makers to consider the environmental impacts of their choice in the formulation of economic policies. As environmental concerns are pronounced increasingly in relation to global commons, environmental issues are treated as international matters. This requires countries to measure, document and publish information about their environmental performance. Hence as an initial step the accurate assessment of environmental conditions is essential.

Early work, involving cross country comparisons of the environmental performance, was based on either descriptive environmental indicators, such as measures of soil salinization, dissolved oxygen in water, and suspended particular matter in air, or indicator system evaluated performance-based environmental indicators which are measured against some physical threshold or normative policy goal.

Therefore, comprehensive evaluation about not only environment state at national level but also economic, social and institutional sectors needed. For this, each international organization and nation including the UN and OECD had developed indicators or indices for evaluation of nation that performed environmental policy. Examples include the Environmental Sustainability Index(ESI) and Sustainable Development Indicators(SDIs).

But ESI and SDIs have disadvantage because they unified a wide area including social, economic and environmental sectors in the developing process. So it is necessary to develop an objective and empirical indicator system that can evaluate the national state considering both economic element and environmental element.

The objective of this study is to evaluate the Environmental-Efficiency Index(EI) considering environment and economy simultaneously and to analyze the EI of the OECD countries. Because the efficiency of production and the improvement of productivity play a major role in economic growth, the evaluation on production efficiency and productivity considering environmental element could be one of the most important indicators that measured the national competitive power. Through these new indicator developments, the nation can decide a policy on economic growth and improvement of environment easily, and new indicator can provide industry policy and environmental regulation of government with important information.

The process of this study is two-fold. First, to estimate the EI of the OECD countries based on each country's technical efficiency and output loss. Second, to evaluate output loss caused by being more efficient in a environment viewpoint.

2. Contents and Methods of the Study

This study estimates efficiency and an output loss including environmental regulation, and analyzes the Environmental Efficiency Index empirically, then forecasts each country's sustainability level through multi-country comparative analysis.

Environmental efficiency index can be constructed by comparing the production processes under alternative assumptions of disposability, by using a hyperbolic measure of productive efficiency. A hyperbolic measure of productive efficiency is a method that can increase production and at the same time, decrease pollutants simultaneously. This measure regards a product unit that achieved more output and less pollutant at the same time as the high efficiency level. It is a measure of productive efficiency that anticipates a simultaneous success of the growth and environment and corresponds to the concept of sustainable development.

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To measure technology efficiency under the environmental regulation, this study used the productive efficiency function that Zaim and Taskin(2000) and Kang(2003) had designed. But this study is different from preceding studies in that the principal pollutant (CO_2, SOx, NOx) is included wholly.

Chapter 2. Model for Estimating Environmental Efficiency

In the context of pollution emissions, environmental efficiency considerations have been taken into account by studies that employ production frontiers techniques. These studies, for which a comprehensive literature survey can be found in Tyteca (1996), mainly concentrated on the analysis of micro level data. For example Fare et al. (1986) examined the impact of environmental regulation on the relative efficiency of US steam electric utilities. Fare et al. (1989b) investigated the magnitude and the sources of relative efficiency changes in the electric utilities before and after regulatory measures are taken. Fare et al. (1989a) investigated the regulatory impact in a sample of 30 US paper mills in 1976. Fare et al. (1996) and Tyteca (1997) developed an environmental performance indicator based on the decomposition of factor productivity into a pollution index, and an input-output efficiency index with an application to data from US fossil fuel-fired electric utilities.[1]

The most important factor using in this study is whether there is technology restrictions accompanying disposability of output and pollutants. Especially, in case pollutants were included in outputs, the gap of outputs and pollutants is different from their disposability. Fare et al(1989), Boyd & McClelland(1999), Zaim & Taskin(2000), Sancho(2000) and Zofio & Prieto(2001) adopted strong and weak disposability based on disposability of pollutants. This study adopts their model and theory.

To describe the theoretical background of the model used, suppose we observe a sample of K production unit, each of which uses inputs $x \in R_+^N$ to produce desirable outputs $y \in R_+^M$, and undesirable outputs $w \in R_+^J$. As a matter of notation let x_i^k be the quantity of input i used by unit k and let y_i^k, and w_i^k be the quantity of desirable and undesirable output i produced by unit k, respectively.

These data can be placed into data matrixes Y, K×Y matrix of desirable output levels whose k, i^th element is y_i^k, W, a K×W matrix of undesirable output levels whose k, i^th element is w_i^k, and X, a K×X matrix of input levels whose k, i^th element is x_i^k. Using the notation, and

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[1] O, Zaim & F. Taskin (2000). “Environmental Efficiency in Carbon Dioxide Emissions in the OECD: A Nonparametric Approach”. Journal of Environmental Management. Vol 58. pp 95-107

assuming that the production process satisfies strong disposability of both outputs (good and bad) and inputs, the Constant Returns to Scale(CRS) output set $F^S(X)$, which denotes the collection of all output vectors $y \in R_+^M$ and $w \in R_+^J$ that are obtainable from the input vector $x \in R_+^N$, can be constructed from observed data by means of:

$$F^S(x) = \{(y, w) : ZY \geq y, ZW \geq w, ZX \leq x, Z \in R_+^K\}$$

where Z is a K×1 intensity vector which serves to construct the boundary of the strongly disposable output set from the convex combinations of the observed inputs and outputs.

Similarly, a CSR technology satisfying the weak disposability of undesirable outputs and strong disposability of desirable outputs and inputs can be represented as an output set as shown below:

$$F^W(x) = \{(y, w) : ZY \geq y, ZW = w, ZX \leq x, Z \in R_+^K\}$$

where the equality $ZW = w$, implies that undesirable outputs in W are not disposable freely, permits to decrease pollutants to the some extent. This equation can use measuring the effect of environmental regulation considering environment factors.

This study suggested two major methodologies (radial efficiency measure based on inputs efficiency function and hyperbolic efficiency measure based on productive efficiency function) that measured the technology efficiency of productive including the environment factors.

In the inputs efficiency measure, because the optimum level that only inputs and pollutants of production unit could be minimized was measured, the radial efficiency measure was adopted. On the other hand, like the preceding study of Boy & McClland(1999) and Zaim & Taskin(2000), suppose we can control the output of production unit and inputs at the same time, we can measure the productive efficiency maximizing the output, but minimizing the inputs and pollutants. In the productive efficiency measure, the optimal efficiency level was measured by level minimizing the pollutants and inputs and maximizing the output simultaneously. Therefore, the hyperbolic efficiency measure was adopted by suitable methodology to evaluate the reciprocal movement between outputs and inputs, pollutants.

1. Hyperbolic Efficiency Measure

The hyperbolic graph measure of technical efficiency seeks the maximum simultaneous equiproportionate expansion for the desirable outputs, and contraction for the inputs and undesirable outputs.

For a CRS technology, which satisfies strong disposability and weak disposability of inputs and outputs, hyperbolic graph measure of technical efficiency measure is defined as:

$$E_p^w(x^k, y^k, w^k) = \min\{\beta^W : (\beta^W x^k, (\beta^W)^{-1} y^k, \beta^W w^k) \in F^W(x)\}$$
$$E_p^S(x^k, y^k, w^k) = \min\{\beta^S : (\beta^S x^k, (\beta^S)^{-1} y^k, \beta^S w^k) \in F^S(x)\} \quad (1)$$

E_P^W and E_P^S, the productive efficiency function is efficiency function about weak disposability and strong disposability, then that technology efficiency level is β^W and β^S, respectively. The optimal solution, β^W and β^S computed by using the linear programming problem are estimated from a value 0 to a value 1 like the technology level of inputs efficiency function. The closer to a value 1, the better efficient is regarded. A value 1 is the optimal productive efficiency. For each technology efficiency level β^W and β^S it can be computed as the solution to the following programming problem:

$$E_P^W(x^k, y^k, w^k) = \min \beta^W$$

subject to LP1:

$$(\beta^W)^{-1} y^k \le \sum_{k=1}^{K} Z^k Y^k$$
$$\beta^W w^k = \sum_{k=1}^{K} Z^k W^k$$
$$\beta^W x^k \ge \sum_{k=1}^{K} Z^k X^k$$
$$Z^k \ge 0 \quad (2)$$

$$E_P^S(x^k, y^k, w^k) = \min \beta^S$$

subject to LP2:

$$(\beta^S)^{-1} y^k \le \sum_{k=1}^{K} Z^k Y^k$$
$$\beta^S w^k \le \sum_{k=1}^{K} Z^k W^k$$
$$\beta^S x^k \ge \sum_{k=1}^{K} Z^k X^k$$
$$Z^k \ge 0 \qquad (3)$$

For computational purposes it is necessary to convert these non-linear programming problems in LP1 and LP2 into linear programming problems. For conversion, β is multiplied in either side of equation (2) and (3), respectively. Through the following process $\Theta^W = (\beta^W)^2$, $\Theta^S = (\beta^S)^2$ and $Z' = Z\beta$, we derive new linear programming problems as the equation (4) and (5) from these conversion process.

$$(E_P^W(x^k, y^k, w^k))^2 = \min \Theta^W$$

subject to LP3:

$$y^k \le \sum_{k=1}^{K} Z'^k Y^k$$
$$\Theta^W w^k = \sum_{k=1}^{K} Z'^k W^k$$
$$\Theta^W x^k \ge \sum_{k=1}^{K} Z'^k X^k$$
$$Z'^k \ge 0 \qquad (4)$$

$$(E_P^S(x^k, y^k, w^k))^2 = \min \Theta^S$$

subject to LP4:

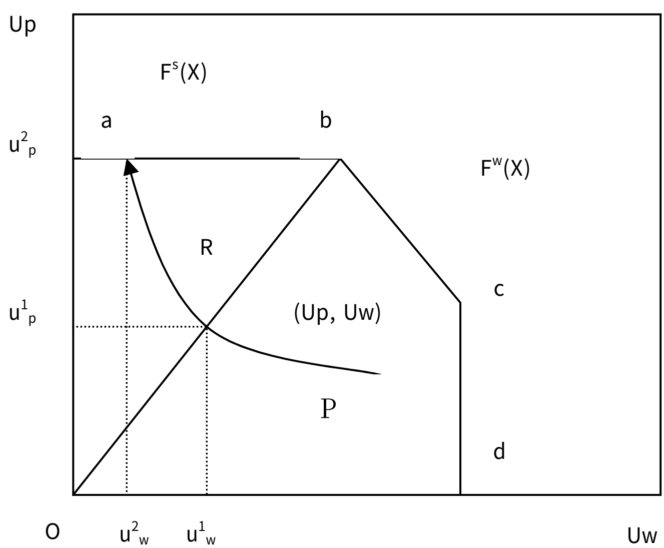
$$y^k \le \sum_{k=1}^{K} Z'^k Y^k$$

$$\Theta^S w^k \leq \sum_{k=1}^{K} Z'^k W^k$$
$$\Theta^S x^k \geq \sum_{k=1}^{K} Z'^k X^k$$
$$Z'^k \geq 0 \tag{5}$$

Using the linear programming problems, we obtain the optimal technology efficiency, $(\Theta^W)^{1/2} = \beta^W$, $(\Theta^S)^{1/2} = \beta^S$, respectively. In the equation (3), the technology efficiency under the weak disposability can catch the level of output loss considering pollutant restriction. And in the equation (4), the technology efficiency under the strong disposability can catch the level of output loss not considering pollutant restriction. Therefore, the measurements of efficiency by using the disposability show how environment restriction constrains the disposability of pollutant.

In general, environment restriction caused the transference of output for treatment of pollution. Therefore, total output decreased, and showed a trade-off relationship with pollutant.

Figure 2-1. Hyperbolic measure of productive efficiency



In Figure 2-1 U^P and U^W denote desirable output(good) and undesirable output(bad), respectively; if the disposal of bad is costless, the line segment ab would be a feasible part of the technology, since a reduction in U^W (a movement from b towards a) would be possible without giving up any U^P. If, however, the disposal of U^W is not costless, then the line segment ab will not be a feasible part of the technology. This is because some resources would be pulled out of the production of U^P in order to clean up U^W, which in turn would imply production of Oa amount of U^P is no longer feasible. Then, it can be said that, the technology bounded by line segments Oa, ab, bc and cd represents the strongly disposable output technology $F^S(X)$, and the technology bounded by line segments Ob, bc and cd represents technology with weakly disposable $F^W(X)$.

Note here that, we refrain from using the terminology 'weakly disposable output technology' since we still maintain strong disposability assumption on the desirable output. The weakly disposable output technology would be bounded by Ob, bc, co.

Finally the environmental efficiency index can be obtained from the ratio of these two efficiency scores as:

$$EI = (y_0 / \beta^W)/(y_0 / \beta^S) = \beta^S / \beta^W \tag{6}$$

Note that this measures takes a value 1 only for those production units which are on the segments bc and cd or for those production units whose hyperbolic expansions fall on these segments. Since line segments bc and cd are common to both technologies with different assumptions on the disposability of bads, for those production units, it is only natural to expect no opportunity cost for transforming the production process from one where all outputs are strongly disposable to the one which is characterized by weak disposability of undesirable outputs. For production units whose EI index is less than 1, the index indicates that there is an opportunity cost due to aforementioned transformation. The opportunity cost expressed in terms of the percentage of desirable output given up due to the reduced disposability of undesirable output, can be measured as 1-EI. Therefore EI index can safely be used as a measure of environmental efficiency.

2. Output Loss Estimation

To estimate output loss, suppose that production function was represented as shown below:

$$y^f = A \times F(x_i) \tag{7}$$

where x_i is input, y^f is output level on a line of production probability curve. These function is similar to a typical Solow(1957)'s production function. Using the equation (7), we can represent the efficiency function under the hyperbolic measure of productive efficiency as shown below:

$$\begin{aligned} E_P = (x^k, y^k) &= \min\{\delta : y/\delta \le A \times F(\delta x_i)\} \\ &= \min\{\delta : y/\delta \le A \times \delta F(x_i)\} \\ &= \min\{\delta : y/(A \times F(x_i)) \le \delta^2) \\ &= [y/(A \times F(x_i))]^{1/2} \end{aligned} \tag{8}$$

Considering the technology efficiency in the hyperbolic measure of productive efficiency, aforementioned efficiency function (equation (8)) reflects both input's decrease and output's increase simultaneously. Therefore, total factor productivity(TFP) derived from multiplying both sides of equation (8).

$$TFP = y/(E_P^2 \times F(x_i)) \tag{9}$$

Output loss under the hyperbolic measure can express a difference between productivity obtained on the line of production probability curve and productivity by real output. That is, output loss is defined as $PL = y/(E_P^2 \times F(x_i)) - y/F(x_i)$, and output loss rate is defined as $PL/(y/E_P^2 \times F(x_i)) = 1 - E_P^2$. Using the relationship between technology efficiency under hyperbolic measure and productivity, we can measure the difference of productivity considering environment regulation. That difference can be expressed as difference of productivity level between the strong disposability and the weak disposability. Namely, output loss considering the environment regulation is defined as:

$$\begin{aligned} PL_P &= (y/E_P^S)/(E_P^S \times F(x_i)) - (y/E_P^W)/(E_P^W \times F(x_i)) \\ &= [(1/(E_P^S)^2 - 1/(E_P^W)^2] \times y/F(x_i) \end{aligned} \tag{10}$$

Chapter 3. Data and Analysis Results

1. Data

The objective of this study analyzes environmental efficiency considering the environment regulation such as control for pollution reduction and cost of pollution treatment.

To compute the environmental efficiency indices for the 21 OECD countries for the period 1985-1999, we chose aggregate output as measured by real Gross Domestic Product (GDP), expressed in international prices (in 1995 US Dollars) as the desirable output, and CO_2 (1,000 metric tons of carbon), NOx (1,000 tons), and SOx (1,000 tons) emissions as the undesirable output. The two inputs considered are aggregate labor input, measured by the total employment, and total capital stock.

The input (labor and capital stock) and the desirable output (real GDP) data are compiled from IMF database (IFS 2003) and European Commission Annual Macro-Economic Database where cross country and overtime comparisons are possible in real value. Pollution related data were obtained from OECD Environmental Data Compendium (2002) and Carbon Dioxide Information Analysis Center Database.

For the empirical analysis, the What's Best (ver 7.0) program that is suitable for computing the optimum solution under the restrict condition is used.

To develop the environmental efficiency index, we used cross-section data on all countries to solve the linear programming problems for each country. The solutions determine the efficiency for each country, for a given year, with respect to two OECD multi-output production frontiers constructed under alternative disposability assumptions for the undesirable output. The ratio of the two efficiency scores gives the index of environmental efficiency for a given year. This computation is repeated for each year between 1985 and 1999 to analyze the development of environmental efficiency over time.

Table 3-1. Data and Sources

Categories	Variables	Data Methodology	Sources (Unit)
Output (Desirable output)	Real GDP	Nominal GDP(national currency) / exchange rate(national currency per US dollar) = nominal GDP(dollar) Real GDP = nominal GDP / GDP Deflator×100	IFS 2003 (Billion dollars)
Pollutants (Undesirable output)	CO_2		Carbon Dioxide Information Analysis Center (1,000 metric tons of carbon)
	SOx		OECD Environmental Data Compendium (2002) (1,000 tons)
	NOx		OECD Environmental Data Compendium (2002) (1,000 tons)
Input	Real Capital Stock	Nominal capital stock(national currency in 1995) / exchange rate(national currency per US dollar) = nominal real capita stock(dollar) Real capital stock = nominal capita stock / GDP Deflator×100	EC AMECO Database (Billion dollars) *Korea: Pyo (2002)
	Labor		IFS 2003 (1,000 peoples)
The rests	Exchange rate	Market Average Rate	IFS 2003 EC AMECO Database
	GDP Deflator		IFS 2003 (1995=100)

2. Data Review

The basic data about inputs, outputs and pollutants are presented in Table 2, respectively.

Table 3-2. Basic data of the OECD Countries

Period	Variables	Mean	Standard Error	Maximum Value	Minimum Value
Ⅰ period (1985-1989)	Real GDP	748.03	1348.05	6023.95	20.48
	CO_2	122815.85	273897.57	1271495.80	6509.80
	SOx	2366.09	4842.09	21012.64	34.23
	NOx	1968.62	4476.59	21071.13	109.84
	Labor	16614.59	25854.52	112299.40	1107.88
	Real Capital Stock	2143.49	3567.33	15369.04	136.19
Ⅱ period (1990-1994)	Real GDP	951.33	1617.18	6803.19	22.07
	CO_2	131363.34	290353.55	1350689.20	6876.60
	SOx	1933.26	4442.53	20663.29	37.17
	NOx	2009.52	4764.26	22467.35	118.60
	Labor	17763.26	27614.19	118951.00	1176.86
	Real Capital Stock	2775.69	4417.37	17268.30	177.70
Ⅲ period (1995-1999)	Real GDP	1061.01	1897.31	8021.57	38.96
	CO_2	140370.49	314945.61	1469715.20	8135.60
	SOx	1515.59	3713.60	17376.15	28.49
	NOx	1990.33	4962.08	23381.99	109.18
	Labor	18681.25	29598.33	129223.60	1425.27
	Real Capital Stock	3119.36	5217.91	19751.80	194.84

The result of data analysis shows that USA scores the highest value in inputs, outputs, and pollutants. That is, USA is the largest producing country as well as the largest pollutants emitting country. In general, the developed countries such as Japan, Germany, and France are commonly more economic outputs and pollutant emissions than other countries. On the contrary, small economy countries such as Norway, Denmark and Ireland are less economic outputs and pollutant emissions than the developed countries. The SOx and NOx emissions among the pollutants selected by this study show a declining trend in the Ⅲ period in comparison with the Ⅰ period as a whole.

Table 3-3. Basic data of Korea

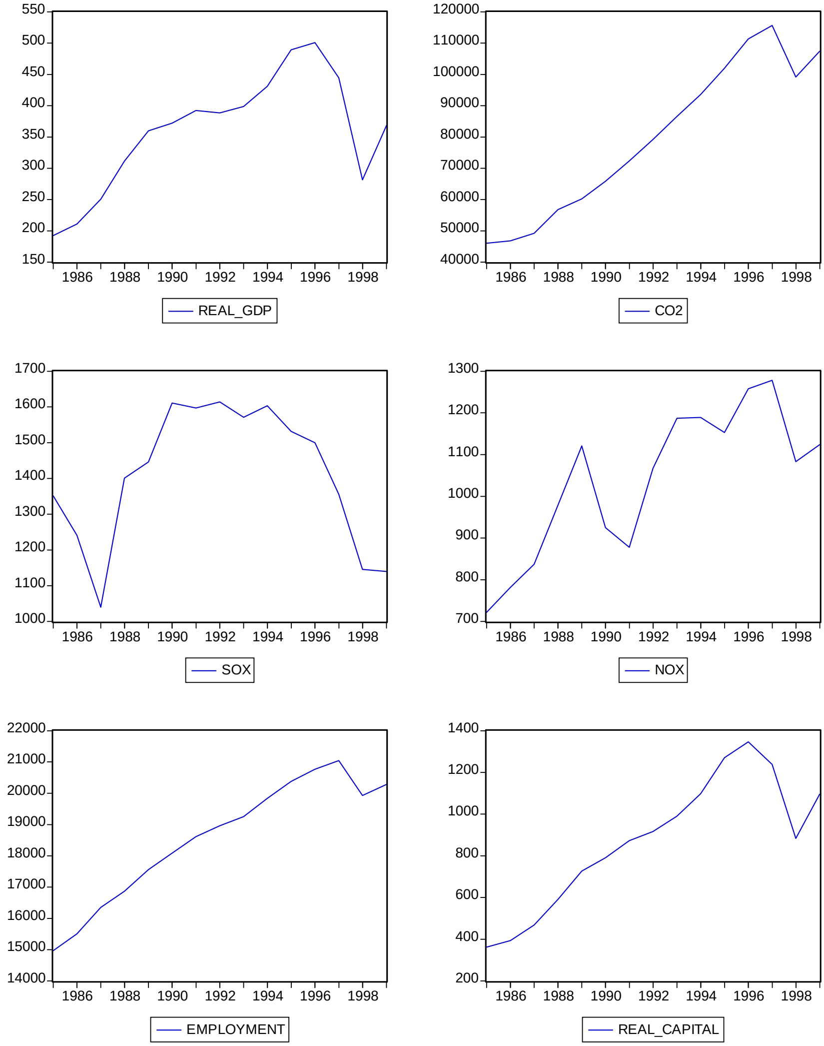
	Real GDP	CO2	SOx	NOx	Labor	Real Capital Stock
Mean	359.55	79481.20	1409.95	1038.87	18560.28	869.72
Standard Error	93.75	24594.40	192.55	175.05	1938.80	315.42
Maximum Value	500.74	115668.00	1614.00	1278.00	21047.70	1346.45
Minimum Value	192.53	46082.00	1040.00	722.00	14970.00	362.67
Average Growth Rate	6.11	6.45	-0.54	3.81	2.22	9.20

In case of Korea, the mean of real GDP is 359.55 billion US $, and annual average growth rate is 6.11% over the 1985-1999. Macro variables such as Labor and real Capital Stock show the increasing trend gradually between 1985 and 1996, but between the year 1998-1999 show a declining trend.

CO_2 of pollutants show a similar trend with economic variable. In a booming stage, the emissions of CO_2 increased, in a recession stage, the emissions of CO_2 decreased generally.

In Korea, there was a structural shock of economic variables and pollutants around the currency crisis and there was a change of trend at this point.

Figure 3-1. Trend of each variable in Korea



3. Result of Empirical Analysis

In this chapter, the estimation result of the technology efficiency level considering an environment regulation is presented by using a hyperbolic measure. A hyperbolic measure of productive efficiency is a method that can increase production and at the same time, decrease pollutants simultaneously. This measure regards a product unit that achieved more output and less pollutant at the same time as the high efficiency level. It is a measure of productive efficiency that anticipates a simultaneous success of the growth and environment and corresponds to the concept of sustainable development. Using the equation (4) and (5) in the chapter 2, we estimate the optimal technology efficiency level, $(\Theta^W)^{1/2} = \beta^W$ and $(\Theta^S)^{1/2} = \beta^S$. That is to say, we can measure the productive efficiency function, E_P^W and E_P^S .

The efficiency measures and the resulting environmental efficiency index are presented in Table 4, Table 5, Table 6, in each period respectively.

The analysis of the efficiency scores indicates that, for all periods in the sample, there are only five countries, Australia, Canada, New Zealand, UK and USA, that are fully efficient with respect to both OECD multi output production frontiers constructed under alternative assumptions on the disposability for pollutants.

But countries such as Japan, Norway, Switzerland and Sweden show the worst environmental efficiency among the 21 countries. In addition to these countries, France, Germany and Spain are always fully efficient with respect to the frontier constructed assuming weak disposability of pollutants but are inefficient with respect to the frontier constructed assuming strong disposability of pollutants. This is as expected theoretically, since the frontier constructed assuming weak disposability of pollutants envelops the data more closely than the frontier constructed using strong disposability assumption for the environmentally undesirable substances. Consequently, the measure of environmental efficiency, defined as the ratio of these two scores, takes the value of one for Australia, Canada, New Zealand, UK and USA and less than one for the other countries during the entire sample period.

Table 7 and Figure 3 present the OECD country's environmental efficiency index from 1985 to 1999 and mean environmental efficiency index of overall OECD country

Table 3-4. Technology efficiency measure and Output loss rate with hyperbolic efficiency measure (1985-1989)

	Efficiency Measure (with strong disposability)	Efficiency Measure (with weak disposability)	Environmental Efficiency Index	Output Loss Rate
Australia	1.000	1.000	1.000	0.000
Austria	0.906	0.965	0.939	11.777
Belgium	0.992	1.000	0.992	1.662
Canada	1.000	1.000	1.000	0.000
Denmark	0.905	0.936	0.967	6.486
Finland	0.895	0.926	0.967	6.567
France	0.935	0.984	0.951	9.611
Germany	1.000	1.000	1.000	0.000
Ireland	0.616	0.635	0.970	5.967
Italy	0.924	0.969	0.953	9.118
Japan	0.917	1.000	0.917	15.864
Korea	1.000	1.000	1.000	0.000
Netherlands	0.874	1.000	0.874	23.564
New Zealand	1.000	1.000	1.000	0.000
Norway	0.885	1.000	0.885	21.721
Portugal	0.964	1.000	0.964	7.105
Spain	0.966	1.000	0.966	6.623
Sweden	0.898	0.966	0.929	13.967
Switzerland	0.878	1.000	0.878	22.969
UK	1.000	1.000	1.000	0.000
USA	1.000	1.000	1.000	0.000
Average	**0.931**	**0.971**	**0.960**	**7.749**

Table 3-5. Technology efficiency measure and Output loss rate with hyperbolic efficiency measure (1990-1994)

	Efficiency Measure (with strong disposability)	Efficiency Measure (with weak disposability)	Environmental Efficiency Index	Output Loss Rate
Australia	1.000	1.000	1.000	0.000
Austria	0.928	1.000	.0928	13.824
Belgium	1.000	1.000	1.000	0.000
Canada	1.000	1.000	1.000	0.000
Denmark	0.919	0.941	0.977	4.629
Finland	0.874	0.893	0.979	4.162
France	0.961	0.998	0.964	7.123
Germany	0.897	1.000	0.897	19.487
Ireland	0.564	1.000	0.564	68.189
Italy	0.924	0.958	0.965	6.957
Japan	0.923	1.000	0.923	14.717
Korea	1.000	1.000	1.000	1.000
Netherlands	0.902	0.985	0.916	16.023
New Zealand	1.000	1.000	1.000	0.000
Norway	0.913	1.000	0.913	16.637
Portugal	1.000	1.000	1.000	0.000
Spain	0.949	1.000	0.949	9.919
Sweden	0.883	0.954	0.926	14.247
Switzerland	0.891	1.000	0.891	20.637
UK	1.000	1.000	1.000	0.000
USA	1.000	1.000	1.000	0.000
Average	**0.930**	**0.987**	**0.942**	**10.312**

Table 3-6. Technology efficiency measure and Output loss rate with hyperbolic efficiency measure (1995-1999)

	Efficiency Measure (with strong disposability)	Efficiency Measure (with weak disposability)	Environmental Efficiency Index	Output Loss Rate
Australia	1.000	1.000	1.000	1.000
Austria	0.885	0.996	0.888	21.119
Belgium	0.979	1.000	0.979	4.248
Canada	1.000	1.000	1.000	0.000
Denmark	0.934	0.978	0.954	8.894
Finland	0.902	0.957	0.942	11.169
France	0.926	1.000	0.926	14.179
Germany	0.863	1.000	0.863	25.561
Ireland	0.701	1.000	0.701	50.911
Italy	0.885	0.942	0.940	11.591
Japan	0.884	1.000	0.884	21.933
Korea	0.960	1.000	0.960	7.768
Netherlands	0.902	0.997	0.905	18.150
New Zealand	1.000	1.000	1.000	0.000
Norway	0.936	1.000	0.936	12.300
Portugal	1.000	1.000	1.000	0.000
Spain	0.912	1.000	0.912	16.786
Sweden	0.873	0.971	0.899	23.303
Switzerland	0.876	1.000	0.876	23.303
UK	1.000	1.000	1.000	0.000
USA	1.000	1.000	1.000	1.000
Average	**0.925**	**0.992**	**0.932**	**12.719**

Table 3-7. Environmental Efficiency Index by each period

	Ⅰ period (1985-1989)	Ⅱ period (1990-1994)	Ⅲ period (1995-1999)
Australia	1.000	1.000	1.000
Austria	0.939	0.928	0.888
Belgium	0.992	1.000	0.979
Canada	1.000	1.000	1.000
Denmark	0.967	0.977	0.954
Finland	0.967	0.979	0.942
France	0.951	0.964	0.926
Germany	1.000	0.897	0.863
Ireland	0.970	0.564	0.701
Italy	0.953	0.965	0.940
Japan	0.917	0.923	0.884
Korea	1.000	1.000	0.960
Netherlands	0.874	0.916	0.905
New Zealand	1.000	1.000	1.000
Norway	0.885	0.885	0.936
Portugal	0.964	1.000	1.000
Spain	0.966	0.949	0.912
Sweden	0.929	0.926	0.899
Switzerland	0.878	0.891	0.876
UK	1.000	1.000	1.000
USA	1.000	1.000	1.000
Average	**0.960**	**0.942**	**0.932**

Figure 3-2. Mean Environmental Efficiency Index of overall OECD Countries

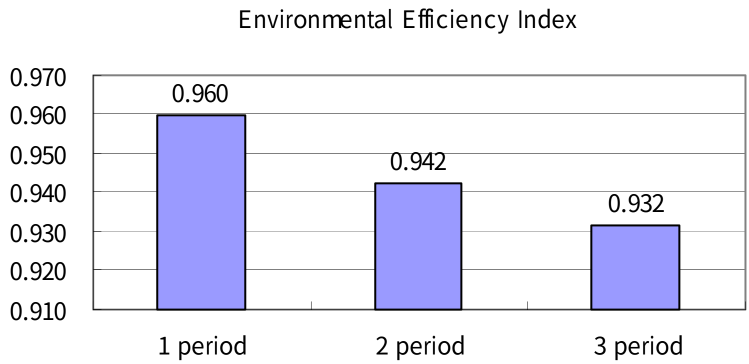


Table 7 and Figure 3 show that, during the sample period, there is a simultaneous decline in the environmental efficiency. Environmental efficiency of Ⅲ period that was computed in the latter half of the 1990's less efficient than environmental efficiency of Ⅰ period estimating in the second half of the 1980's.

The result classified by countries shows that environmental efficiency of Ireland more fluctuant than other countries. Also, Table 7 shows that the trend of environmental efficiency in Germany declines simultaneously over the 1985-1999.

The analysis reveals that among the 21 OECD countries, USA, UK, Australia, Canada and New Zealand are among the best performers and Ireland, Japan, Netherlands, Switzerland and Sweden are among the worst, on the basis of mean environmental efficiency computed over the 1985-1999.

Despite the differences in overall means, countries such as Norway and Portugal showed improved performance while countries like Austria, Germany and Spain, exhibited deterioration.

Table 3-8. Output loss from imposing weak disposability of pollutants

	Ⅰ period (1985-1989)		Ⅱ period (1990-1994)		Ⅲ period (1995-1999)	
	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)
Australia	0.00	0.00	0.00	0.00	0.00	0.00
Austria	8.29	1.92	14.16	1.88	23.98	1.94
Belgium	1.36	0.31	0.00	0.00	5.41	0.44
Canada	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	3.83	0.89	3.49	0.46	7.68	0.62
Finland	3.81	0.88	2.53	0.34	7.15	0.58
France	49.41	11.43	49.30	6.54	106.63	8.64
Germany	0.00	0.00	209.87	27.86	302.37	24.49
Ireland	0.62	0.14	9.62	1.28	11.66	0.94
Italy	50.24	11.62	44.76	5.94	65.48	5.30
Japan	214.03	49.53	301.80	40.07	533.43	43.21
Korea	0.00	0.00	0.00	0.00	16.52	1.34
Netherlands	29.91	6.92	28.64	3.80	37.13	3.01
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00
Norway	11.97	2.77	10.95	1.45	9.25	0.75
Portugal	3.03	0.70	0.00	0.00	0.00	0.00
Spain	15.50	3.59	31.54	4.19	48.73	3.95
Sweden	16.30	3.77	18.66	2.48	25.00	2.02
Switzerland	23.84	5.52	27.93	3.71	34.19	2.77
UK	0.00	0.00	0.00	0.00	0.00	0.00
USA	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**432.13**	**100**	**753.23**	**100**	**1234.61**	**100**

To investigate the opportunity cost of transforming the production process from one where all outputs are freely disposable to the one where pollution emissions are costly to dispose, we additionally compute the output loss as $(1-EI)\times GDP$ in constant 1995 International Dollars. Table 8 shows, for each country, the value of output loss, a country's share in the total OECD output loss for the 3 periods.

Table 8 suggests that if weak disposability for pollutants emissions were strictly imposed as the result of an environmental regulation, the total value of output loss to the OECD countries as a whole would be 432.13 billion US Dollars, 753.23 billion US Dollars, 1234.61 billion US Dollars for the periods Ⅰ,Ⅱ,Ⅲ, respectively. In terms of the impact of such a regulation on individual countries, in USA, UK, Canada, Australia, New Zealand, environmental regulation is not binding so that there is no loss in output. However, in terms of foregone output as a percentage of the total OECD loss, Japan(49.53%), Italy(11.62%), France(11.43%) in Ⅰ period; and Japan(40.07%), Germany(27.86%), France(6.54%) in Ⅱ period; and Japan(43.21%), Germany(24.49%), France(8.64%) are the countries that would assume the largest share due to this transformation.[2]This results on the whole correspond to Zaim & Taskin(2000)'s study. In their study, countries that showed the largest output loss were Japan, France and Italy.

In case of Korea, even if environmental regulation was imposed for output process, there is no loss in output in Ⅰ,Ⅱ period, respectively. But value of output loss would be 165 billion US Dollars in Ⅲ period and it corresponds to 1.34% of total OECD output loss.

The following Figure 4, Figure 5, Table 9 and Table 10 give a concise explanation of the Environmental Efficiency Index, Output loss for OECD countries and Korea. Based on this result, we can explain some important points.

First, the trend of environmental efficiency index in OECD countries shows a simultaneous decline. In the model that includes all kinds of pollutants, the analysis of the efficiency scores indicates that the efficiency in the latter half of the 1990's is lower than the efficiency in the second half of the 1980's.

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[2] These results are quite robust with regards to the choice of technique in evaluating the cost of pollution reduction. In fact, an OECD report (OECD, 1991) which simulates the cost of reducing CO_2 emissions within a general equilibrium modeling framework also ranks France and Japan among the countries which will incur the highest costs.

Figure 3-3. Comparison of Environmental Efficiency Index by each model in the overall OECD Countries

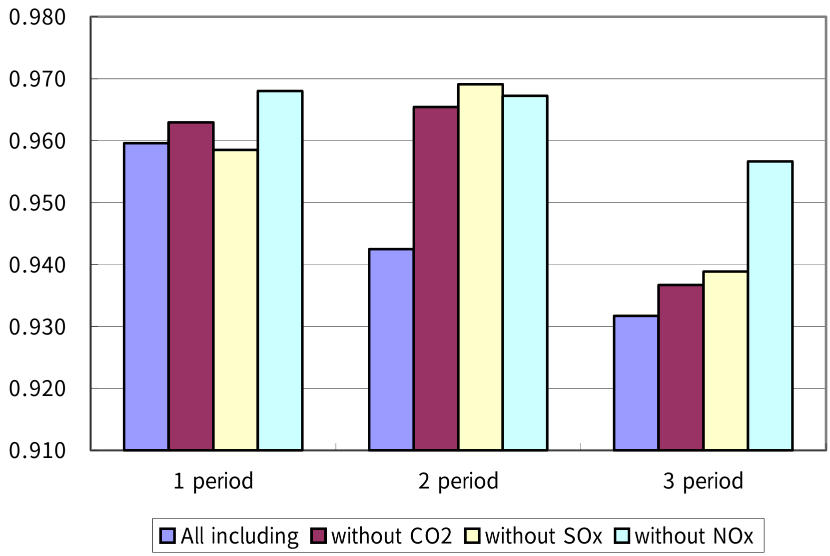

Table 3-9. Comparison of Output loss by each model in the overall OECD Countries

	Ⅰ Period (1985-1989)	Ⅱ Period (1990-1994)	Ⅲ Period (1995-1999)
	Output Loss (billion, $)	Output Loss (billion, $)	Output Loss (billion, $)
All including	423.13	753.23	1234.61
Without CO2	414.45	678.70	1108.29
Without SOx	603.43	701.22	1168.73
Without NOx	398.10	555.40	890.39

Figure 3-4. Comparison of Environmental Efficiency Index by each model in Korea

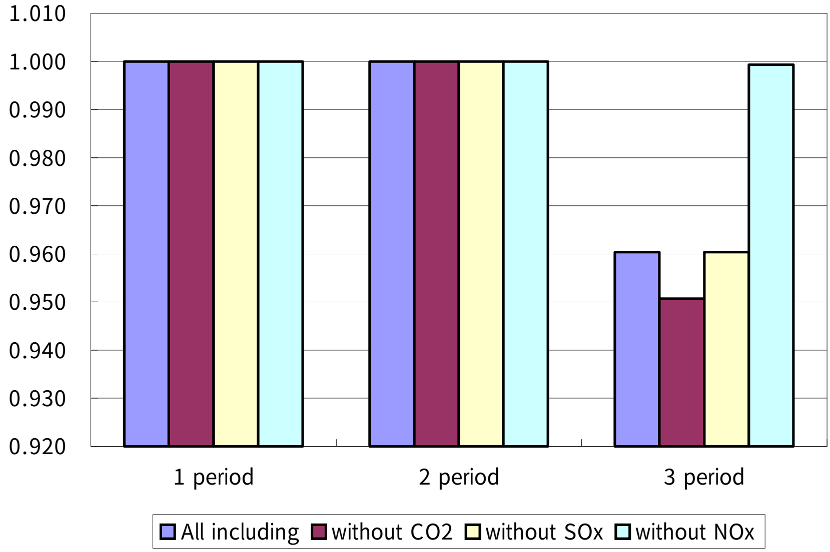

Table 3-10. Comparison of Output loss by each model in Korea

	Ⅰ Period (1985-1989)	Ⅱ Period (1990-1994)	Ⅲ Period (1995-1999)
	Output Loss (billion, $)	Output Loss (billion, $)	Output Loss (billion, $)
All including	0.00	0.00	16.52
Without CO2	0.00	0.00	20.57
Without SOx	0.00	0.00	16.52
Without NOx	0.00	0.00	0.29

Second, in terms of the treatment of pollutants, Japan, Germany and France are countries that have a considerable burden in getting rid of the pollutants. In particular, Japan is a country that would assume the largest share due to this transformation.

Third, as a result of estimation excluding each pollutant, overall countries have an economic burden in disposing the pollutants. Table 9 shows that, in the model that includes all kinds of pollutants, environmental efficiency is higher than estimated value in the model which excluding by each pollutant. It means that the larger a difference between value in the model including all kinds of pollutants and value in the model excluding by each pollutant is, the more costly the cost for dealing with the pertinent pollutant is. In terms of this result, model that shows the largest difference is model excluding the NOx emission. That is to say, in the case of model adding the NOx emissions, we can estimate an additional cost wholly. These results appear on the whole in the OECD countries similarly.

Forth, in case of Korea for estimation of environmental efficiency index, the result shows that Korea displayed excellent environmental efficiency, but in the latter half of the 1990's (Ⅲ period), the environmental efficiency of Korea became slightly worse. During the same period, Korea had a burden in dealing with NOx just like the other OECD countries.

Chapter 4. Conclusion

Product efficiency or improvement of productivity considering an environmental factor is one of the important indicators that measure the national competitive power. These new indicators can provide critical information to the government in the implementation of industrial and regulation policies.

This study estimates the technology efficiency considering environmental factors for the OECD countries including Korea, develops the environmental efficiency index, and appraises the level of output loss for individual countries for the period 1985-1999. In contrast to methods that gauge the environmental efficiency with the levels of emissions of pollutants, the index developed in this study is based on a production approach that explicitly differentiates between the disposability characteristics of the environmentally desirable and undesirable outputs. Employing this measure, the value of desirable output loss associated with weak disposability of pollutants for each country and their share in the total OECD output loss are computed. And for estimating model that excludes by each pollutant, we can estimate the far-reaching effects about environmental efficiency and output loss.

The results indicate that the Environmental Efficiency Index of OECD countries gradually show a downward trend. In the model that includes all kinds of pollutants, the analysis of the efficiency scores indicates that the efficiency in the latter half of the 1990’s is lower than the efficiency in the latter half of the 1980’s. In terms of the treatment of pollutants, Japan, Germany and France are countries that have a considerable burden in getting rid of pollutants. In particular, Japan is a country that would assume the largest share due to this transformation. In case of Korea for estimation of environmental efficiency index, the result shows that Korea displayed excellent environmental efficiency, but in the latter half of the 1990’s (Ⅲ period), the environmental efficiency of Korea became slightly worse.

The results of this study reveal that as far as the environmental regulations or the pollutant treatment costs are concerned, environmental efficiency in Korea is not so bad compared with the other countries. However, there are some points to be improved about environmental efficiency.

Therefore, the manufacturing industry or the pollution industry need to transform into environmentally friendly production process, and be concerned about the treatment of NOx particularly. For the sustainable and environmentally friendly economic growth, under the basis of this study, the level of pollutant emissions was refrained strongly. And it is necessary to study the case of countries that shows the high environmental efficiency in same condition as compared with our country.

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Appendix

Table A1. Environmental Efficiency Index by each period in the model without CO_2

	Ⅰ period (1985-1989)	Ⅱ period (1990-1994)	Ⅲ period (1995-1999)
Australia	1.000	1.000	1.000
Austria	0.940	0.929	0.890
Belgium	0.992	1.000	0.979
Canada	1.000	1.000	1.000
Denmark	0.974	0.982	0.963
Finland	0.973	0.981	0.950
France	0.953	0.983	0.941
Germany	1.000	0.897	0.897
Ireland	0.973	0.957	0.701
Italy	0.957	0.986	0.959
Japan	0.917	0.923	0.884
Korea	1.000	1.000	0.951
Netherlands	0.874	0.930	0.909
New Zealand	1.000	1.000	1.000
Norway	0.885	0.913	0.936
Portugal	0.964	1.000	1.000
Spain	0.966	0.949	0.922
Sweden	0.957	0.954	0.919
Switzerland	0.897	0.891	0.876
UK	1.000	1.000	1.000
USA	1.000	1.000	1.000
Average	**0.963**	**0.965**	**0.937**

Table A2. Output loss from imposing weak disposability of pollutants in the model without CO_2

	Ⅰ period (1985-1989)		Ⅱ period (1990-1994)		Ⅲ period (1995-1999)	
	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)
Australia	0.00	0.00	0.00	0.00	0.00	0.00
Austria	8.18	1.97	14.01	2.06	23.61	2.13
Belgium	1.36	0.33	0.00	0.00	5.41	0.49
Canada	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	3.03	0.73	2.74	0.40	6.22	0.56
Finland	3.08	0.74	2.26	0.33	6.24	0.56
France	47.25	11.40	23.77	3.50	85.11	7.68
Germany	0.00	0.00	209.87	30.92	226.56	20.44
Ireland	0.54	0.13	0.96	0.14	11.66	1.05
Italy	46.54	11.23	17.16	2.53	44.47	4.02
Japan	214.03	51.64	301.80	44.47	533.43	48.13
Korea	0.00	0.00	0.00	0.00	20.57	1.86
Netherlands	29.91	7.22	23.99	3.54	35.44	3.20
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00
Norway	11.97	2.89	10.95	1.61	9.25	0.83
Portugal	3.03	0.73	0.00	0.00	0.00	0.00
Spain	15.50	3.74	31.54	4.65	43.51	3.93
Sweden	9.96	2.40	11.73	1.73	19.96	1.80
Switzerland	20.06	4.84	27.93	4.11	34.19	3.08
UK	0.00	0.00	0.00	0.00	2.55	0.23
USA	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**414.45**	**100**	**678.70**	**100**	**1108.29**	**100**

Table A3. Environmental Efficiency Index by each period in the model without SOx

	Ⅰ period (1985-1989)	Ⅱ period (1990-1994)	Ⅲ period (1995-1999)
Australia	1.000	1.000	1.000
Austria	0.942	0.941	0.899
Belgium	0.992	1.000	0.979
Canada	1.000	0.997	1.000
Denmark	0.967	0.977	1.000
Finland	0.967	0.981	0.976
France	0.951	0.966	0.930
Germany	0.846	0.897	0.863
Ireland	0.984	0.995	0.701
Italy	0.956	0.968	0.951
Japan	0.917	0.923	0.884
Korea	1.000	1.000	0.960
Netherlands	0.972	0.975	0.930
New Zealand	1.000	1.000	1.000
Norway	0.885	0.941	0.936
Portugal	0.964	1.000	1.000
Spain	0.963	0.959	0.967
Sweden	0.947	0.940	0.906
Switzerland	0.878	0.891	0.876
UK	1.000	1.000	1.000
USA	1.000	1.000	1.000
Average	**0.959**	**0.969**	**0.939**

Table A4. Output loss from imposing weak disposability of pollutants in the model without SOx

	Ⅰ period (1985-1989)		Ⅱ period (1990-1994)		Ⅲ period (1995-1999)	
	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)
Australia	0.00	0.00	0.00	0.00	0.00	0.00
Austria	7.95	1.32	11.68	1.67	21.74	1.86
Belgium	1.36	0.23	0.00	0.00	5.41	0.46
Canada	0.00	0.00	1.92	0.27	0.00	0.00
Denmark	3.83	0.63	3.42	0.49	6.85	0.59
Finland	3.77	0.63	2.32	0.33	2.97	0.25
France	49.12	8.14	45.54	6.49	101.87	8.72
Germany	200.21	33.18	209.87	29.93	302.37	25.87
Ireland	0.33	0.05	0.12	0.02	11.66	1.00
Italy	47.83	7.93	39.87	5.69	53.63	4.59
Japan	214.03	35.47	301.80	43.04	533.43	45.64
Korea	0.00	0.00	0.00	0.00	16.52	1.41
Netherlands	6.66	1.10	8.67	1.24	27.11	2.32
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00
Norway	11.97	1.98	7.49	1.07	9.25	0.79
Portugal	3.03	0.50	0.00	0.00	0.00	0.00
Spain	17.25	2.86	25.53	3.64	18.41	1.58
Sweden	12.26	2.03	15.07	2.15	23.31	1.99
Switzerland	23.84	3.95	27.93	3.98	34.19	2.92
UK	0.00	0.00	0.00	0.00	0.00	0.00
USA	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**603.43**	**100**	**701.22**	**100**	**1168.73**	**100**

Table A5. Environmental Efficiency Index by each period in the model without NOx

	Ⅰ period (1985-1989)	Ⅱ period (1990-1994)	Ⅲ period (1995-1999)
Australia	1.000	1.000	1.000
Austria	0.940	0.928	0.903
Belgium	0.992	1.000	0.979
Canada	1.000	1.000	1.000
Denmark	0.968	0.979	0.959
Finland	0.969	0.985	0.963
France	0.952	0.968	0.948
Germany	1.000	0.983	0.954
Ireland	0.984	0.978	0.982
Italy	0.960	0.969	0.957
Japan	0.917	0.923	0.895
Korea	1.000	1.000	0.999
Netherlands	0.874	0.919	0.927
New Zealand	1.000	1.000	1.000
Norway	0.948	0.913	0.936
Portugal	0.964	1.000	1.000
Spain	0.966	0.949	0.912
Sweden	0.952	0.927	0.900
Switzerland	0.941	0.891	0.876
UK	1.000	1.000	1.000
USA	1.000	1.000	1.000
Average	**0.968**	**0.967**	**0.957**

Table A6. Output loss from imposing weak disposability of pollutants in the model without NOx

	Ⅰ period (1985-1989)		Ⅱ period (1990-1994)		Ⅲ period (1995-1999)	
	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)	Output Loss (billion,$)	Share in total output loss (%)
Australia	0.00	0.00	0.00	0.00	0.00	0.00
Austria	8.17	2.05	14.16	2.55	20.86	2.34
Belgium	1.36	0.34	0.00	0.00	5.41	0.61
Canada	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	3.77	0.95	3.15	0.57	6.99	0.78
Finland	3.48	0.87	1.84	0.33	4.63	0.52
France	47.89	12.03	43.16	7.77	75.56	8.49
Germany	0.00	0.00	34.59	6.23	101.77	11.43
Ireland	0.32	0.08	0.49	0.09	0.69	0.08
Italy	42.77	10.74	39.61	7.13	46.96	5.27
Japan	214.03	53.76	301.80	54.34	481.86	54.12
Korea	0.00	0.00	0.00	0.00	0.29	0.03
Netherlands	29.91	7.51	27.87	5.02	28.37	3.19
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00
Norway	5.40	1.36	10.95	1.97	9.25	1.04
Portugal	3.03	0.76	0.00	0.00	0.00	0.00
Spain	15.50	3.89	31.54	5.68	48.73	5.47
Sweden	11.04	2.77	18.32	3.30	24.83	2.79
Switzerland	11.43	2.87	27.93	5.03	34.19	3.84
UK	0.00	0.00	0.00	0.00	0.00	0.00
USA	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**398.10**	**100**	**555.40**	**100**	**890.39**	**100**

Abstract in Korean

최근 들어 경제성장과 환경오염 사이의 관계에 대한 연구가 폭넓게 이루어지고 있다. 환경에 대한 관심이 증가함에 따라, 정책결정자는 주요 경제정책을 시행할 때, 정책결정에 대한 환경적 영향을 고려하고 있다. 현재 환경 문제들은 국제적인 문제로 다루어지고 있는데, 각 국가들은 환경 수행에 대한 정보를 공표하고 문서화하고 측정하기 위해 노력하고 있다. 그러나 이를 위해서는 환경질(Environment Quality)에 대한 정확한 평가가 필수적이다.

본 연구는 환경과 경제를 연계한 환경효율지수(Environmental-Efficiency Index: EI)를 기초로 하여 다국가비교분석(multi-country comparative analysis)을 통한 지속가능성 평가를 주 목적으로 하고 있다. 생산의 효율과 생산성의 향상은 국가경쟁력을 결정하는 경제성장의 주요 기여 인자로서, 환경요소가 고려된 생산효율이나 생산성 측정은 국가 경쟁력을 측정하는 중요한 지표 중 하나라고 할 수 있다. 이러한 새로운 지표 개발은 국가의 생산 효율과 생산성 향상 및 환경에 대한 의사결정 뿐만 아니라 정부의 산업정책과 환경규제정책의 수행에 주요한 정보를 제공할 수 있다.

본 연구는 OECD 국가의 환경제약을 포함한 기술효율과 생산성 상실을 추정하여 환경효율지수를 실증분석하고, 다국가 비교연구를 통해서 국가별 지속가능발전 정도를 전망하는 연구이다. 이를 분석하기 위해서 본 연구는 생산가능곡선을 이용한 생산의 기술효율을 측정하는 척도 중 쌍곡선효율척도(hyperbolic measure of productive efficiency)를 사용하여 기술효율을 측정한다. 기술효율의 쌍곡선 척도는 생산을 증가시키면서 동시에 같은 일정한 비율로 오염물을 동시에 감소시킬 수 있는 기술효율 척도로서 상대적으로 오염량은 적게 발생시키면서 높은 산출량을 달성하는 생산단위에 대해서 높은 효율을 부여한다. 이는 생산과 환경의 동시적인 성공을 기대할 수 있으며, 또한 환경친화적이고 지속가능한 성장의 개념에 부합하는 효율의 척도기준으로서 생산단위들로 하여금 이런 방향으로 최선의 생산계획을 유도할 수 있고 환경기술의 개선에도 큰 자극을 줄 수 있다는 장점이 있다. 환경제약을 포함한 기술효율을 추정하기 위해서는 환경제약의 여부를 측정해야 하며, 이를 위해 강처분(strong disposability) 기술과 약처분(weak disposability) 기술로 구분하여 생산의 기술효율을 추정해야 한다. 여기에서 강처분 기술은 규제나 제약으로 인한 추가적 비용 없이 산출물에 대한 비용만을 부담하여 생산할 수 있는 경우를 말하며, 약처분 기술은 생산자가 일정한 환경제약의 기준을 만족시켜야만 하는 경우, 즉 생산비용 이외에 오염 처리의 비용에 직면하게 되는 생산기술 상태를 의미한다. 이러한 효율의 분석은 환경요인이나 산출물의 변화가 생산의 기술효율이나 생산성에 미치는 영향을 각각 보여줄 수 있다.

이러한 방법을 이용해서 본 연구에서는 1985-1999년 기간 동안 OECD 국가들의 각 제약조건 별 기술효율 수준 및 환경효율성지수, 그리고 제약조건에 따른 산출손실액을 각각 추정하였으며, 한편으로는 오염인자를 하나씩 제외한 모형을 추정하여 해당

오염물질이 환경효율성이나 산출손실액에 어느 정도 파급영향을 가지고 있는지에 대해서도 추정해 보았다.

연구 결과, OECD 각 국가들의 환경효율성지수는 점차 하락하고 있는 추세를 보여주고 있다. 모든 오염물질을 포함하여 추정한 전체 모형에서 환경효율성지수는 80년대 후반을 측정한 Ⅰ기에 비해, 90년대 후반을 측정한 Ⅲ기는 지수가 0.3 정도 하락하는 것으로 나타나고 있다. 그리고 오염물질을 처리하는데 있어서 일본, 독일, 프랑스 등의 국가에서 오염물 처리에 상당한 부담을 가지고 있는 것으로 나타났다. 특히 일본은 전 기간을 통해서 가장 많은 산출 손실과 비중을 차지하는 것으로 나타나서 오염물 처리에 상당한 부담이 있다는 것을 제시하고 있다.

한편, 각 오염인자를 제외한 분석 결과, 질소산화물을 처리하는데 대한 부담이 전반적으로 큰 것으로 나타났다. 전체 모형에서 추정한 산출손실액에 비해서 가장 많은 차이를 보이고 있는 모형이 질소산화물을 제외한 모형이며, 이는 곧 질소산화물을 포함하였을 경우의 추가적인 비용 부담의 정도를 예측해 볼 수 있는데, 이와 같은 현상은 OECD 국가 전반적으로 비슷하게 나타나고 있다.

한국의 경우, 전반적으로 환경효율성이 우수하게 나타나지만, 90년대 후반(Ⅲ기) 기간동안 환경효율성이 악화된 것으로 나타났으며, 이 기간동안 OECD 국가들과 비슷하게 질소산화물을 처리하는데 대한 부담이 큰 것으로 나타났다. 한국의 환경효율성은 외환위기와 경제위기가 있었던 Ⅲ기 기간에 환경효율성이 0.960으로 이전 기간에 비해 더 악화된 것으로 나타나고 있으며, 이는 각각 오염물질을 제외하고 추정한 모형에서도 동일하게 나타나고 있다.

본 연구 결과, 우리나라의 환경규제 및 오염처리 비용을 고려했을 경우의 환경효율성은 다른 국가들에 비해서 나쁘지 않지만 개선될 여지가 있는 것으로 나타났기 때문에 향후 제조업 및 오염유발 산업에서 친환경적인 생산 공정으로의 전환이 필요하며, 오염물질 중에서는 질소산화물 처리에 대한 각별한 관심이 요구된다. 향후 지속가능하고 환경친화적인 경제성장을 위해서는 앞서 분석한 다국가 비교분석을 토대로 우리와 비슷한 환경에 있으면서도 환경효율수준에서 높은 효율을 보이고 있는 국가를 벤치마킹하여 오염배출 수준을 억제하면서도 지속적인 경제성장을 이룩할 수 있는 초석을 삼아야 할 것이다.