

An Empirical Study of the Relationships between CO₂ Emissions, Economic Growth and Openness

Eunho Choi, Almas Heshmati, and Yongsung Cho*

개방화와 경제성장에 따른 한국, 중국, 일본의
이산화탄소 배출량 비교 분석

최은호 · Almas Heshmati · 조용성*

고려대학교 식품자원경제학과(Department of Food and Resources Economics, Korea University)

제출: 2011년 8월 17일 수정: 2011년 12월 1일 승인: 2011년 12월 8일

국문 요약

한국과 중국, 일본 세 국가의 1971년부터 2006년까지의 시계열 자료를 바탕으로 이산화탄소 배출량과 경제성장 그리고 경제개방도의 인과관계를 파악하고, 환경 쿠즈네츠 곡선(Environmental Kuznets Curve, EKC)의 존재여부에 대해 분석하였다. 경제개방도나 경제성장에 따른 이산화탄소 배출량은 국가별로 상이한 형태를 보였다. 추정된 EKC는 국가별로 다른 패턴을 보이는데, 경제성장과 CO₂ 배출량의 경우 한국은 U자 곡선, 중국은 상승추세, 일본은 역 N자 형태를 보였다. 일본은 약 30,000달러의 경제성장을 달성하면서 이산화탄소 배출 감소구간을 보이고 있다. 이와 같은 결과를 통해, EKC의 최고점에 이르지 않고도 선진국의 경험과 기술을 이용하여 티널을 거쳐 환경이 개선될 수 있다는 가능성을 확인할 수 있었다. 경제개방도와 CO₂ 배출량의 관계를 보면 한국은 역 U자 곡선, 중국의 경우 U자 곡선, 일본은 증가추세를 보였다. 또한 벡터자기회귀모형(vector auto regression, VAR)과 벡터오차수정모형(vector error correction model, VECM)을 사용하여 변수들 간의 동태적 관계를 분석하였다. 각 국가의 경제성장, 개방화 정도에 따른 이산화탄소 배출과의 관계를 보다 가시적으로 접근했다는 데 의의가 있다.

■ 주제어 ■ 이산화탄소(CO₂), 환경 쿠즈네츠 곡선(EKC), 경제성장, 자유무역

Abstract

This paper investigates the existence of the environmental Kuznets curve (EKC) for carbon dioxide (CO₂) emissions and its causal relationships with economic growth and openness by using time series data (1971-2006) from China (an emerging market), Korea (a newly industrialized country), and Japan (a developed country). The sample countries span a whole range of development stages from industrialized to newly industrialized and emerging market economies. The environmental consequences

* corresponding author : yscho@korea.ac.kr

** We are grateful to the editor and three anonymous referees for constructive comments. The paper had supported by a Korea University Grant.

according to openness and economic growth do not show uniform results across the countries. Depending on the national characteristics, the estimated EKC show different temporal patterns. China shows an N-shaped curve while Japan has a U-shaped curve. Such dissimilarities are also found in the relationship between CO₂ emissions and openness. In the case of Korea, and Japan it represents an inverted U-shaped curve while China shows a U-shaped curve. We also analyze the dynamic relationships between the variables by adopting a vector auto regression or vector error correction model. These models through the impulse response functions allow for analysis of the causal variable's influence on the dynamic response of emission variables, and it adopts a variance decomposition to explain the magnitude of the forecast error variance determined by the shocks to each of the causal variables over time. Results show evidence of large heterogeneity among the countries and variables impacts.

Keywords Carbon Dioxide (CO₂), Environmental Kuznets curve (EKC), Economic Growth, Free Trade, Development

I . Introduction

Improvements in economic growth and welfare can affect the types of technological and financial opportunities used to avoid and manage environmental problems. In this situation, it is interesting to know whether economic growth and environmental preservation can coincide or not. In general, environmental goods and their quality are good, denoting that increased earnings from free trade would increase an individual's demand for higher environmental quality. In the early stage of economic development, a small portion of excess income is typically allocated for environmental problems, and thus, at this stage, the industrialization process is likely to be accompanied by environmental problems. When GDP per capita increases and exceeds a certain threshold, the level of pollution typically decreases. This combined effect can result in an inverted U-shaped relationship between GDP per capita and the level of pollution.

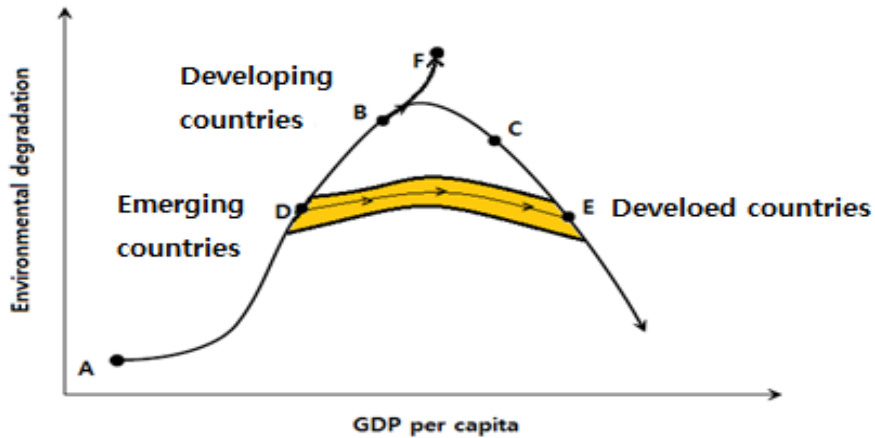
This inverted U-shaped relationship between GDP per capita and various indicators of pollution is referred to as the environmental Kuznets curve (EKC), which was introduced by Kuznets (1955). This hypothesis, which suggests a U-shaped or inverted U-shaped relationship between two variables, implies a non-linear relationship that is applicable to many areas. A number of studies have examined the environmental consequences of trade liberalization and economic growth in recent decades. Furthermore, the climate change

phenomenon, which has been an important research topic in recent years, has been considered to be one of the most important consequences of the global energy system and use. Carbon dioxide (CO₂) accounts for the largest portion of greenhouse gas emissions and is a major source of environmental problems. Thus, it is meaningful to examine the causal relationships between environmental pollution, trade liberalization, and economic growth.²

By applying the EKC theory, previous studies have provided a better understanding of the environmental consequences of international trade and suggested that economic growth can improve the environment and that economic growth is necessary for maintaining or improving the quality of the environment. However, most of the previous studies have not taken into account the different levels of income across countries. In this regard this study is an attempt to remedy this limitation by focusing on the comparison of relationships between CO₂, trade liberalization, and economic growth by accounting for levels of development.

According to the EKC concept, CO₂ emissions are expected to have a positive relationship with the level of income or trade liberalization before the EKC threshold and a negative relationship beyond the threshold. For example, if there is a negative relationship between CO₂ emissions and free trade, then GHG emissions are likely to decrease as the country becomes more exposed to open markets. Similarly, if there is a positive relationship between CO₂ emissions and free trade, then the country is not likely to have experienced its optimal level of trade liberalization. The EKC framework implies the existence of an inverted U-shaped relationship between GDP per capita and environmental degradation to be a local pollutant. However, the existence of the EKC for the global pollutant, for example carbon dioxide emissions resulting in problems of international scale, has not been agreed. There are different views relating to EKC. Galeotti et al. (2006) explained that empirical studies for the EKC hypothesis for CO₂ emissions are “at best mixed.”. Even though we cannot find an EKC curve for CO₂ emissions being evidence of sustainable development, we can find another way of sustainable development through international cooperation. Munasinghe (1999) suggested that the hypothesis of “sustainomics” can be the key to green growth and insisted that developing countries can achieve their target economic growth while maintaining a lower pollution level. Figure 1 illustrates the position of countries at different stages of their development on the EKC.

Figure 1 Tunneling through the EKC using international cooperation and sustainable policies



Munasinghe (1999) insisted on the usefulness of the “tunnel effect,” which may enable developing countries to attain their target economic growth while maintaining a lower level of pollution. Suppose that developing countries lie on Point B in Figure 1, then these countries can move to Point C by using clean technologies and developing and implementing sustainable development policies. Although it is difficult to facilitate the global pollutant to follow this pathway, we can expect a lower rate of increase than from point B to F. Further, if developed countries not only provide financial support to emerging markets and newly industrialized countries to help them cope with environmental degradation, but also transfer their environment-friendly technologies to those countries, the poorer countries may be able to shift from Point D to Point E, which is the basic concept behind the “tunnel.”

The empirical results of this study are based on data from China, Korea, and Japan. These countries, representing the Northeast Asian region, reflect different levels of economic development and have achieved considerable economic development. In addition to investigating the existence of EKC relationships, this study examines the dynamics relationships among three variables—CO₂ emissions, openness, and GDP per capita—by using vector auto regression (VAR) and vector error correction model (VECM). These

models, which use impulse response tests and variance decomposition functions, allow for the analysis of interrelationships among various variables and enable the determination of variables with stronger effects.

This study is unique in that it estimates the EKC by taking the evaluation and policy perspectives for an interesting sample of countries. It focuses on the CO₂ emissions trends of each country and tries to analyze its relationships with openness and GDP per capita conditional on specific, growth, openness, and other characteristics. Such a method allows for the positioning of countries on the EKC. The results indicating their position before and after the turning point have important implications for their growth and environmental policy.

Determining the existence of EKC for CO₂ as a global pollutant is important. If developed countries have an inverted U-shaped curve, it is likely that the global pollutant can be reduced through international cooperation and financial support. Therefore, this study focuses on the existence of EKC for China, Korea, and Japan. Figure 1 illustrates the three countries' economic development levels and their positions on the EKC. Note that China, Korea, and Japan represent an emerging market, a newly industrialized country, and a developed country, respectively, which reflects the characteristics of the above hypothesis. The results of this case study have useful implications for developing and implementing appropriate policies for realizing the tunnel effect.

The rest of this paper is organized as follows. Section 2 provides a brief review of previous research on the EKC, and Section 3 presents the data. Section 4 specifies the relationships between environmental quality, economic growth, and openness by considering country characteristics and technologies. Section 5 presents the dynamic estimation results obtained using the VAR and VECM methods and the results of tests that examined the properties of the data and model specifications, and Section 6 provides some appropriate policy recommendations based on the empirical results and concludes.

II. The Literature on the Environmental Kuznets Curve

An analysis of sustainable economic growth and development requires careful consideration of the environmental consequences of such development. Previous studies examining the nexus causal relationships between the environment, trade liberalization, and economic growth have stressed the need for further research in this area. We now provide a brief review of the growing body of literature investigating this topic.¹⁾

Grossman and Krueger (1993) analyzed the relationship between environmental quality and GDP per capita by focusing on the level of urban air pollution to estimate the turning point for the atmospheric concentration of suspended particular matter (SPM) and sulfur dioxide (SO₂). They proposed that air pollution can improve when GDP per capita increases to sufficient levels. They estimated the turning point to be \$4,000~5,000 (in 1985 U.S. dollars). This is the point at which people typically become concerned about the quality of their environment. If GDP per capita is approximately \$10,000, people may become involved in a number of activities to improve their environment, and thus, the quality of their environment is likely to improve considerably. Seldon and Song (1994) analyzed the relationship between income and air pollutants by using fixed and random effect models with panel data. In contrast to Grossman and Krueger's turning point (i.e., \$5,000 or less for SPM and SO₂), their turning point for these pollutants is greater than \$8,000. They found that nitrogen oxides (NO_x) and sulfur dioxide (SO₂) have a Kuznets curve representing the existence of a relationship between national output and environmental quality.

Copeland and Taylor (1994) investigated the relationship between free trade and environment quality and suggested that free trade has three types of effects on countries. The first is the technology effect in which rising income increases the consumption of environmental goods. Free trade induces people's interest in and understanding of environmental issues and people require effective pollution control and management policies. Thus, the technology effect through free trade is likely to improve the environment. The second is the scale effect. Free trade can lead to increases in world trade volume, and each

1) The methodology has been extended to other types of causal relationships such as GDP growth, inequality and poverty (e.g. Heshmati, 2006).

country increases its output, which can in turn deteriorate the environment. The third is the composition effect. Developing countries tend to attract pollution-intensive industries, and developed countries are likely to avoid such industries to attract foreign direct investment. A decrease in pollution depends on the relative size of the technology and composition effects. Cole et al. (1997) investigated the relationship between GDP per capita and a wide range of indicators by using cross countries panel data and suggested that meaningful EKC's exist only for local pollutants. More global or indirect environmental effects tend to increase monotonically with income, which implies that it is easier to improve urban air pollution than to reduce national air pollution. They also suggested that concentrations of local pollutants tend to reach a turning point at a lower level of GDP and that global air pollutants are likely to reach a turning point at a higher level of GDP per capita.

Table 1 EKC empirical analyses based on SO_x and CO₂

References	Functional form	Model type	Countries	EKC results
<i>SO_x</i>				
Grossman and Krueger (1991)	Level, cubic	FE	32 countries	Inverted U-shaped
Selden and Song (1994)	Level, square	pooling, FE, RE	30 countries	Inverted U-shaped
Cole et al. (1997)	Level, log square	GLS, RE	11 OECD countries	Inverted U-shaped
Torras and Boyce (1998)	Level, Cubic	OLS	19-42 countries	N-shaped
List and Gallet (1999)	Level, square & cubic	FE	US data	Inverted U or N-shaped
Bradford et al. (2000)		FE, RE	Various cities	Inverted U or N-shaped
Stern and Common (2001)	square	FE	73 countries	Inverted U-shaped
Cole (2004)	Log cubic	FE	18 OECD countries	Inverted U-shaped
<i>CO₂</i>				
Shafik and Bandyopadhyay (1992)	square & cubic	Log linear	135 countries	Straight line, upward
Selden and song (1994)	square	FE, RE	30 countries	Straight line, upward
Cole et al (1997)	Level, log square	GLS, FE	11 OECD countries	Straight line, upward
Agras and Chapman (1999)	Log square	FE	34 countries	Inverted U-shaped
Hill and Magnani (2002)	square & cubic	GLS	156 countries	Straight line, upward
Friedl and Getzner (2003)	square & cubic	Linear	Austria	N-shaped
Akbostanci et al. (2009)	square & cubic	Time series	Turkey	Straight line, upward

A noteworthy study by Moomaw and Unruh (1997) examined the relationship between CO₂ and the level of income in developed countries. They selected 16 OECD member countries to investigate the EKC. Most of the countries showed an inverted U-shaped trend, and their turning point occurred between 1970 and 1980. Furthermore, by applying the cubic model specification to the 16 countries, they determined that the N-shaped curves for all the estimated coefficients were statistically significant. The first and second threshold points were between \$12,810 and \$18,330. Friedl and Getzner's (2003) study showed that both linear and quadratic models were not suitable for analyzing the case of Austria, but the cubic model can represent it more appropriately. The relationship between GDP and CO₂ emissions followed an N-shaped curve between 1960 and 1999. Galeotti and Lanza (2003) verified the inverted U-shape curve for the relationship between CO₂ emissions and GDP.

Huang et al. (2008) considered economic development and greenhouse gas (GHG) emissions, which have been the focus of the Kyoto Protocol. The Protocol attempts to limit increases in GHG emissions among developed countries. They analyzed single-country time series and GDP data and found that most of the Annex II countries do not provide evidence supporting the EKC hypothesis. Akbostanci et al. (2009) investigated the relationship between income and environmental degradation in Turkey. By using a time series model spanning from 1968 to 2003, they found that CO₂ emissions and income tend to have a monotonically increasing relationship in the long run. This monotonically increasing relationship implies that the EKC hypothesis does not hold in this case. Galeotti et al. (2009) explained that EKC is not found at all the times relating to CO₂. Furthermore, this paper makes a significant contribution to the statistical robustness of the EKC by giving it a direction. The authors emphasize that theoretical and empirical investigations are clearly organized before the existence and that the validity of EKC is established. The review of previous research indicates that there are substantial differences among the countries, suggesting that the hypothesis of the Kuznets curve has a number of weaknesses that need to be addressed.

III. The Data

The data is an annual time series aimed to be used in time series regression analysis of three countries, namely China, Korea, and Japan. The data spanned from 1971 to 2006 and contained key variables, such as CO₂, GDP, and Openness, and some information on the source of CO₂ emissions and variables underlying openness.

CO₂ emissions, measured in metric tons, were transformed into a per capita measure to adjust for the population size of the three countries. GDP was measured as real GDP per capita. A country-specific GDP deflator was used to convert the monetary values into fixed ones. Openness, a measure of trade liberalization, was measured as the sum of imports and exports as a share of total GDP in a given year.

The carbon dioxide emission variables are obtained from Carbon Dioxide Information Analysis Center (CDIAC). The source of Real GDP per capita and openness is the Penn World Table 6.3. A number of variables (RE, FOP and energy type shares) are added to account for the nature of the energy system. RE is the contribution of renewable energies and energy from waste. This data is sourced from OECD data. The FOP data were drawn from the 2009 BP Statistical Review of World Energy. Through this source, we obtained data on the consumption of oil (in million tons), natural gas (in million tons of oil equivalent), and coal (in million tons of oil equivalent). These three variables were totalled for each country and then divided by the total population of the country to obtain FOP (fossil consumption per capita).

Table 2 Definition and descriptive statistics of the variables, 1971-2006

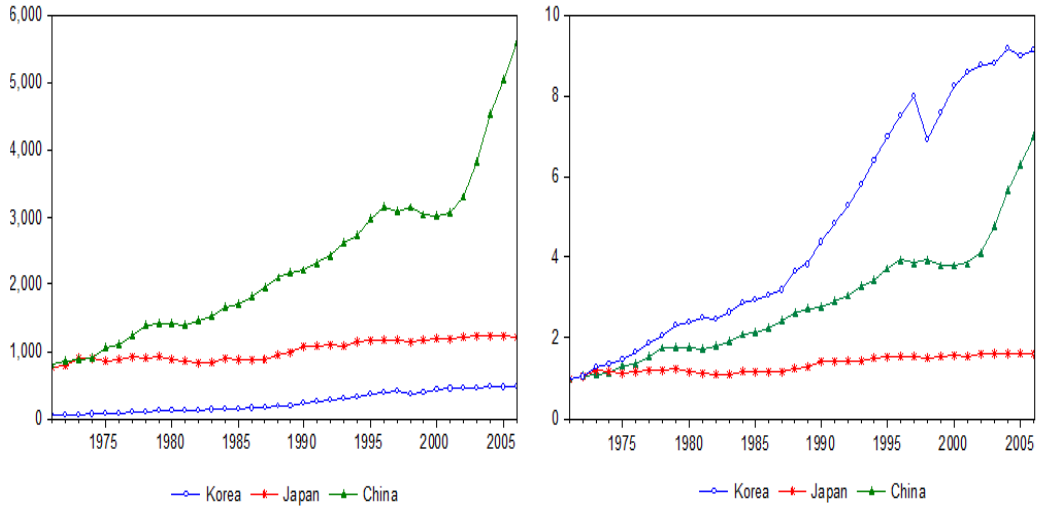
Variables	Definition	China		Korea		Japan	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
CO ₂ emission	CO ₂ emissions in Mt	2306.249	1192.676	11447.640	148.825	1013.063	151.843
CO ₂	CO ₂ / Population (ton CO ₂ /capita)	2.013	0.801	5.548	2.915	8.359	0.890
RE	Contribution of renewable energies (%)	26.586	6.942	0.731	0.269	3.031	0.544
FOP	Fossil consumption/ capita x 100	0.059	0.023	0.200	0.124	0.254	0.027
GDP	Real GDP per capita	2379.074	1837.098	11447.640	6415.589	23317.610	5174.324
OPEN	The degree of openness	32.800	13.768	39.922	19.649	17.448	4.479

A summary of statistics in the annual time series data is presented in Table 2. Japan's emission per capita is the highest, followed by Korea and China. A similar pattern is found concerning GDP per capita. China has a much higher share of renewable energy sources in its per capita energy consumption, while Japan has a higher share of fossil consumption per capita. Korea, followed by China, has a relatively higher dependency on an imported primary source of energy than Japan.

Figure 2 shows the development of CO₂ over time in level and changes for the three countries. Figure 2.A on the left shows the development of the CO₂ level over time, while Figure 2.B on the right shows the trends in the growth rate of total carbon dioxide emissions of individual countries normalized at 1971 values.

Generally, CO₂ emissions tend to increase. In Korea, there is a declining area in relation to the Asian Financial Crisis, but CO₂ emissions were on the rise again after 1998 in relation to the recovery of the economy. At the beginning, the level of CO₂ was close in Japan, and the economic reform in China changed the situation dramatically. By the end of the period in China, the gap had increased by more than 6-fold. China also has the fastest increasing trend, but we can find a slowdown, and even slight decline, after the Tiananmen square riots. The graph shows a rapid rise in the CO₂ emissions since 2001. CO₂ emissions fluctuated a lot in the case of Japan; however, its trend is slowly increasing, in particular after 1985. The Figure 2.B displays emission trends of three sample countries jointly in the same graph normalized at 1971 values. The objective is to enable a comparison of the levels and its development concerning the relative emissions of each country. Here the Figure 2.B shows that the growth rate is much higher in Korea than in China, but the gap has been shrinking since 2002. The growth in Japan is very low, and the level is relatively constant during the entire period.

Figure 2.A and 2.B The trends of carbon dioxide and its growth rate 1971-2006



IV. Empirical Analysis

1. Specification of Environmental Kuznets Curve

We specify and estimate the environmental Kuznets curve (EKC) based on CO₂ emissions per capita for China, Korea, and Japan to determine whether these countries have an EKC. The results are expected to have important implications for the countries, as they establish environmental targets for CO₂ emissions. To verify the shape of the EKC, we specify and estimate the following multiple regression equations for each country:

$$(1) \quad \ln CO_{2t} = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 (\ln GDP_t)^2 + \alpha_4 OPEN_t + \alpha_5 OPEN_t^2 + \alpha_6 \ln RE_t + \alpha_7 Trend_t + \alpha_8 \ln FOP_t + \varepsilon_t$$

$$(2) \quad \ln CO_{2t} = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 (\ln GDP_t)^2 + \alpha_3 (\ln GDP_t)^3 + \alpha_4 OPEN_t + \alpha_5 OPEN_t^2 + \alpha_6 \ln RE_t + \alpha_7 Trend_t + \alpha_8 \ln FOP_t + \varepsilon_t$$

where CO_2 denotes CO_2 emissions per capita and is an endogenous variable that represents better environmental quality if it is a lower level. The main exogenous variables are $\ln GDP$, which is logarithm of GDP per capita and OPEN representing trade openness or trade dependence on foreign countries. We focus on the relationships among trade, income, and environment. In this context, several research works are Lucas et al (1992), Baek et al (2009) and Hossain (2011). To test the presence of EKC, equations (1) and (2), which are derived from the relationships between pollution levels, GDP, and Openness, will be used. The relationships are estimated as being conditional on renewable energy share, fossil energy consumption, and time trend.

Figure 3.A The inverted U-shaped Environmental Kuznets Curve

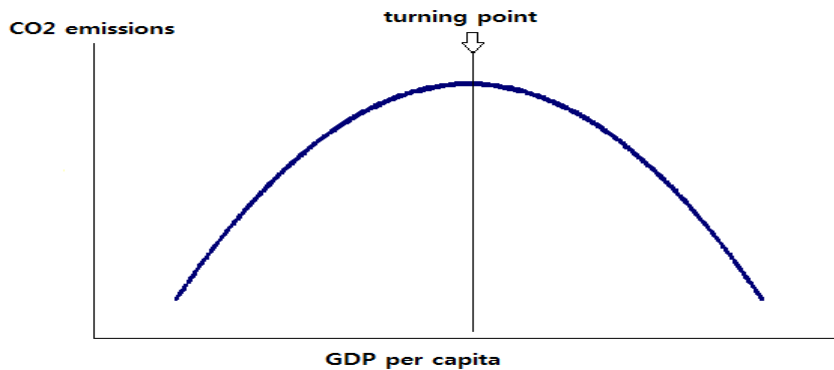
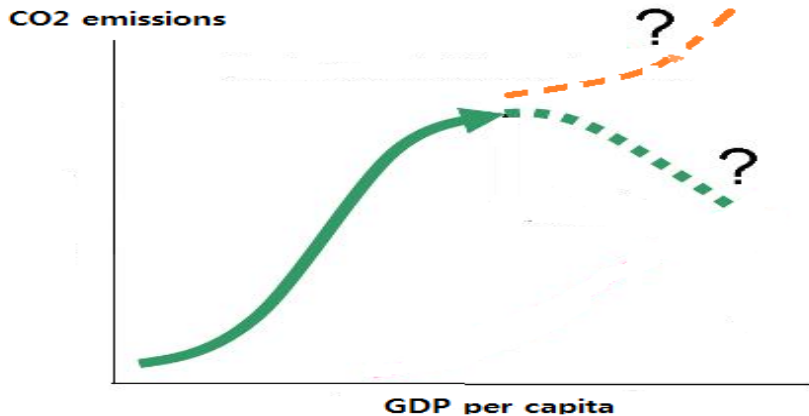


Figure 3.B The N-shaped Environmental Kuznets curve



Pollution levels are expected to increase with growing income up to a threshold level beyond which pollution levels are expected to decrease with higher income levels. The combination of these two effects, $\alpha_1 > 0$ and $\alpha_2 < 0$ in Model (1), creates the inverted U-shaped relationship between per capita CO₂ emissions and GDP. A representative inverted U-shape example of an expected EKC is shown in Figure 3.A. Furthermore, we can easily test the presence of an N-shaped curve (Figure 2.B) by using cubic functional form ($\alpha_3 > 0$) as shown in Model (2). In the EKC empirical analysis based on the SO₂ pollution case, N-shaped curve is found by Torras and Boyce (1998), List and Gallet (1999), Bradford et al. (2005), and others. Therefore, this paper adds a variable GDP^3 , representing a cubic model specification to verify the existence of N-shaped relationships between carbon dioxide and economic growth.

In an attempt to broaden the concept of EKC, we investigate the relationship between environmental quality and trade openness. This is motivated by the fact that at early stages of economic development, free trade leads to an increase in real income, and at the same time, it increases the pollution level because environmental quality is regarded as a luxury good and not a normal good. However, as countries achieves a certain level of GDP, the increased income from free trade encourages consumers to increase their demand for a clean environment, which leads to an attempt to reduce environmental damages through increases in clean production and improvements in environmental quality (Galeotti and Lanza, 1999). Based on the pattern described above, a country tends to follow increasing pollution levels as trade openness proceeds ($\alpha_4 > 0$), and later we find declining pollution levels at more advanced stages of free trade ($\alpha_5 < 0$). We have already explained variables RE and FOP, so in this part, we will skip the explanations of these conditional variables. Trend is a time trend variable used as a proxy to represent the effects of other exogenous time dependent variables, such as the trend in pollution abatement, environmental policy change, and technological change.

2. Empirical Results

As noted above, estimating and quantifying the effect of free trade on income and environmental quality is necessarily an empirical problem, and it varies according to

circumstances, such as individual countries' development stage, degree of openness, population, and policies of countries. In this paper, we deal with exogenous variables, such as GDP, OPEN, and other indicators of environment and development. Through individual countries' OLS estimation results, we can obtain an estimation of the effects on each country's environment. Separate country regressions allow for heterogeneous effects in response to differences in level of development of the sample countries. Thus, in order to investigate the relationships between environmental degradation, economic growth, and trade liberalization, we use simple OLS regression analysis. Table 3 reports the estimation results.

Table 3 summarizes the regression results of each country based on the two model specifications, differing with square and cubic GDP specifications. Since the two models differ only by one parameter, the t-test can be used to determine the level of generality of the model. A matter of primary concern is the estimated coefficients, their signs, and significance. We are interested in not only quadratic Model 1, but also cubic Model 2 to establish the absence of EKC, inverted-U, or N-shaped nature of the Kuznets curve.

In the case of Korea, GDP per capita and its square are statistically significant in Model 1, and the cubic component in Model 2 was also statistically significant. On the other hand, unlike in Model 1, the OPEN and its square term in Model 2 are statistically insignificant. The Durbin-Watson statistics for these models are 1.8587 in Model 1 and 2.2016 in Model 2, respectively. The Durbin-Watson statistic is a test for first-order serial correlation. The DW test statistic, 2.2016 in Model 2, rejects the null hypothesis that there is no positive serial correlation, but the test result for Model 1 cannot reject the null hypothesis. Therefore, these statistics suggest that the estimated standard errors, and the significance of the coefficients of the parameters in Model 1 are reliable. Therefore, Model 1 is more suitable for estimating the EKC for Korea.

In looking at the estimated coefficient of GDP, we notice that it is negative and that the GDP^2 has a positive sign. This shows that economic growth does not have the expected Kuznets effect on environmental circumstances in Korea. At the early stage of economic growth, environmental pollution cannot be avoided, but when reaching a higher level, circumstances would gradually be improved as the level of development and welfare improves. The result is in contradiction to the expected results, and thereby cannot find an

inverted U-shaped threshold point. In Figure 3, we show the results of regressions of per capita CO₂ emissions on per capita GDP. Here we can find evidence of a U-shaped EKC. The turning point²⁾ is estimated to be \$8210. In the early stage, there is declining trend, but it immediately begins to rise after the turning point. This result refutes the EKC hypothesis in the case of Korea.

Table 3 Results from OLS estimation method (N=37)

	China		Korea		Japan	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Constant	11.28983*** (4.9389)	7.69721*** (3.4422)	27.62023*** (6.0186)	26.51399*** (7.6471)	49.43529*** (12.020)	54.67682*** (11.5849)
GDP	2.41E-05 (0.2366)	0.00086*** (3.2158)	-0.00031*** (-3.4569)	-0.00049*** (-6.3095)	-0.00035*** (-2.8226)	-0.00159** (-2.4923)
GDP ²	1.97E-08* (1.9269)	-1.52E-07*** (-2.8866)	1.90E-08*** (7.2172)	3.13E-08*** (9.4679)	7.99E-09*** (2.9193)	6.77E-08** (2.2365)
GDP ³	- -	1.12E-11*** (3.3067)	- -	-2.81E-26*** (-4.6396)	- -	-9.17E-13* (-1.9795)
OPEN	-0.02270* (-2.4854)	-0.02768*** (-3.4801)	0.07756*** (3.7144)	-0.01384 (-0.5490)	0.08298 (0.9852)	0.09749 (1.2134)
OPEN ²	0.00024* (1.9206)	0.00041*** (3.4182)	-0.00089*** (-5.1414)	4.16E-05 (0.1723)	-0.00218 (-1.2146)	-0.00155 (-0.8906)
RE	-0.06152*** (-3.5965)	-0.07239*** (-4.8291)	0.04843 (0.3283)	-0.08182 (-0.7136)	0.12545 (1.2545)	0.05252 (0.5154)
Trend	-0.01922 (-1.4797)	-0.04951*** (-3.4392)	-0.43874*** (-3.7855)	0.07547 (0.5347)	0.00689 (0.3776)	-0.00645 (-0.3465)
FOP	0.94606** (2.6709)	0.48827 (1.4663)	3.41883*** (6.2256)	3.05923*** (7.2647)	6.46996*** (8.8037)	5.95312*** (7.9868)
R ²	0.9951	0.9965	0.9985	0.9992	0.9891	0.9905
F-value	784.2839	940.1131	2613.3790	4027.8280	350.6743	340.4996
DW-statistics	1.8549	2.3707	1.8587	2.2016	1.6817	1.7348
Wald-test	<i>H</i> ₀ : the quadratic curve, <i>H</i> ₁ : the cubic curve					
	3.4424*		0.0041		3.9187*	

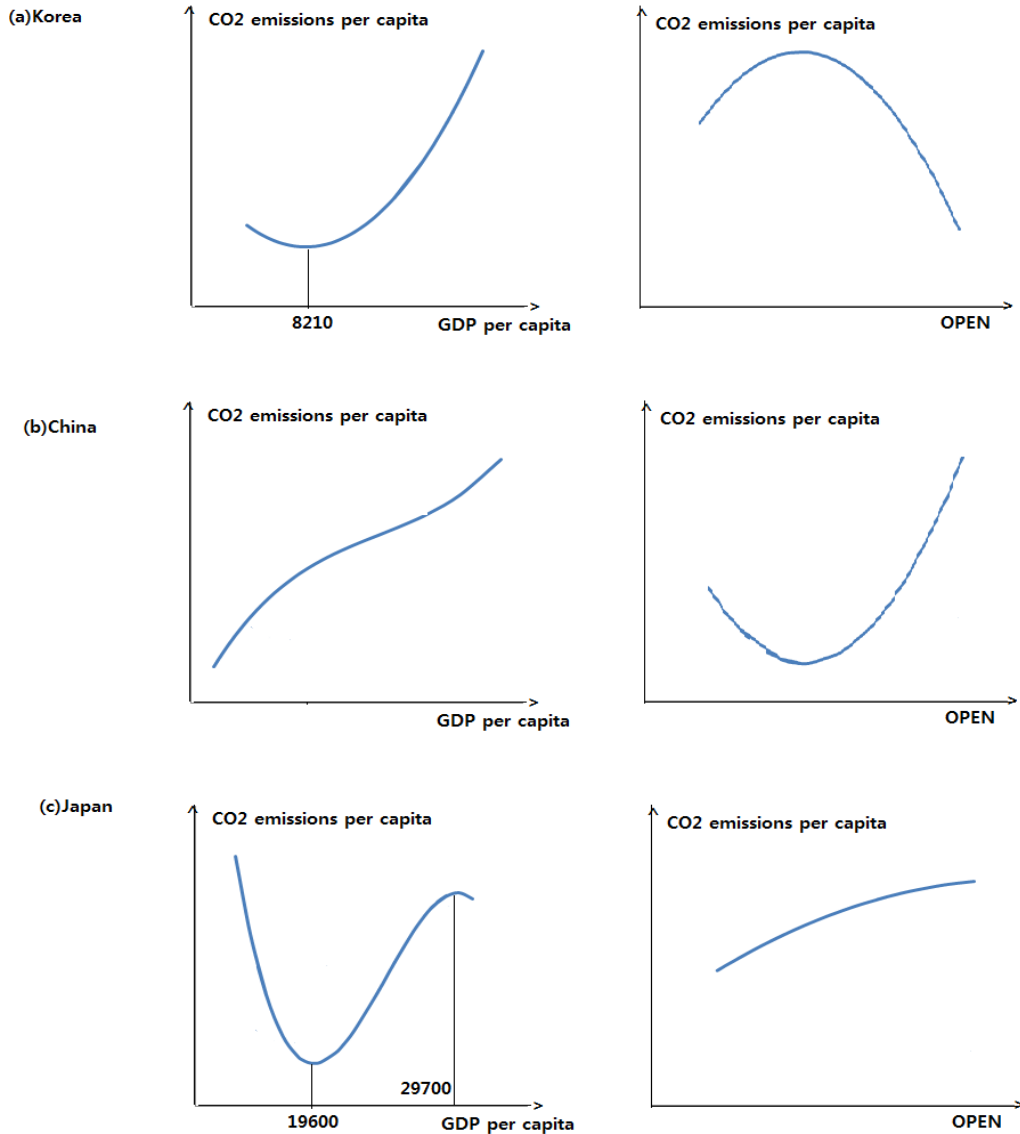
Note: significant at the 1% (***), 5% (**) and 10% (*) levels of significance, t-values in parenthesis.

2) The conditions for this to occur are for estimated coefficient $\alpha_1 > 0$, $\alpha_2 < 0$, its turning point is computed as $-\frac{\alpha_1}{2\alpha_2}$.

Dependence on foreign trade has a significant impact on CO₂ emissions. The variables OPEN and $OPEN^2$ exhibit inverted U-shaped relationships with CO₂ emissions. Similar conclusions are reached by Taskin and Zaim (2000), as there is almost a common agreement that there exists a U-curve type quadratic relationship with the environmental quality where OPEN represents a positive coefficient and $OPEN^2$ shows negative coefficient. At the early stage of free trade, it leads to increased environmental pollution, but when individual countries exceed certain level of openness, then the conditions for a polluted environment would be improved. This is because the more trade circumstances liberalize, the more people make an effort to meet international environmental standards for international trade, collaboration and, competition purposes. RE shows a positive relationship, but this variable is not statistically significant. Time trend represents the technological change, and it represents a negative CO₂ relationship with time suggesting a decline in emissions, as was our expectation. As technologies develop, it is conducive to environmental quality.

In the case of China, GDP per capita and CO₂ emissions are shown not to be statistically significantly related to Model 1, but they are to Model 2. For this reason, we find Model 2 to be more suitable in estimating the EKC of China's case. We notice the positive coefficient of GDP, negative coefficient of GDP^2 , and again the positive coefficient of GDP^3 . These together suggest an N-shaped curve describing the relationship between pollution and GDP. First comes the initial deterioration of environmental conditions and then comes economic growth which leads to an improvement in the environment. In spite of the efforts of environment-friendly development, environmental circumstances cannot get better continually. Through the signs of the coefficient, we think intuitively, the curve has an N-shape. However, after depicting the graph, we can work out that the cubic function is monotonically an increasing function which does not have any external value. In cases with such pattern, there is no use verifying the threshold point on the EKC.

Figure 4 The EKC for CO₂ emission per capita in China, Korea, and Japan



Also in China's case, the variables related to free trade have a significant impact on the environment. These openness variables represent a U-curve type quadratic relationship with CO₂ emissions. It means that there is a threshold level of openness, but in reversed form. RE and Trend represent negative and, by expectation, consistent relationships. Increasing the

amount of application of New and Renewable Energy sources and developing the technology of energy efficiency can contribute to emissions decrease in China.

In the case of Japan, it was difficult to determine the more appropriate model. The DW test statistic was not helpful in selecting the appropriate model. In Model 1, beyond a certain level, CO₂ emissions showed an increasing trend. The estimated turning point was \$29,700 in terms of GDP per capita. In spite of many efforts to reduce carbon dioxide emissions, it is not easy to achieve desired reductions if economic growth is based upon a premise. In Model 2, their respective signs suggest an inversed N-shaped curve. The relative minimum turning point is calculated at \$19,600, and the relative maximum turning point is calculated to be \$29,700. Parameters estimated with the both models are significant at a 1%. Therefore, it is not easy to judge which model is preferred. Hence, the Wald test³⁾ is performed to select the more appropriate model between the quadratic and the cubic function (see also Table 3). It is shown that the null can be rejected at the 10% level of significance, so the cubic model is described as the relationship between GDP per capita and CO₂ emissions. Through this regression of Model 2, we notice that Japan has an inversed N-shaped curve which exhibits the inverted U-shaped curve in the later parts of the curve.

In terms of openness, the more economy is dependent on trade, the more carbon dioxide is emitted. However, if Japan exceeds a certain level of openness, then CO₂ emissions decrease. This is interpreted that the rise in GDP through trade will in turn generate increases in demand for environmental goods. Part of the gain is then used to alleviate environmental pollution. However, it is not statistically significant and thereby hard to determine whether a decreasing part exists.

3) The Wald statistics is to test the parameter restriction in $\alpha_3 = 0$, the null of the quadratic specification when $\alpha_3 = 0$ against the alternative of the cubic specification when $\alpha_3 \neq 0$.

V. The Vector Autoregressive and Vector Error Correction Models

1. The Framework

After having established the relationship between CO₂ emissions, GDP, and openness, this paper uses a vector auto regression (VAR) to test the short-run relationship among the determinants of environmental variables. VAR has the advantage that it is very useful by allowing all variables to interact with themselves (past values) and each other in regression analysis without any theoretical structure on the estimators. Furthermore, VAR can conduct dynamic analysis and is useful in overcoming the static disadvantage of OLS because VAR can explain the dynamic structure of time series better than the static OLS estimation method, albeit at the expense of complexity in interpretation of effects. In time series data, most of the indicators tend to have trends. To avoid this problem, non-stationary variables should be differentiated at least once to transform them into a stationary form.

Through such a transformation process, we can make the variables stationary, but the differentiation procedure may entail some loss of the long-term characteristics of the original data. However, Engle and Granger (1987) proposed that even though all the variables in the model are non-stationary, the series may be stationary if the variables have a linear combination. In such a case, we can consider the variables to be cointegrated. Because the use of VAR depends on the stationary condition of the data set, we first briefly discuss and present the results of a unit root test—the augmented Dickey-Fuller (ADF) test.

Another test to be conducted is the adaption of the Johansen's Cointegration test, which will follow. If there exists a long-run equilibrium relationship, we will adopt the Vector Error Correction Model (VECM). Through the Error Correction Mechanism, a proportion of the disequilibrium in one period is corrected in the next period. Engle and Granger (1987) proposed that once the variables are determined to be cointegrated, there always exists a corresponding error correction representation, implying that changes in the dependent variable are a function of the level of disequilibrium in the cointegrating relationship captured by the error correction term (ECT). The ECT is used to correct such disequilibrium, and thus, we used it to examine the short-run and long-run relationships between CO₂ emissions and its determinants.

2. Unit Roots and Cointegration Tests Results

The possibility of the nonstationarity of time series data raises an important issue. A stationary series is defined as a series that tends to return to its mean value and fluctuate around it within a more or less constant range, whereas a non-stationary series is defined as a series whose means differ at different points in time and variance increases with the sample size. If a data set contains non-stationary series, OLS cannot provide valid estimation results and interpret various relationships. Most parts of economic variables generally are non-stationary. To avoid this problem, non-stationary variables should be differentiated. The variables are differentiated d times, and then stationary and OLS results are valid in interpretation.

The Unit root test is conducted to test stationary. Individual variables are tested by the Augmented Dickey-Fuller (ADF) test, and the results are shown in Table 4. The results indicate that there is a unit root in all the level series but not in the first-difference series. Therefore, we conclude that each series follows an I (1) process.

Table 4 Results of Unit Roots Tests

Test statistics	Log(CO ₂)	Log(GDP)	Log(OPEN)
China			
Level t value	0.1252	1.4435	1.1566
The first differences	3.4044***	3.5004***	4.7947***
Korea			
Level t value	1.9837	2.2068	0.9824
The first differences	5.6869***	5.6787***	5.1769***
Japan			
Level t value	1.3957	0.4453	0.4453
The first differences	5.1872***	6.6458***	6.6458***

Note: MacKinnon (1996) one-sided p-values, ***= $p < 0.01$; **= $p < 0.05$; *= $p < 0.1$

In any time series analysis, it is important to determine whether one economic variable can help forecast another. For example, If x Granger-causes y but y does not cause x Granger-, then the past value of x is useful in predicting the current and future values of y. The Granger causality test assumes that the information is related to each variable. To confirm how the variables are arranged in the vector form, this step applied the pair-wise Granger causality tests. We conducted the test to determine the direction of causality and the short-run effect of the relationship. This process requires the use of VAR or VEC models because the results obtained using these models are influenced by the ordering of variables. The result of the Granger causality tests show that in the case of China, Korea, and Japan, OPEN Granger-causes GDP. According to the results of the causality tests, we determined an ordering of the variables in the following way:

$$(3) \text{ } CO2_t = f(CO2_{t-p}, OPEN_t, OPEN_{t-p})$$

where p is the number of lags in the model. Prior to finding the proper number of lag, we decided to use a VAR model. In general, SC (Schwartz Information Criterion), AIC (Akaike Information Criterion), and HQC (Hannan-Quinn Information Criterion) are used to determine the optimal number of lags (p). In this paper, AIC is selected to estimate the optimal lag because SC tends to underestimate the lag (p). Under the lag length selection rule we have chosen the smallest value, and this paper uses 5 lags as the maximum lag length. The optimal lag order length is selected by the criterion, in Korea p=5, in China p=3, and in Japan p=2. In the analysis of the VAR model, each variable should be stationary, and there must be no cointegration among the variables. To determine whether the variables were cointegrated, we used the Johansen cointegration test. Through this test, we can choose among the two VAR or VECM models. If the data is stationary and the variables are cointegrated, a VECM model is preferred. To test for the co-integration relationship, this paper uses lag length chosen by the information criteria above. The result of the Johansen co-integration test is reported in Table 5. In the case of China and Korea, the null-hypothesis of zero is rejected at the 5% level so there is one cointegrating vector.

In this case, we also use the VECM model. For the Japanese case, all of the null-hypothesis are not rejected at the 5% level. Hence, we can conclude that there is no cointegrating vector, and the VAR model will be adopted for the Japanese data.

Table 5 Results of Johansen Cointegration Test

Hypothesized No. of CE(s)	Eigen value		Trace Statistic	Λ-max	
China					
None *	r = 0	r=1	0.66738	44.7673	36.3254
At most 1		r=2	0.16182	8.44195	5.82530
At most 2		r=3	0.07623	2.61665	2.61665
Korea					
None *	r = 0	r=1	0.58719	37.8305	29.1060
At most 1		r=2	0.02904	8.1201	8.6530
At most 2		r=3	-	-	-
Japan					
None	r = 0	r=1	0.22830	13.4583	8.81147
At most 1		r=2	0.12372	4.64683	4.49069
At most 2		r=3	0.00458	0.15613	0.15613

Note: * Significant at the 5% level

3. The VAR Model

The Vector Autoregression (VAR) model, suggested by Johansen, is used to investigate the dynamic interrelationships between CO₂ emission, GDP, and Openness. The Johansen method uses this model, including up to k lags as follow:

$$(4) \quad X_t = u + A_0 + A_1 X_{t-1} + A_2 X_{t-2} + \dots + A_k X_{t-k} + u_t$$

where

$$(5) \quad X_t = \begin{bmatrix} Open_t \\ GDP_t \\ CO2_t \end{bmatrix} \quad \text{and} \quad u_t = \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix}$$

If all variables are non-stationary, cointegrating vectors exist. Under such conditions, the Vector Error Correction Model (VECM) is defined as:

$$(6) \quad \Delta X_t = u + \Gamma_1 \Delta X_{t-1} + \Gamma_2 \Delta X_{t-2} + \dots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k+1} + u_t$$

where X_t and u_t are defined previously. Δ is the difference operator. Γ are the coefficient matrices of short-run dynamics and Π are the matrix of long-run coefficients. Long-run impact is calculated from matrix $\Pi = \alpha\beta'$ (Johansen, 1988; and Johansen and Juselius, 1992).

4. The Long-run and Short-run Relationship (VECM) in Korea and China

The long-run estimation results for the VECM are reported in Table 6. The coefficient of the ECT (α), which indicates the speed-adjustment coefficient on the long-run correction term, and the β coefficient, which means individual variables' coefficient in the error correction term, are reported.

Table 6 Long-run Coefficient of the VECM

	CO ₂	GDP	OPEN
China			
<i>β</i> coefficients of the ECT	1.00000	-0.62996*	0.08608
(standard errors)		(0.02671)	(0.06927)
Coefficient on the ECT(α)	-0.25538*	0.18578*	-0.15166
(standard errors)	(0.10598)	(0.07743)	(0.24865)
Korea			
<i>β</i> coefficients of the ECT	1.00000	-0.02536*	0.12603
(standard errors)		(0.0018)	(0.64538)
Coefficient on the ECT(α)	-1.25677*	-49.55878*	0.01101
(standard errors)	(0.28036)	(11.77440)	(0.04438)

Note: * Significant at the 5% level, (standard errors are in parentheses). ECT is error correction term.

The results show that, in the case of Korea, since all of the β coefficients of the ECT's t-statistics are greater than the critical value, it is interpreted that GDP is significant in this equation, and OPEN is insignificant. GDP and its square have negative signs. Therefore, GDP is found to have a positive long-run relationship. In China's case, the β coefficients of the ECT of GDP have a negative sign while OPEN has a positive sign, but OPEN is not statistically significant. Therefore, CO₂ and GDP have a positive long-run relationship. The results based on both Korea and China not only take into consideration the impact of the long-term factors on the equilibrium but they also allow examination of the short-run impact factors.

The coefficient on the ECT (α), adjustment speed in the long-run for CO₂, and GDP in case of Korea is -1.25677 and -49.55878. If the coefficient value is over-valued, then it will be adjusted downward and vice versa. The ECT suggests that once a shock emerges, convergence to equilibrium is rapid, so that the size of coefficient of the ECT (α) can be interpreted as an adjustment speed. The coefficient on the error correction term implies that a deviation from the equilibrium level during the current period will be corrected in the next period. In the same way, we can analyze the coefficient of the ECT (α) for GDP in China. The size of coefficient on the ECT is interpreted as speed of adjustment, where 0.18578 means that about 18.6% of the imbalance situation is corrected in the first period.

In Korea, the coefficient of OPEN is significant at the 5% level, and its sign is negative. The degree of openness (OPEN) increases by 1%, and then CO₂ emissions decrease by 5.8%. This negative relation varies from -0.0520 to -0.0852 only in the short-run. On the contrary, OPEN does not have a significant long-run relationship. The coefficient of GDP is not significant at the 5% level. In the previous statement, we have already mentioned our observation that CO₂ has a positive long-run relationship, but the relationship of CO₂ and GDP is insignificant in a short-run perspective.

The short-run results based on the VECM model for China and Korea are reported in Table 7. In China, there is no significant short-run relationship between OPEN and CO₂, but the relationship of OPEN and GDP is significant. If GDP increases by 1%, it leads to a 0.67% increase in CO₂ emission just in the short-run. However, we have already obtained

the result that CO₂ and GDP have a positive long-run relationship. In case of China, the CO₂ emissions and GDP have a positive relationship regardless of whether it is long-run or short-run.

Table 7 Short-run Coefficient of the VECM

	ΔCO_2	ΔGDP_2	$\Delta OPEN_1$
China			
ΔCO_2	0.72255*	0.08195	0.15548*
ΔCO_2	0.09690	-0.21302	0.08384
ΔGDP_{t-1}	0.66768*	0.25377	1.43166*
ΔGDP_{t-2}	0.66936*	0.16016	-1.92163*
$\Delta OPEN_{t-1}$	0.00819	0.04755	0.12301
$\Delta OPEN_{t-2}$	-0.06540	-0.01917	-0.13983
Korea			
ΔCO_2	1.60505*	0.03353	61.01750*
ΔCO_2	2.28986*	0.16965	100.54520*
ΔCO_2	1.13167*	0.18171*	45.85240*
ΔCO_2	1.98281*	0.04843	51.65980*
ΔGDP_{t-1}	0.69992	0.00571	58.85880
ΔGDP_{t-2}	1.08607	-0.17354	-38.68920
ΔGDP_{t-3}	-1.32363	-0.17354	-38.68920
ΔGDP_{t-4}	-0.93165	-0.31816	-38.68920
$\Delta OPEN_{t-1}$	-0.05754*	-0.00064	-2.24494*
$\Delta OPEN_{t-2}$	-0.08521*	-0.00473	-3.59916*
$\Delta OPEN_{t-3}$	-0.05204*	-0.00307	-2.09347*
$\Delta OPEN_{t-4}$	-0.07674*	-0.31816	-138.96500*

Note: * Significant at the 5% level.

Table 8 The results of VAR

	$\log(CO_2)$	$\log(GDP)$	$\log(OPEN)$
$\log(CO_2_{t-1})$	0.85890*	-0.16866*	0.21871
$\log(GDP_{t-1})$	0.12751*	1.01912*	-0.01818
$\log(OPEN_{t-1})$	-0.07109	0.04519	0.90097*
Constant	-0.09093	0.86724*	-1.02319

Note: * Significant at the 5% level.

5. VAR in Japan

Table 8 shows the result of VAR estimation for Japan. All variables in the VAR model are transformed into natural logs. As a result of the estimation, we find that the increased GDP in the preceding term increases CO₂ emissions. However, the estimated coefficient of the OPEN is not statistically significant in the equation of the CO₂. Even though the VAR model is useful in showing the dynamic relationship among the variables, the estimated coefficient is not easy to interpret intuitively. Therefore, variance decompositions (VDCs) and the impulse response functions will be carried out to check the stability of the models.

6. Test of Stability

If the estimated VAR and VECM are stable, then all coefficients should be less than 1 and inside the unit circle. If the VAR and VECM are not stable, analyzing certain results are meaningless. If the number of endogenous variables is k and the maximum lagged period is p , then the number of unit roots that we have is k times p . If we estimated the model with r cointegrating relations, then $k-r$ roots lie inside the unit circle. In case of China and Japan, when we use CO₂, GDP, and OPEN as endogenous variables, this model is a poor VAR and VECM model. As a result, further analysis is not needed because the results do not mean anything. To satisfy the stability, modified models are need. The solution is using the endogenous variables $\log(\text{CO}_2)$, $\log(\text{GDP})$, and $\log(\text{OPEN})$. Here the used VAR and VECM model are not misspecified models.

The VAR and VECM models through the impulse response functions allow for analysis of certain variable's influence on dynamic response of endogenous variables. The results of the VAR/VECM stability test showed that: Korea's VEC specification imposes 1 unit root, China's imposes 2 unit roots of which no roots lies outside the unit circle, and finally in the case Japan, VAR satisfies the stability condition.

7. Variance Decompositions (VDCs) and Impulse Response Functions

We adapt variance decomposition to explain the magnitude of the forecast error variance determined by the shocks to each of the explanatory variables over time. The results are presented in Table 9.

Detecting Granger causality is strictly restricted to within-sample tests and does not show the relative magnitude of these variables. In order to estimate the degree of exogeneity of the variables, dynamic properties of the system, and the relative strength of the Granger-causal relationship beyond the sample period, we consider the decomposition of variance methodology. The variance decomposition method measures the percentage of a variable's forecast error variance that occurs as the result of a shock from each of the variables into contributions arising from its own and the other variables' variance. The results of variance decomposition for the three countries are summarized in Table 9 over a 20-year period.

Based on the Korean data, the variance decomposing value of GDP and OPEN is almost the same level at the end of year six. Afterwards, the variance of OPEN decreases rapidly. From 13th year to 20th year, OPEN approximately accounted for 7% of the total variance. At the same time, GDPs share increased rapidly. Finally, after 20 years, the forecast error variance for CO₂, explained by its own innovations, is at 25.75%, and GDP represents 67.25% percent of the variance of CO₂. In the short-run, OPEN considerably effects CO₂ emission. This result coincides with the analysis of the coefficient of VECM. Furthermore, in the long-run, GDP absolutely influences CO₂ emission.

In the case of China, at the first period, the forecast error variance for CO₂ is perfectly explained by its own innovation. Interestingly, at the early part of the period, the forecast error variance of CO₂ explained by its own innovation is at 100.0%, but the variance decomposition of results indicates that GDP and OPEN have great influences as time elapses. For instance, at the end of years three, the direct effect of CO₂ falls rapidly by as much as 74.26%. Also notable is the fact that OPEN's share sharply increases, and it accounted for 56.36 percent by the seventh year. CO₂ can be mainly explained by innovations in OPEN during the early stages. After that, the situation is reversed. Since the seventh year, the Table 9 shows a rapid rise in GDP from 8.68% to 77.56%. After 20 years,

the forecast error variance for CO₂, explained by its own innovations, is just 3.35%, and other variables show higher percentage error variance in explaining CO₂ variations. This result corresponds to Granger causality tests that GDP and OPEN Granger-cause CO₂.

Table 9 Decomposition of Variance

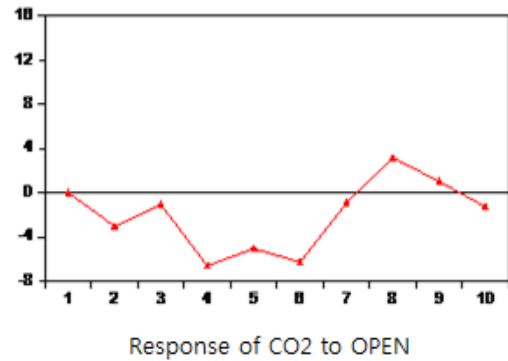
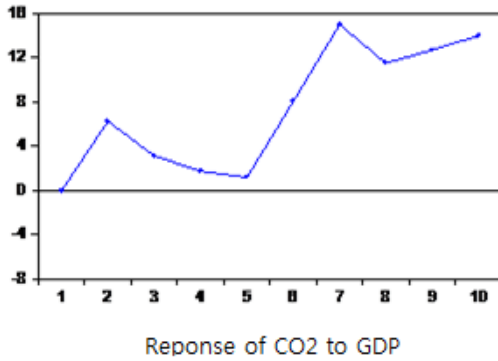
Period	China				Korea				Japan			
	S.E.	CO ₂	GDP	OPEN	S.E.	CO ₂	GDP	OPEN	S.E.	CO ₂	GDP	OPEN
1	11.41	100.00	0.00	0.00	12.12	100.00	0.00	0.00	0.046	100.00	0.00	0.00
2	12.21	88.79	1.05	10.16	15.30	79.23	16.83	3.93	0.048	99.32	0.34	0.34
3	14.21	74.26	13.35	12.39	15.65	75.69	20.09	4.22	0.055	97.84	1.16	1.00
4	14.93	68.91	13.16	17.92	17.12	63.74	17.86	18.39	0.059	95.71	2.48	1.81
5	14.98	68.43	13.23	18.34	17.91	58.51	16.75	24.74	0.062	93.13	4.25	2.63
6	16.75	58.88	11.38	29.75	20.76	44.93	27.55	27.52	0.064	90.32	6.37	3.31
7	22.05	34.97	8.68	56.36	25.93	31.06	51.17	17.76	0.065	87.53	8.70	3.77
8	24.17	30.45	15.24	54.31	28.75	26.56	57.74	15.70	0.066	84.95	11.07	3.98
9	27.12	24.80	31.45	43.75	31.64	23.10	63.84	13.07	0.067	82.70	13.31	3.99
10	31.52	32.44	34.75	32.81	35.39	22.69	66.73	10.58	0.068	80.82	15.27	3.90
11	35.45	39.55	33.82	26.64	39.37	24.05	66.63	9.32	0.069	79.28	16.90	3.83
12	37.89	39.58	37.02	23.40	41.28	22.95	68.53	8.51	0.069	77.97	18.15	3.88
13	39.81	36.00	42.65	21.35	43.26	22.41	69.75	7.84	0.070	76.81	19.05	4.14
14	48.61	25.35	57.34	17.31	44.97	22.85	69.89	7.26	0.071	75.69	19.65	4.66
15	56.75	18.83	67.27	13.90	45.51	22.46	70.36	7.18	0.072	74.56	20.00	5.43
16	73.95	11.22	68.68	20.11	45.71	22.35	70.46	7.18	0.072	73.39	20.16	6.45
17	93.39	7.04	70.16	22.79	45.94	22.41	70.36	7.23	0.073	72.18	20.17	7.64
18	110.96	5.59	74.12	20.29	46.17	22.45	70.27	7.28	0.074	70.96	20.09	8.96
19	134.95	4.28	75.99	19.73	46.53	23.59	69.24	7.17	0.074	69.75	19.93	10.32
20	166.01	3.35	77.56	19.08	47.21	25.75	67.25	6.99	0.075	68.62	19.73	11.66

When the Japanese data is concerned, the forecast error variance for CO₂ is explained by its own innovation by 68.62% at the end of the 20th year. GDP has an effect equal to twice as much as OPEN, but these have a weaker influence on CO₂ emissions after 20 years from the shocks. The difference of Japan's data is very marked indeed, compared to Korea and China. Japan explains 69.0% of its own shocks.

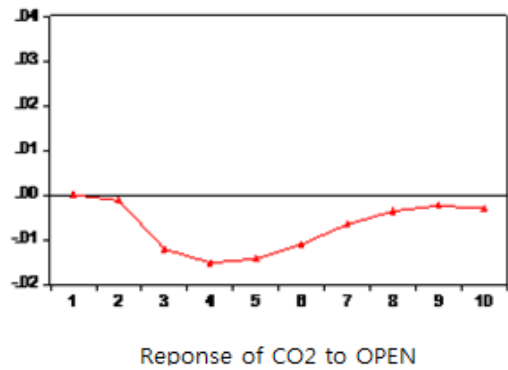
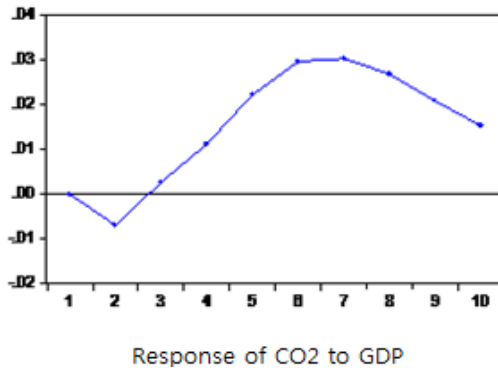
In order to identify the impulse response, we impose an additional restriction on the VAR/VECM model. This paper uses the Choleski impulse functions. The impulse response functions are described in Figure 5.

Figure 5 Response of Generalized one S.D. Innovation to GDP and OPEN

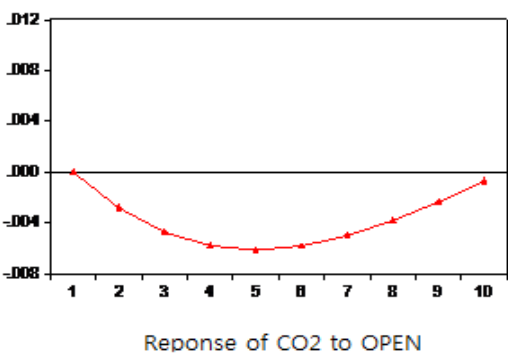
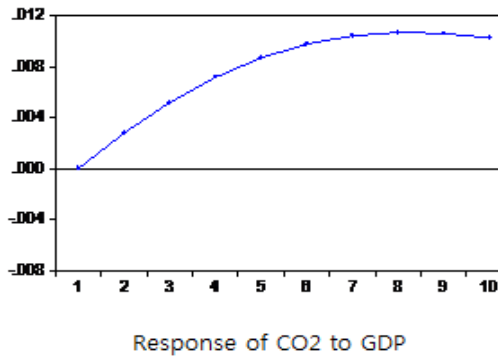
(a) Korea



(b) China



(c) Japan



The graphs reported in Figure 5 show how much carbon dioxide would change in response to one standard deviation(SD) of innovation to GDP and OPEN in each country. First, in the Korean case, the response to innovation of CO₂ to GDP increases until period 2. Afterwards, during the period 2-5, it drops. The periods are 5-7, 7-8, and 8-10. During these periods, the response to innovation repeatedly rises and falls. Overall, the long-run relationship of CO₂ and GDP is positive. This coincides with the previous results. Both in the short-run and long-run, the impact is not gone, and this pattern is also similar to the response to innovation of CO₂ to OPEN. In the early stages, it repeatedly rises and falls sensitively, and at the same time, CO₂ and OPEN maintain their negative relationships. This is in line with and corresponds closely to the previous results.

In looking at the responses of CO₂ to GDP, in case of China, we note that during the first two periods, these three variables have negative relationships, and there would be a positive response after period 3. After the 7th period, the increasing pattern is reversed, but the positive relationship is maintained. CO₂ and GDP have a positive relationship in the long-run, and this coincides with the previous results as well. According to the response of CO₂ to OPEN, since the first period, the relations between CO₂ and OPEN is found to be negative. However, from the 9th period onwards, the shock wave abates until it finally dies away.

The response of CO₂ to GDP and CO₂ to OPEN has a very similar pattern, but with the difference that the sign is opposite. These are reported in Figure 5. Japan's CO₂ and GDP also have a positive long-run relationship. GDP and OPEN show a negative reaction, but at the end of period, it vanishes.

VI. Conclusion

Previous studies have provided a better understanding of the environmental consequences of economic growth and international trade. This paper addresses this topic in the context of China, Korea, and Japan, three main East Asian countries that reflect different levels of economic development. The paper takes into account the debate over the existence of the environmental Kuznets curve (EKC) and uses the econometric time series technique to

develop VAR/VEC models. The results indicate the existence of dynamic relationships among key variables of interest.

In this study, we estimated the EKC by using annual time series data on CO₂ emissions (1971 to 2006). The three countries showed considerable differences in the temporal patterns of environmental quality and economic growth. For Korea, there was no inverted U-shaped EKC. We find a turning point at \$8,210 in the estimated result, but it represents a U-shaped curve. Thus, it is difficult to conclude that this curve would show a decreasing trend after a new turning point. Considering only the coefficient's signs, beyond a certain income level, CO₂ emissions and economic growth have a part representing a negative relationship. However, if we look at the figure of EKC curve, we find only an increasing trend. For Japan, the inverted N-shaped curve was statistically significant. There was no traditional EKC, but the fact that Japan showed a decreasing trend in recent years is noteworthy. Japan is a representative of developed countries. In finding decreasing trend in such countries, we do not need to wait for such higher income as an environmental turning point. The fact that developed countries are having a decreasing trend will help the developing countries or emerging countries to attain lower turning point by adopting measures and technologies from the developed ones.

For Korea and China, CO₂ emissions and GDP had a positive long-run relationship. However, CO₂ emissions and OPEN had a negative short-run relationship for Korea. There was no significant short-run relationship between CO₂ emissions and GDP. For China, CO₂ emissions and GDP linkage had only a significant positive relationship. Thus, for China, economic growth increased CO₂ emissions both in the short-run and in the long-run. As the results of variance decompositions and impulse response functions shows, the forecast error variance for CO₂ explained by its own innovations is 25.7% after 20 years for Korea, and it is mostly influenced by GDP by up to 67.2%. In contrast, OPEN is the least influential factor. The percentage of the variance in CO₂ that can be explained by GDP is about 77.6% and OPEN about 19.1%. CO₂ explained by its own lag is only 3.0%. Japan shows a clear distinction. The GDP share is 19.7%, and the OPEN share is 11.7%. However, after 20 years post shock, CO₂ explains over 68.6% of its own shock. When compared with Korea and China, it is very remarkable.

Despite the notable findings, this study has some limitations. Most importantly, the sample size was too small. Access to data was limited, and only annual time series data on individual countries were available. The data on environmental quality is the major limitation, especially CO₂ emissions. As we can see above Table 1, most of the empirical studies used panel data to examine the EKC hypothesis of countries, and not enough attention was given to country-specific EKCs. Based on the inability to provide a better picture of the environmental quality associated with specific phases of development and openness in individual countries, we devote to time-series analysis. However, if the dataset can be extended to quarterly or monthly series, we may be able to get better results. The empirical robustness of EKC relation still remains.

Reducing CO₂ emissions is not a legal requirement; thus, each countries tend to develop and implement environmental policies that reflect their own interests, and they typically establish their own reduction goals. Further, it would be difficult to develop global measures and enforce them. Thus, voluntary efforts to improve the environment have thus far been the only realistic approach. The results suggest that CO₂ emissions are likely to increase as the economy continues to expand. Thus, reducing CO₂ emissions has become a critical global issue, and developing measures for reducing CO₂ emissions has become an urgent task. However, developed countries, like Japan have the capability to reduce CO₂ emissions, although CO₂ is not a local pollutant but a global one. Hence, CO₂ emissions can be reduced by international cooperation. The results of this study are expected to be useful in providing a better understanding of the environmental problems and for identifying the ways in which the negative effects of CO₂ emissions can be minimized.

References

- Agras, J. and D. Chapman. 1999. "A dynamic approach to the Environmental Kuznets Curve hypothesis". *Ecological Economics*, 28(2): 267–277.
- Akbostancı, E., S. Türüt-Aşık, and G. İpek-Tunç. 2009. "The relationship between income and environment in Turkey: Is there an environmental Kuznets curve?" *Energy Policy*, 37: 861-867.
- Baek, J. H, Y. S. Cho, and W. W. Koo. 2009. "The environmental consequences of globalization: A country-specific time-series analysis". *Ecological Economics*, 68: 2255-2264.
- Brandford, D. F., R. Schlieckert, and S. H. Shore. 2000. "The Environmental Kuznets Curve: exploring a fresh specification". *NBER Working paper* 8001.
- Bradford, D. F., R. Schlieckert, and S. H. Shore. 2005. "The Environmental Kuznets Curve: Exploring a Fresh Specification". *Economic Analysis & Policy*, 4(1): Article 5.
- Cole, M. A., A. J. Rayner, and J. M. Bates. 1997. "The environmental Kuznets Curve: and empirical analysis". *Environmental and Development Economics*, 2: 401-416.
- Cole, M. A. 2004. "Trade, the pollution haven hypothesis and environmental Kuznets curve: examining the linkages". *Ecological Economics*, 48: 71–81.
- Copeland, B. R. and M. S. Taylor. 1994. "North-South trade and the environment". *Quarterly Journal of Economics*, 109(3): 755-787.
- Engle, R. and C. W. J. Granger. 1987. "Cointegration and Error Correction: Representation, Estimation and Testing". *Econometrica*, 55: 251–276.
- Esty, D. and D. Giradin. 1998. "Environmental Protection and International Competitiveness: A Conceptual Framework". *Journal of World Trade*, 32(3): 5–46.
- Friedl, B. and M. Getzner. 2003. "Determinants of CO₂ emissions in a small open economy". *Ecological Economics*, 45: 133–148.
- Galeotti, M. 2003. "Economic Growth and the Quality of the Environment: Taking Stock". *Fondazione Eni Enrico Mattei Working Paper*, N.89.
- Galeotti, M. and A. Lanza. 1999. "Richer and cleaner? A study on carbon dioxide emissions in developing countries". *Energy Policy*, 27: 565–573.
- Galeotti, M. and A. Lanza. 2005. "Desperately seeking (environmental) Kuznets". *Environmental Modelling and Software*, 20: 1379-1388.

- Galeotti, M., A. Lanza, and F. Pauli. 2006. "Reassessing the environmental Kuznets curve for CO₂ emissions: A robustness exercise". *Ecological Economics*, 57: 152-163.
- Galeotti, M., M. Manera, and A. Lanza. 2009. "On the Robustness of Robustness Checks of the Environmental Kuznets curve Hypothesis". *Environmental and Resource Economics*, 42: 551-574.
- Grossman, G. M. and A. B. Krueger. 1991. "Environmental impacts of a North American Free Trade Agreement". *NBER working Paper Series*, 3914.
- Grossman, G. M. and A. B. Krueger. 1993. "Environmental impacts of the North American Free Trade Agreement". *The U.S. Mexico Free Trade Agreement*. Peter Garber ed. Cambridge: MIT Press.
- Heshmati, A. 2006. "Conditional and unconditional inequality and growth relationships". *Applied Economics Letters*, 13: 925-931.
- Hill, R. J. and E. Magnani. 2002. "An exploration of the conceptual and empirical basis of the environmental Kuznets curve". *Australian Economic Papers*, 41 (2): 239-254.
- Hossain, S. 2011. "Panel estimation for CO₂ emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries". *Energy policy*, 39 (11): 6991-6999.
- Huang, W. M., G. W. M. Lee and, C. C. Wu. 2008. "GHG emissions, GDP growth and the Kyoto Protocol: A revisit of Environmental Kuznets Curve hypothesis". *Energy Policy*, 36: 239-47.
- Johansen, S. 1988. "Statistical Analysis of Cointegrating Vectors". *Journal of Economic Dynamic and Control*, 12: 231-254.
- Johansen, S. 1995. "Likelihood-based inference in cointegrated vector autoregressive models". Oxford: Oxford University Press.
- Johansen, S. and K. Juselius. 1990. "Maximum Likelihood Estimation and Inference on Cointegration -with Applications to the Demand for Money". *Oxford Bulletin of Economics and Statistics*, 52: 169-210.
- Johansen, S. and K. Juselius. 1992. "Testing Structural Hypotheses in a Multivariate Cointegration Analysis of the PPP and the UIP for UK". *Journal of Econometrics*, 53(1-3): 211-244.
- Kuznets, S. 1955. "Economic Growth and Income Inequality". *American Economic Review*, 45(1): 1-28.
- List, J. A. and C. A. Gallet. 1999. "The environmental Kuznets curve: does one size fit all?" *Ecological Economics*, 31: 409-423.

- Lucas, R. E. B., D. Wheeler, and H. Hettige. 1992. "Economic development, environmental regulation and the international migration of toxic industrial pollution:1960-1988". *International Trade and the Environment, world Bank discussion paper*, no.159.
- Mackinnon, J. G. 1996 "Numerical distribution Functions for unit root and cointegration tests". *Journal of Applied Econometrics*, 11: 601-618.
- Munasinghe, M. 1999. "Is environmental degradation an inevitable consequence of economic growth: tunneling through the environmental Kuznets curve". *Ecological Economics*, 29: 89-109.
- Moomaw, W. R. and G. C. Unruh. 1997. "Are environmental Kuznets curves misleading us? The case of CO₂ emissions". *Environment and Development Economics*, 2: 451-463.
- Seldon, T. M. and D. Song. 1994. "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics And Management*, 27: 147-162.
- Shafik, N. and S. Bandyopadhyay. 1992. "Economic Growth and Environmental Quality: Time Series and Crosscountry Evidence". *Background Paper for the World Development Report 1992*. Washington DC.: World Bank.
- Stern, D. I. and M. S. Common. 2001. "Is There an Environmental Kuznets Curve for Sulfur?" *Journal of Environmental Economics and Management*, 41(2): 162-178.
- Taskin, F. and O. Zaim. 2000. "Searching for a Kuznets curve in environmental efficiency using kernel estimation". *Economics Letters*, 68: 217-223.
- Torras, M. and J. K. Boyce. 1998. "Income, Inequality, and Pollution: A Reassessment of the Environmental Kuznets Curve". *Ecological Economics*, 25(2): 147-160.