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CO_2 Emissions Embodied in International Trade and Economic Growth: Empirical Evidence for OECD and Non-OECD Countries

Hyunsoo Kang

Department of International Trade, Wonkwang University, Iksan 54538, Korea; agkang75@wku.ac.kr

Abstract: This study examined the relationship between CO_2 emissions embodied in international trade and economic growth for OECD and non-OECD countries between 2005 and 2015. Unlike the traditional environmental Kuznets curve (EKC) hypothesis, which does not account for trade patterns, CO_2 emissions embodied in trade balances were adopted in several models. To analyze the panel series, this study utilized econometric procedures: panel regression, the panel unit root test, the panel cointegration test, and panel Granger causality. To investigate evidence supporting the pollution haven hypothesis (PHH), this study constructed an equation including CO_2 emissions embodied in net exports as a proportion of consumption. The results from the panel regression model validated the EKC hypothesis, even considering the CO_2 emissions embodied in trade. Results of the panel unit root, panel cointegration, and Granger causality tests showed that CO_2 emissions embodied in trade and economic growth have bi-directional Granger causality. This study provided evidence for the PHH, although some upper countries of net exporters or net importers for CO_2 emissions can be observed. This study highlighted the need to intensify international cooperation to decrease environmental pollutants in both developed and developing countries, and considered the importance of CO_2 emissions embodied in trade by expanding globalization.

Keywords: CO_2 embodied in trade; economic growth; the EKC hypothesis; pollution haven; Granger causality

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1. Introduction

Carbon dioxide emissions have crucially affected natural ecosystems and sustainable development throughout human history, but controversy remains regarding global climate change [1]. While the Covid-19 pandemic has temporarily reduced emissions, carbon dioxide emission levels are still at record highs and rising. Under such conditions, the international community have begun to discuss carbon neutrality. Carbon neutrality ensures that net carbon emissions are zero, so that the concentration of carbon dioxide is no longer increased, also referred to as "Net-Zero". Carbon neutrality can be achieved by balancing carbon dioxide emissions from human activities with global carbon dioxide absorption. For this purpose, we need to reduce greenhouse gases, and the substantial emissions must be reduced to zero by increasing the amount of absorption, such as through forest restoration, or removed using reduction technology.

However, carbon emissions are the result of economic activities, and energy consumption is still a source of economic growth [2]. If we ignore economic growth and emphasize reducing greenhouse gases from carbon dioxide emissions, with zero economic growth, capital accumulations can be stopped early, and long-term economic growth can be disrupted [3]. The relationship between CO_2 emissions and economic growth has been analyzed and most studies are based on the environmental Kuznets curve (EKC) hypothesis [4–6]. The EKC hypothesis implies that environmental deterioration first rises and then falls as economic development proceeds. This has become one of the "stylized facts" of environmental economics, but it has been varied for different indicators, with the trend reversing [7,8]. In particular, the EKC hypothesis has an advantage in the setup of the model based on the nonlinearity of the independent variable, the U-shaped or N-shaped relationship of the CO_2 emissions. Furthermore, environmental policy can be presented through income turning points. In recent years, the EKC hypothesis has expanded to analyze various factors such as trade openness, energy efficiency, industrial structure, food security, and technology innovation [9–12].

With regard to the role of the EKC in carbon emissions, it can be considered an important aspect of international trade in economic development and the CO_2 emissions embodied in international trade. Historically, international trade played an important role in economic growth through the efficient allocation of resources. In addition, globalization steadily increased international trade and specialization, and therefore, gains from trade now vary between exporting and importing countries. In this process, production is mainly generated in regions with poor environmental performance, but consumption mainly occurs in regions with strong environmental legislation. Consequently, we can expect the separation of production and consumption in the global market and the implications of international trade for global pollutants [13].

The differences between production and consumption of products result in the international trade of products; in the same way, the amount of carbon indirectly contained in product in the international trade is the difference between the amount of carbon emissions from the production process and the amount of carbon emissions from consumption that are indirectly contained. That is, we consider both CO_2 produced in one country through domestic production and CO_2 embodied in trade. For example, China is a net exporter of CO_2 emissions but the United States is a net importer, and in general, developed countries consume more CO_2 than they emit, while developing or poor countries have the opposite situation.

Previous studies have pointed out the divergence and transfer of CO_2 emission trends between developed and developing countries with rapidly increasing international trade [14,15]. Peters et al. [15] mentioned that international trade causes a gradual separation between consumption and production, and reduces domestic pollution at the expense of foreign producers. Hotak et al. [1] highlighted the responsibility of high-income countries that are mainly emission-importers for the global emission, and for the improvement of energy saving, including emission intensive technology.

This study aimed to investigate the nexus between CO_2 emissions embodied in international trade and economic growth by adopting panel data for OECD and non-OECD members between 2005 and 2015, based on the EKC hypothesis. The divided countries between OECD and non-OECD are useful to investigate by national income levels, trade scales, and trade patterns. Furthermore, this study analyzed the causal relationship of estimated variables using Granger causality, and quantified the situation of CO_2 emission exporters and importers in international trade based on the concept of the pollution haven. Therefore, this study addressed a small niche in the literature on the EKC hypothesis by focusing on the role of CO_2 emissions embodied in international trade. This study also emphasized international cooperation and efforts to reduce CO_2 emissions to avoid environmental issues, and presented a need for continuous monitoring of CO_2 emissions embodied in international trade. Through this study, it is possible to get some answers to questions about who has more responsibility in CO_2 emissions, and who has more impact on CO_2 emissions embodied in international trade.

The remainder of this study is organized as follows. Section 2 introduces the previous literature on the relationship between CO_2 emissions and economic growth, based on CO_2 emissions embodied in international trade. Section 3 describes the empirical model specification and data description. Sections 4 and 5 present the results and conclusions, including policy implications, respectively.

2. Literature Review

The EKC hypothesis explains the empirical existence of a relationship between environmental pollution and economic growth, especially the inverted U-shaped nexus between

CO_2 emissions and income level [16]. This section introduces literature on the basic aspects of the EKC model and the importance of CO_2 emissions embodied in international trade.

The old debates on the EKC hypothesis are mainly based on the fundamental determinants of long-term improvements in environmental correction and the changes in a certain income threshold [17]. Traditionally, Grossman and Krueger [4] demonstrated an inverted U-shaped relationship between environmental degradation and income level, in which environmental pollution levels rise in the early stage of economic growth, while we can experience a reduction in pollution beyond the income threshold. In addition, this inverted U-shape was assumed to be a dynamic process of economic structural changes and environmental quality through three channels: scale effect, composition effect, and technical effect [18–21].

Since the establishment of the World Trade Organization system, several studies have analyzed the economic effect of increasing international trade, especially in terms of expanding on the EKC hypothesis. Mahmood et al. [19] investigated the relationship between trade openness and CO_2 emissions in Tunisia from 1971 to 2014. They suggested that the effect of increasing trade openness contributes to a positive effect on CO_2 emissions and that an increase in foreign trade is associated with environmental degradation. Similarly, Managi et al. [20] found that trade is beneficial to the environment in OECD countries, while it has detrimental effects in non-OECD countries. Bernard and Mandal [21] examined the impact of trade openness on environmental quality using a dynamic panel model for 60 emerging countries and highlighted that CO_2 emissions and trade have a crucial effect on negative environmental quality.

Most previous studies utilized trade openness, which is measured as the sum of exports and imports as a percentage of gross domestic product (GDP), capturing the nexus between trade and CO_2 emissions [19–21]. However, a more complex global value chain enables a country to import carbon-intense products, and more cross-border transfer of production processes induce the reallocation of energy use [1]. Therefore, existing trade openness has a disadvantage in that the recent international trade situation is not well reflected.

From another perspective, Peters and Hertwich [13] argued that international trade plays a significant role in economic development by providing a mechanism for efficiently allocating resources. They also mentioned that production may occur in regions with poor environmental performance, without costing externalities. That is, if environmentally unfriendly production was moved to other regions, the originating country would enjoy a reduction in CO_2 emissions or environmental pollution, and then the issue of pollution embodied in international trade can be stimulated by the separation of production and consumption in the global market. Similarly, Hotak et al. [1] addressed how carbon trade balances are related to carbon emissions under fragmented production, including 58 countries during the period between 1990 and 2014. They provided the important implications of emissions embodied via international trade and mentioned that emission importers, partially high-income countries, need to have more responsibility for global emission issues.

Although this study tried to analyze the nexus between pollution embodied in trade and economic growth, focusing on the existing EKC hypothesis, there are several research gaps. First, this study constructed an economic model by expanding on the EKC hypothesis, including CO_2 emissions embodied in international trade. That is, this study suggested important implications for pollution emissions separated from production and consumption through a comparison of traditional EKC and expanded EKC hypotheses. Second, during the period of 2005 to 2015, this study compared the panel data from OECD and non-OECD countries; therefore, conclusions offered more plentiful implications by income levels. Finally, this study adopted the concept of the pollution haven using pollution embodied in trade, and compared net exporters and importers for CO_2 emissions embodied in international trade.

3. Methodology and Data

3.1. Traditional EKC Model

Traditional EKC was hypothesized as the nexus between various indicators of environmental degradation and income, which implies that the environmental impact indicator had an inverted U-shaped function of income and also a quadratic function of the logarithm of income [7]. In addition, since Grossman and Krueger [4] highlighted the EKC hypothesis, this approach has been the popular methodology, including ambient pollution concentrations and aggregate emissions.

First, this study introduced the one-person model of Andreoni and Levinson [21], which assumed the utility of agents from the consumption of one private good, denoted *C*, and from pollution, *P*. The model of Andreoni and Levinson [21] is very useful for supporting economic modeling by CO_2 emissions and economic growth, and it includes the main channel between pollution and energy consumption. The simple utility function is as follows:

$$U = U(C,\ P) \tag{1}$$

where $U_C > 0$ and $U_P < 0$. In addition, pollution is an increasing function of *C* and a decreasing function of environmental effort, *E*:

$$P = P(C,\ E) \tag{2}$$

Finally, each individual maximizes *U* subject to a limited endowment, *M*. Consider a simple linear utility function substituting Equation (2) into Equation (1) as follows:

$$U = -C^a E^b \text{ subject to } C + E = M \tag{3}$$

In Equation (3), *C* is gross pollution before abatement and $C^a E^b$ represents abatement. Solve Equation (3) and determine the optimal levels:

$$C^* = \frac{a}{a+b}M,\ E^* = \frac{b}{a+b}M \tag{4}$$

Substituting Equation (4) into Equation (3), we obtain the optimal pollution level:

$$P^*(M) = \frac{a}{a+b}M - \left(\frac{a}{a+b}\right)^a \left(\frac{b}{a+b}\right)^b M^{a+b} \tag{5}$$

Differentiating Equation (5) with respect to *M*:

$$\frac{\partial P^*}{\partial M} = \frac{a}{a+b} - (a+b)\left(\frac{a}{a+b}\right)^a \left(\frac{b}{a+b}\right)^b M^{a+b-1} \tag{6}$$

Therefore, the optimal pollution-income paths of EKC depend on "$a + b$", in which abatement exhibits increasing returns to scale if $a + b > 1$, and then evidence of an inverted U-shaped relationship exists.

In terms of Equation (6) and the EKC hypothesis, this study constructed the traditional EKC model as follows:

$$CO_2 = f(\text{GDPP, EC, REEC}) \tag{7}$$

where CO_2 is CO_2 emissions, GDPP is GDP per capita, EC is energy consumption, and REEC is renewable energy consumption. In various studies, the nexus of CO_2 emissions, energy consumption, and economic growth of independent variables for Equation (7) is related to the input factor in production, and energy consumption affects both economic growth and the level of CO_2 emissions [22–30]. Also, Leitão and Lorente [29] denoted that renewable energy allowed decreasing climate change and greenhouse gas, and this negative relationship between the renewable sources and CO_2 emissions stimulated energy efficiency within the energy mix. Furthermore, this study utilized the panel data set to estimate pollution across the OECD and non-OECD countries, and the econometric model for country levels (i) taking a natural logarithm is as follows:

$$\ln(\text{CO}_{2it}) = \alpha_0 + \alpha_1 \ln(\text{GDPP}_{it}) + \alpha_2 \ln(\text{EC}_{it}) + \alpha_3 \ln(\text{REEC}_{it}) + \delta_{it} \quad (8)$$

In addition, to identify the non-linear form of the EKC, this study included the GDPP squared variable in Equation (8) and specified the model.

3.2. CO_2 Emissions Embodied in International Trade on the EKC Model

Emissions embodied in trade (EET) can explain the relationship between the production and consumption of the country for global climate change while calculating the EET can become complex because of the linkage of production and consumption systems through international trade data [13]. Nevertheless, the most general method for EET is environmental input-output analysis (IOA), which requires the decomposition of IOA into domestic and traded components [31]. In particular, Peters and Hertwich [13] utilized a simple IOA to obtain EET and the total CO_2 emissions for each country are as follows:

$$f_k = F_k(I - A_{kk})^{-1}\left(y_{kk} + \sum_l e_{kl}\right) \quad (9)$$

where f_k is the total CO_2 emissions for country "k", F_k is a row vector with each element for CO_2 emissions per unit output, I is the identity matrix, y_{kk} is the products produced and consumed domestically in country "k", and e_{kl} is the bilateral exports from country "k" to country "l". In particular, e_{kl} is divided by intermediate and final consumption, and then domestic demand on domestic production (country "k") and the EET from country "k" to country "l" are as follows:

$$f_{kk} = F_k(I - A_{kk})^{-1} y_{ll} \quad (10)$$

$$f_{kl} = F_k(I - A_{kk})^{-1} e_{kl} \quad (11)$$

Therefore, the total emissions embodied in exports (f_k^{ex}) from country "k" to all other countries and the total emission embodied in imports (f_k^{im}) from all other countries to country "k" are as follows:

$$f_k^{ex} = \sum_l f_{kl} \quad (12)$$

$$f_k^{im} = \sum_l f_{lk}. \quad (13)$$

The important indicator discussed in this study is the balance of emissions embodied in trade (BEET), (As a result of analyzing CO_2 emissions for 87 countries by Peters and Hertwich [13], approximately 21.5% of the global CO_2 emissions were embodied in international trade.) and the BEET for country "k" can be calculated by the difference between total emissions embodied in exports and imports ($f_k^{ex} - f_k^{im}$). If the BEET for one country is greater (or less) than zero, that country can be regarded as a net emission exporter (or importer). As mentioned in previous section, the main issue of this study is to investigate the relationship between CO_2 emissions embodied in international trade and economic growth, and the BEET is a key factor that can be identified as direct and indirect channels of trade. Similar to Hotak et al. [1], this study constructed a CO_2 emissions equation including the EKC hypothesis as follows:

$$\text{BEET}_{it} = \beta_0 + \beta_1 \ln(\text{GDPP}_{it}) + \beta_2 \ln(\text{EC}_{it}) + \beta_3 \ln(\text{REEC}_{it}) + \varepsilon_{it} \quad (14)$$

where BEET_{it} is the balance of CO_2 emissions embodied in trade for country "i". Equation (14) is very close to Equation (8) which includes the EKC hypothesis, while the dependent variable in

Equation (14) contains the pollution embodied in trade to determine the nexus between net emission exporters (or importers) and economic growth. In addition, Equation (14) is accomplished by a model specification to test for nonlinearity, including the GDDP squared variable.

3.3. Econometric Procedures: Pooled OLS, Fixed Effects, Random Effects

Panel data can be referred to multilevel data including two-level structures of upper and lower levels (for example, upper and lower levels can be "country" and "time", respectively). In addition, panel analysis has some advantages, such as analyzing the common and individual behaviors of groups, containing more information, and minimizing estimation bias [32]. In this study, three types of panel data regressions were utilized as pooled ordinary least squares (OLS), fixed effects, and random effects. The pooled OLS is a simple method of estimating OLS, which needs to qualify for assumptions of homogeneity across panel groups, unbiased estimator, and homoscedasticity [32]. However, based on the properties of panel data, the pooled OLS can violate these assumptions; therefore, we may adopt another panel regression estimation to solve this problem. Among the general alternative estimations of pooled OLS, fixed effects can explore the relationship between predictor and outcome variables within a group including heterogeneity of time-invariant error and time-varying error. In addition, random effects assume that error terms within the model are not constant but random variables; therefore, we can include time-invariant variables and allow generalization of the inferences beyond the sample [33]. To determine the appropriate regression analysis method, this study ran a Hausman test to determine whether the unique errors were correlated with regressors, as well as using the Breusch-Pagan Lagrange multiplier to determine whether variances across entities were zero.

3.4. Panel Unit Root Test, Panel Cointegration, and Panel Granger Causality Test

Before testing the relationship between two variables, especially the causality relation, we need to investigate the stationarity of each variable to gain statistical power and to avoid spurious regression [34]. First, this study utilized several types of tests for variables, such as the Levin-Lin-Chu [35], Harris-Tzavalis [36], Breitung [37], Im-Pesaran-Shin [38], Fisher-type [34], and Hadri [39]. In particular, the previously mentioned tests (except for Hadri) have the null hypothesis that all the panels contain a unit root, and all test results show panel specific means and time trends in the model.

After testing the stationarity for each variable, some non-stationary series can be stationary by the first difference, known as I(1). If some data tend to wander by non-stationary series, the result of cointegration analysis implies that there will not be a long-run equilibrium relationship among the series. Therefore, to check the cointegration in panel data, this study used Pedroni's cointegration test [40] which includes the null hypothesis of no cointegration in non-stationary panels. Pedroni [40] introduced cointegration test statistics that allow for heterogeneity in the panels, both the long-run slope and intercept coefficients [41]. This test has some advantages in that does not consider normalization and simply shows the degree of evidence among variables.

Finally, this study estimated the causal relationships between the two variables. Granger [42] introduced a methodology for analyzing causal relationships in time series as follows:

$$y_t = \pi + \sum_{k=1}^{K} \delta_k y_{t-k} + \sum_{k=1}^{K} \sigma_k x_{t-k} + \delta_t \quad \text{with } t = 1, \ldots, T \tag{15}$$

where x_t and y_t are two stationary series. Equation (15) means that if past values of x are significant of the current value of y, then we can conclude that x has a causal relationship for y based on the F test as follows:

$$H_0: \ \sigma_1 = \cdots = \sigma_K = 0$$

As this study utilized the panel series, an extension Granger causality could be tested, as proposed by Dumitrescu and Hurlin [43]:

$$y_{i,t} = \pi + \sum_{k=1}^{K} \delta_{ik} y_{i,\ t-k} + \sum_{k=1}^{K} \sigma_{ik} x_{i,\ t-k} + \delta_{i,t} \quad \text{with } i = 1, \ldots, N \text{ and } t = 1, \ldots, T \tag{16}$$

where $x_{i,t}$ and $y_{i,t}$ are estimated variables for individual "i" in period "t". The powerful aspects of the Dumitrescu and Hurlin causality test can be designed to detect causality at the panel level by providing for the W-bar (the average Wald statistic), Z-bar (the standardized statistic when Wald statistics are independently and identically distributed across individuals), and Z-bar tilde (the approximated standardized statistic for a fixed T dimension with $T > 5 + 3\ K$) [44].

3.5. Pollution Haven Hypothesis

Previous studies criticized the EKC hypothesis, which may not account for international trade patterns [45]. In addition, the EKC hypothesis does not explain the phenomenon that some developed countries transfer their CO_2 emissions for developing or less developed countries through international trade, while the pollution haven hypothesis (PHH) can partially help understand the trade pattern on environmental issues between North and South problems. According to Cole [45], the PHH implies that polluting industries in developed countries relocate to jurisdictions with less environmental regulations, for example developing countries, and the PHH can be identified by using net exports as a proportion of consumption (NETXC) as follows:

$$\text{NETXC}^{j}_{ikt} = \frac{X^{j}_{ikt} - M^{j}_{ikt}}{P_{ikt} - X^{w}_{ikt} + M^{w}_{ikt}} \tag{17}$$

where X, M, and P indicate exports, imports, and production, respectively. For example, X^{j}_{ikt} is exports from developed country "i" to developing country "j", sector "k", and time period "t", with superscript w meaning the rest of the world. According to Equation (17), this study applied "CO_2 emission embodied on NETXC" (CO_2NETXC) to investigate the existence of pollution havens within OECD and non-OECD countries as follows:

$$\text{CO}_2\text{NETXC}^{j}_{ikt} = \frac{f^{ex}_{ik} - f^{im}_{ik}}{\text{FDCO}_2} \tag{18}$$

where $(f^{ex}_{ik} - f^{im}_{ik})$ is CO_2 emissions embodied in net exports as a proportion of consumption and $FDCO_2$ is CO_2 emissions embodied in domestic (country "i") final demand. Equations (17) and (18) are very similar, but Equation (18) involves the CO_2 emissions embodied in the trade variable. If the level of CO_2NETXC falls (or approaches zero), this indicates that one country's proportion of CO_2 emissions embodied in net exports on CO_2 emissions embodied in domestic final demand also decreases. That is, in the environmental pollution industry, one country experiences a reduction in its specialization relative to its consumption, and there will be no proof supporting the PHH.

3.6. Descriptive Data

This study used panel data during the period of 2005 to 2015 for 36 OECD countries and 26 non-OECD countries. (According to the OECD database, there are 28 non-OECD countries, while this study utilizes only 26 countries, due to missing data (excluding Hong Kong and Chinese Taipei). The CO_2 emissions embodied in international trade data were obtained from OECD.Stat and the rest of the data were collected from the World Bank Open database. Table 1 presents the name of the variable, the definition (including unit), and the source of each variable.

Table 1. Definition and source of estimated variables.

Variables	Definition (Units)	Source
BEET	CO_2 emissions embodied in gross export, balance (Tonnes, Millions)	OECD. Stat (https://stats.oecd.org/Index.aspx?DataSetCode=IO_GHG_2019) (accessed on 25 August 2021)
GDPP	GDP per capita, PPP (constant 2017 international $)	World Bank Open Data (https://data.worldbank.org/) (accessed on 25 August 2021)
EC	Energy Use (kg of oil equivalent per capita)	
REEC	Renewable energy consumption ($ of total final energy consumption)	
CO_2	CO_2 emissions (kt)	

Table 2 indicates the descriptive statistics of each variable, especially by the characteristics of the panel data set, and standard deviation, and min/max value are divided by overall, between, and within, respectively. In particular, deviations of "between the panel" are greater than deviation of "within the panel", implying that each variable is not significantly different within the countries than between the countries.

Table 2. Descriptive data.

Variables		Mean	Std. Dev.	Min	Max	Observations
BEET	Overall	1.95	221.78	−1021.32	1670.67	N = 682 n = 62 T = 11
	Between		221.64	−782.01	1460.19	
	Within		27.95	−240.94	212.43	
GDPP	Overall	32,877.37	20,128.13	2120.55	114,889.2	
	Between		20,167.16	2808.60	108,062.1	
	Within		2097.53	21,859.94	47,648.67	
EC	Overall	3405.53	2597.36	251.27	18,178.14	
	Between		2581.40	326.79	16,150.35	
	Within		424.85	−2219.93	5621.96	
REEC	Overall	20.60	18.77	0.01	91.64	
	Between		18.73	0.01	89.10	
	Within		2.55	10.37	31.02	
CO_2	Overall	438,671.90	1,254,303	1650	9,936,680	
	Between		1,248,438	2103.63	8,281,222	
	Within		193,816.2	−2,023,460	2,094,130	

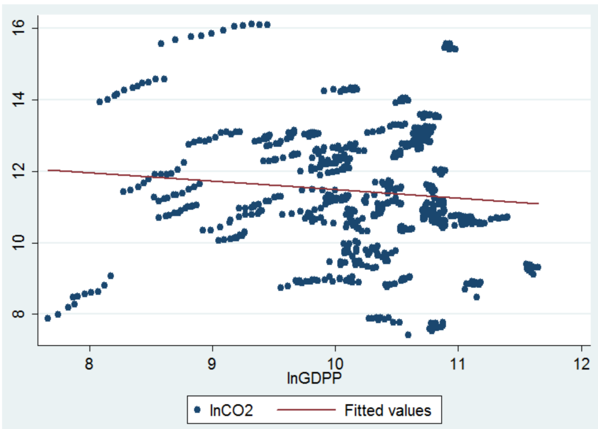
Table 3 indicates the top 10 countries of the CO_2 emissions trade balance in 2015. The primary net exporters (importers) are China, the Russian Federation, and India (the United States, Japan, and the United Kingdom). Only one country, Korea is both a net exporter and an OECD country, while only one country, Saudi Arabia is both a net importer and a non-OECD country.

Figures 1 and 2 illustrate the simple relationship between CO_2, BEET, and GDPP. Although almost all results have a slightly negative relationship, the fitted lines between CO_2 emissions and GDPP are identified as having a negative relationship, and this implies that total countries tend to decrease CO_2 emissions by increasing GDP per capita. Also, the negative relationship between BEET and GDP per capita exists more strongly in the case of non-OECD countries and the fitted line of non-OECD countries cross the zero level of BEET, and this indicated that non-OECD countries tend to be net importers on CO_2 emissions embodied in trade by increasing GDP per capita.

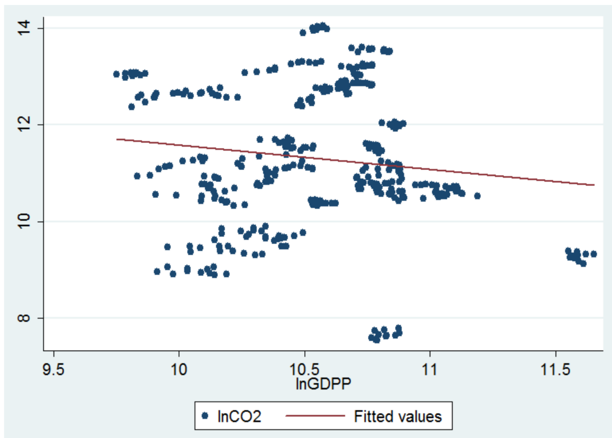
Table 3. The top ten countries of the CO_2 emissions embodied in gross export balance in 2015 (Tonnes, Millions).

Rank	Country	2015	Rank	Country	2015
1	China	1308.842	1	United States †	−785.334
2	Russian Federation	320.738	2	Japan †	−158.236
3	India	124.153	3	United Kingdom †	−142.519
4	South Africa	100.552	4	France †	−131.613
5	Singapore	52.496	5	Germany †	−84.608
6	Korea †	48.207	6	Italy †	−75.838
7	Kazakhstan	46.252	7	Saudi Arabia	−55.027
8	Malaysia	28.571	8	Switzerland †	−48.831
9	Thailand	28.351	9	Turkey †	−38.925
10	Viet Nam	20.783	10	Australia †	−33.578
	Top 10 average	207.89		Top 10 average	−155.45

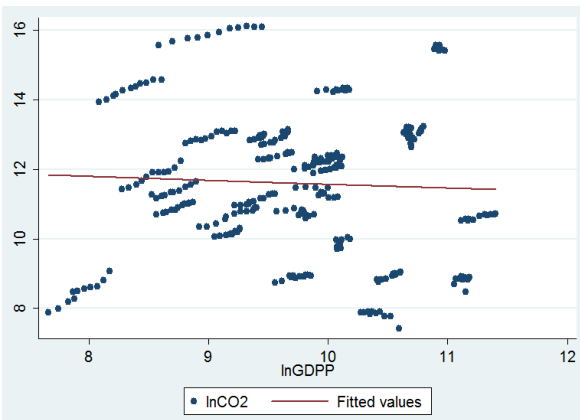
Notes: † indicates OECD member.



(**a**)

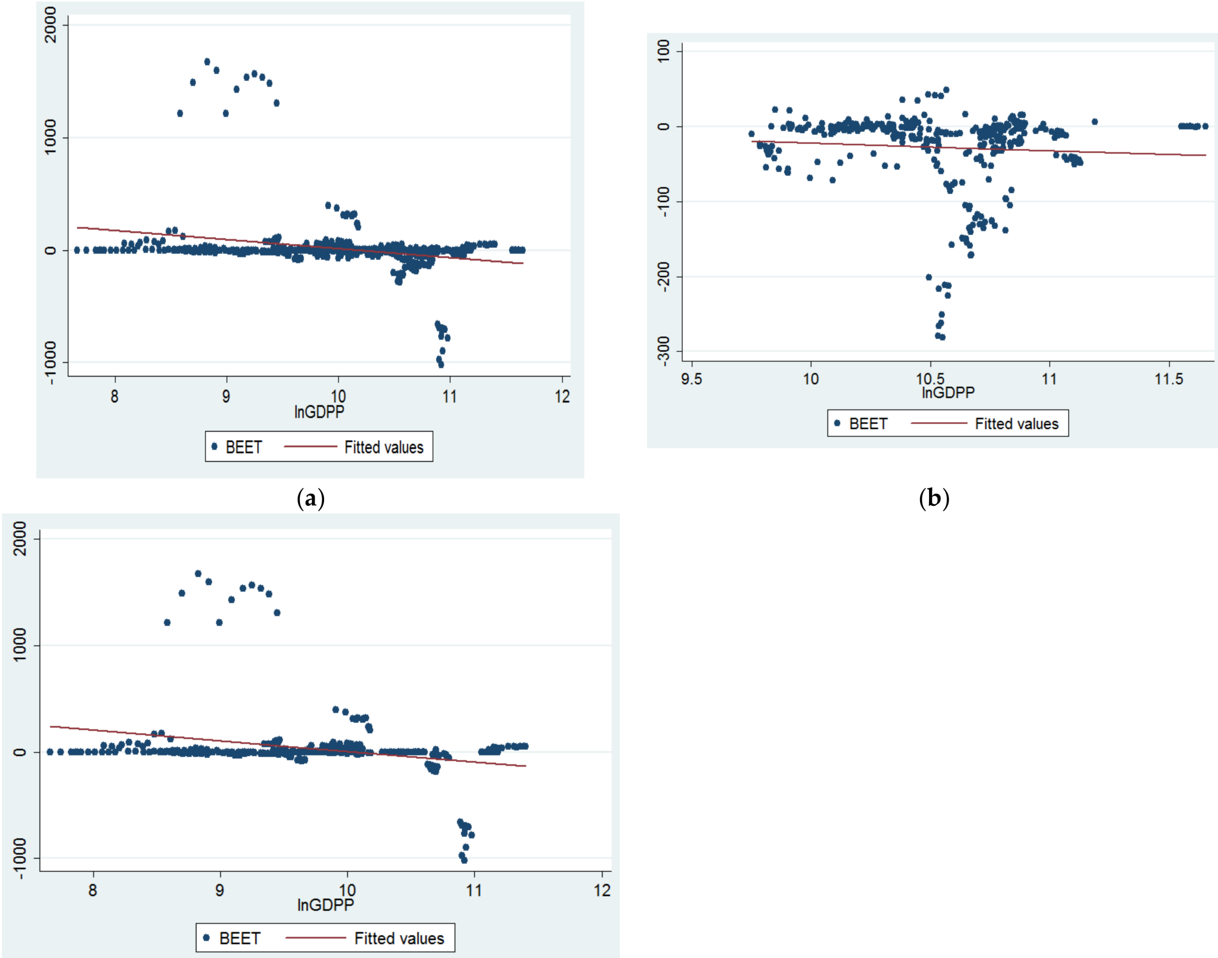


(**b**)



(**c**)

Figure 1. Simple relationship between CO_2 and GDP per capita. (**a**) Total countries. (**b**) OECD countries. (**c**) Non-OECD countries.



(**a**) (**b**) (**c**)

Figure 2. Simple relationship between BEET and GDP per capita. (**a**) Total countries. (**b**) OECD countries. (**c**) Non-OECD countries.

4. Empirical Results

4.1. Panel Regression Results

Tables 4–6 show the results of the panel regression for the traditional EKC model with respect to the pooled OLS, fixed effects, and random effects. Model 1 presents the linear relationship between CO_2 emissions and economic growth, and Model 2 shows the quadratic form using the GDPP squared. In the pooled OLS results of Model 1, the coefficients of GDP per capita (GDPP) for total and non-OECD countries are negative and statistically significant at the 1% level. However, the coefficient of GDPP for OECD countries is positive and statistically significant at the 5% level, implying that the economic growth of OECD countries results in a 0.11% increase in CO_2 emissions. The energy consumption (EC) for total countries, OECD countries, and non-OECD countries has a positive effect on CO_2 emissions while the coefficient of EC for non-OECD countries has the largest value (=3.23), with statistical significance at the 1% level. In the pooled OLS results of Model 2, the coefficients of GDPP and GDPP squared for total countries are positive and negative, respectively, and are statistically insignificant. On the other hand, in OECD and non-OECD countries, there is evidence of an inverted U-shaped relationship with a positive GDPP and a negative GDPP squared.

Table 4. Panel regression results of EKC model for Total countries.

Variable	Total Countries (Number of Observations = 682)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
ln(GDPP)	−1.33 *** (−7.43)	5.12 (0.58)	0.48 *** (13.04)	2.65 *** (7.07)	0.47 *** (12.55)	2.76 *** (7.28)
$[\ln(\mathrm{GDPP})]^2$		−0.32 (−0.83)		−0.11 *** (−5.80)		−0.11 *** (−6.06)
ln(EC)	1.04 *** (6.18)	0.98 *** (5.88)	0.59 *** (14.62)	0.53 *** (12.59)	0.58 *** (14.30)	0.52 *** (12.64)
ln(REEC)	−0.13 *** (−3.17)	−1.44 *** (−3.49)	−0.12 *** (−11.13)	−0.12 *** (−11.11)	−0.12 *** (−10.94)	−0.12 *** (−10.94)
constant	17.10 *** (17.09)	−14.13 * (−1.72)	2.13 *** (6.36)	−7.76 *** (−4.47)	2.31 *** (5.71)	−8.12 *** (−4.60)
R-squared	0.08	0.08	0.67	0.69	0.67	0.69
Hausman test					Prob>chi2 = 0.19	Prob>chi2 = 0.55
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

Table 5. Panel regression results of EKC model for OECD countries.

Variable	OECD Countries (Number of Observations = 396)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
ln(GDPP)	0.11 ** (2.11)	45.95 *** (7.41)	0.30 *** (5.92)	1.06 (0.71)	0.29 *** (5.80)	0.63 (0.41)
$[\ln(GDPP)]^2$		−2.16 *** (−7.44)		−0.06 (−0.91)		−0.04 (−0.61)
ln(EC)	0.48 *** (2.67)	0.74 *** (4.31)	0.54 *** (10.79)	0.54 *** (10.81)	0.52 *** (10.30)	0.52 *** (10.20)
ln(REEC)	−0.80 *** (−11.03)	−0.84 *** (−12.40)	−0.15 *** (−10.75)	−0.15 *** (−10.76)	−0.16 *** (−10.89)	−0.16 *** (−10.85)
constant	18.65 *** (10.38)	−22.30 *** (−6.86)	4.05 *** (7.13)	11.07 (1.43)	4.23 *** (6.85)	9.05 (1.15)
R-squared	0.28	0.38	0.63	0.63	0.63	0.63
Hausman test					Prob>chi2 = 0.79	Prob>chi2 = 0.93
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

Before investigating the results of the fixed and random effects, this study utilized the Hausman test to decide between two panel regressions. In Tables 4–6, the chi-squared statistic results of all cases are greater than 0.05, and, therefore, the random effect is the preferred model because it rejects the null hypothesis. In addition, this study adopted the Breusch-Pagan Lagrange multiplier, in which the null hypothesis is that variances across entities are zero, and the results of the chi-squared statistic results of all cases can reject the null hypothesis. Finally, we can choose the random effects model rather than pooled OLS.

In the random effect model results of Tables 4–6, the case of total countries and non-OECD countries have an inverted U-shaped relationship, while OECD countries do not. This result suggests that OECD countries have no effect on reducing CO_2 emissions according to economic growth.

Table 6. Panel regression results of EKC model for non-OECD countries.

Variable	Non-OECD Countries (Number of Observations = 286)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
ln(GDPP)	−2.58 *** (−10.86)	0.96 *** (3.42)	0.56 *** (9.72)	3.01 *** (5.40)	0.59 *** (10.46)	3.16 *** (5.54)
$[\ln(GDPP)]^2$		−0.84 *** (−4.71)		−0.12 *** (−4.36)		−0.13 *** (−4.56)
ln(EC)	3.23 *** (13.82)	3.20 *** (13.44)	0.56 *** (8.56)	0.46 *** (7.18)	0.55 *** (8.68)	0.47 *** (7.07)
ln(REEC)	0.30 *** (5.23)	0.28 (1.41)	−0.09 *** (−5.66)	−0.09 *** (−5.89)	−0.10 *** (−6.23)	−0.09 *** (−5.40)
constant	12.13 *** (7.87)	4.66 (0.44)	2.08 *** (3.80)	−8.71 *** (−3.51)	1.95 *** (4.59)	−9.35 *** (−3.65)
R-squared	0.38	0.38	0.71	0.73	0.71	0.73
Hausman test					Prob>chi2 = 0.55	Prob>chi2 = 0.44
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

Tables 7–9 illustrates the results of CO_2 emissions embodied in the trade model based on the EKC hypothesis. Based on the results of the Hausman and Breusch-Pagan Lagrange multiplier tests, we can also conclude that the random effect is the preferred model. According to results of the random effect, in Model 3, the coefficient of GDPP within total countries has a negative sign with statistical significance at the 1% level, and this result indicates that economic growth can contribute to a decrease in the balance of net exports for CO_2 emissions embodied. In addition, in Model 4, total countries and non-OECD countries show evidence of an inverted U-shaped relationship, similar to the traditional EKC model results. That is, even if we consider the CO_2 emissions embodied in international trade, we find that the early stage of economic growth increases the net export of CO_2 emissions in trade, before declining with net exports after a threshold.

Table 7. Panel regression results of CO_2 emissions embodied in trade model on EKC model for Total countries.

Variable	Total Countries (Number of Observations = 682)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 3	Model 4	Model 3	Model 4	Model 3	Model 4
ln(GDPP)	−210.95 *** (−9.51)	14.04 (0.07)	−2.68 ** (−2.23)	520.43 *** (3.21)	−11.08 *** (−2.72)	508.29 *** (3.26)
$[\ln(GDPP)]^2$		−11.37 (−1.07)		−27.12 *** (−3.24)		−26.82 *** (−3.34)
ln(EC)	130.93 *** (6.26)	129.00 *** (6.14)	−7.13 (−0.42)	−22.14 (−1.25)	−5.48 (−0.33)	−18.61 (−0.10)
ln(REEC)	−9.24 * (−1.79)	−9.66 * (−1.87)	10.86 ** (2.26)	11.65 ** (2.44)	10.41 ** (2.25)	11.06 ** (2.40)
constant	1140.78 *** (9.21)	51.50 (0.05)	59.49 (0.42)	−2323.30 *** (−3.11)	133.06 (0.98)	−2257.83 *** (−3.11)
R-squared	0.13	0.13	0.13	0.29	0.12	0.29
Hausman test					Prob>chi2 = 0.56	Prob>chi2 = 0.32
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

Table 8. Panel regression results of CO_2 emissions embodied in trade model on EKC model for OECD countries.

Variable	OECD countries (Number of Observations = 396)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 3	Model 4	Model 3	Model 4	Model 3	Model 4
ln(GDPP)	−28.18 *** (−2.95)	−1401.65 *** (−5.29)	−18.29 * (−1.68)	−237.07 (−0.74)	−18.16 (−1.08)	−325.37 (−1.13)
$[\ln(GDPP)]^2$		64.58 *** (5.19)		10.62 (0.68)		14.85 (1.07)
ln(EC)	21.13 *** (2.82)	28.91 *** (3.91)	14.46 (1.34)	14.70 (1.36)	13.34 (1.40)	13.25 (1.39)
ln(REEC)	10.80 *** (3.58)	12.09 *** (4.13)	20.71 *** (6.58)	20.68 *** (6.57)	19.97 *** (6.87)	19.91 *** (6.86)
constant	67.81 (0.91)	7292.72 *** (5.23)	−7.60 (−0.06)	1114.89 (0.67)	2.16 (0.02)	1588.93 (1.07)
R-squared	0.67	0.13	0.13	0.13	0.13	0.13
Hausman test					Prob>chi2 = 0.82	Prob>chi2 = 0.62
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

Table 9. Panel regression results of CO_2 emissions embodied in trade model on EKC model for non-OECD countries.

Variable	Non-OECD Countries (Number of Observations = 286)					
	Pooled OLS		Fixed Effects		Random Effects	
	Model 3	Model 4	Model 3	Model 4	Model 3	Model 4
ln(GDPP)	−342.22 *** (−7.79)	1468.474 *** (3.55)	7.36 (0.25)	872.74 *** (2.94)	−4.35 (0.15)	848.13 *** (3.02)
$[\ln(GDPP)]^2$		−94.13 *** (−4.40)		−46.00 *** (−2.93)		−45.12 *** (−3.05)
ln(EC)	212.12 *** (4.92)	177.25 *** (4.16)	20.93 (0.63)	52.09 (1.51)	13.42 (0.41)	42.03 (1.26)
ln(REEC)	−22.99 ** (−2.11)	−45.35 *** (−3.87)	4.53 (0.52)	7.45 (0.86)	4.48 (0.57)	6.05 (0.72)
constant	1835.01 *** (6.46)	−6849.93 *** (−3.40)	112.14 (0.51)	−3695.61 *** (−2.81)	169.73 (0.77)	−3611.48 *** (−2.87)
R-squared	0.17	0.22	0.04	0.34	0.03	0.33
Hausman test					Prob>chi2 = 0.51	Prob>chi2 = 0.49
Breusch-Pagan					Prob>chi2 = 0.00	Prob>chi2 = 0.00

Notes: *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. The numbers in parentheses are t-values.

4.2. Panel Unit Root and Cointegration Test Results

This study performed a variety of unit root tests to determine the stationarity in panel data. Table 10 presents the results of the panel unit root test based on six methodologies with respect to raw and first differential data. The null hypothesis of non-stationarity cannot be rejected for all variables at the 10% significance level, whereas the first differential variables can be rejected for six different unit root tests. This indicates that all series are stationary levels in the first difference and then all panel data are heterogeneous unit roots with integration of order one (that is, I(1) process).

Table 10. Panel unit root test results.

Variables	Levin–Lin–Chu Test			Harris–Tzavalis Test			Breitung Test		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
BEET	−14.19 *** (0.00)	−7.02 *** (0.00)	−2.02 ** (0.02)	0.29 *** (0.00)	0.40 *** (0.00)	0.98 (0.25)	−1.33 * (0.09)	−1.92 ** (0.02)	−1.93 ** (0.02)
D. BEET	−17.60 *** (0.00)	−16.98 *** (0.00)	−19.05 *** (0.00)	0.09 *** (0.00)	0.08 *** (0.00)	0.09 *** (0.00)	−8.47 *** (0.00)	−10.02 *** (0.00)	−15.39 *** (0.00)
ln(GDPP)	−16.82 *** (0.00)	−15.30 *** (0.00)	4.15 (0.99)	0.71 (0.99)	0.68 * (0.07)	1.03 (0.99)	9.01 (0.99)	2.22 (0.98)	8.07 (0.88)
D.ln(GDPP)	−27.01 *** (0.00)	−16.84 *** (0.00)	−21.52 *** (0.00)	0.28 *** (0.00)	0.15 *** (0.00)	0.37 *** (0.00)	−10.67 *** (0.00)	−11.73 *** (0.00)	−15.49 *** (0.00)
ln(EC)	−13.55 *** (0.00)	−5.74 *** (0.00)	−2.63 *** (0.00)	0.20 *** (0.00)	0.74 (0.45)	1.01 (0.50)	−2.18 ** (0.01)	4.27 (0.99)	−1.01 (0.15)
D.ln(EC)	−14.95 *** (0.00)	−14.02 *** (0.00)	−13.89 *** (0.00)	−0.07 *** (0.00)	−0.27 *** (0.00)	−0.07 *** (0.00)	−8.93 *** (0.00)	−10.61 *** (0.00)	−14.11 *** (0.00)
ln(REEC)	−13.68 *** (0.00)	−7.56 *** (0.00)	1.11 (0.86)	0.33 ** (0.01)	0.90 (0.99)	1.00 (0.63)	0.26 (0.60)	7.23 (0.99)	−0.25 (0.39)
D.ln(REEC)	−16.28 *** (0.00)	−14.87 *** (0.00)	−10.87 *** (0.00)	0.19 *** (0.00)	−0.10 *** (0.00)	0.25 *** (0.00)	−7.79 *** (0.00)	−10.21 *** (0.00)	−11.24 *** (0.00)
ln(CO_2)	−17.52 *** (0.00)	−6.86 *** (0.00)	−0.68 (0.24)	0.16 *** (0.00)	0.85 (0.99)	1.00 (0.51)	−0.87 (0.18)	5.55 (0.99)	0.88 (0.81)
D.ln(CO_2)	−20.27 *** (0.00)	−20.32 *** (0.00)	−11.41 *** (0.00)	0.09 *** (0.00)	−0.21 *** (0.00)	0.10 *** (0.00)	−7.05 *** (0.00)	−10.31 *** (0.00)	−12.67 *** (0.00)
BEET	−5.27 *** (0.00)	−1.03 (0.15)		262.34 *** (0.00)	190.13 *** (0.00)		−0.12 (0.55)	1.01 (0.15)	
D. BEET	−9.67 *** (0.00)	−9.06 *** (0.00)		319.27 *** (0.00)	428.98 *** (0.00)		5.89 *** (0.00)	10.94 *** (0.00)	
ln(GDPP)	2.25 (0.96)	−6.88 *** (0.00)		189.10 ** (0.05)	366.74 *** (0.00)		−0.91 (0.81)	43.50 *** (0.00)	
D.ln(GDPP)	−11.27 *** (0.00)	−6.62 *** (0.00)		363.60 *** (0.00)	213.37 *** (0.00)		19.01 *** (0.00)	8.84 *** (0.00)	
ln(EC)	−6.72 *** (0.00)	1.79 (0.96)		232.52 *** (0.00)	156.77 ** (0.02)		−3.49 (0.99)	−1.38 (0.91)	
D.ln(EC)	−10.74 *** (0.00)	−10.35 *** (0.00)		329.77 *** (0.00)	430.47 *** (0.00)		9.63 *** (0.00)	33.81 *** (0.00)	
ln(REEC)	−3.44 *** (0.00)	2.73 (0.99)		273.68 *** (0.00)	142.85 (0.11)		−0.87 (0.80)	−2.55 (0.99)	
D.ln(REEC)	−9.10 *** (0.00)	−8.03 *** (0.00)		275.33 *** (0.00)	381.20 *** (0.00)		8.98 *** (0.00)	39.97 *** (0.00)	
ln(CO_2)	−5.68 *** (0.00)	2.57 (0.99)		320.88 *** (0.00)	149.38 * (0.06)		−1.72 (0.95)	−0.23 (0.59)	
D.ln(CO_2)	−9.75 *** (0.00)	−9.47 *** (0.00)		374.00 *** (0.00)	495.95 *** (0.00)		7.89 *** (0.00)	37.35 *** (0.00)	

Notes: The number of parentheses denote *p*-value. T_1 means test results including both constant and trend, T_2 means test results including only constant, and T_3 means test results without constant and trend. *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. Im-Pesaran-Shin, Fisher-type, and Hadri LM tests cannot be carried out the T_3 procedure.

Table 11 shows the result of the Pedroni cointegration test if there exists a long-run relationship in the four types of models. This test includes the null hypothesis of no-cointegration in the non-stationary panel series. Thus, the Pedroni cointegration test allows both panel-specific cointegrating vectors and the autogressive coefficient to vary over panels [40]. In Table 11, three types of test statistics reject the null hypothesis with respect to the total, OECD, and non-OECD country groups, and we conclude that four types of estimated models have a long-run relationship.

Table 11. Pedroni cointegration test result.

	Statistics	Total Countries	OECD	Non-OECD
Model 1	Modified Phillips-Perron t	−6.43 *** (0.00)	−5.01 *** (0.00)	−4.86 *** (0.00)
	Phillips-Perron t	−12.68 *** (0.00)	−13.62 *** (0.00)	−3.08 *** (0.00)
	Augmented Dickey-Fuller t	−10.02 *** (0.00)	−9.03 *** (0.00)	−5.40 *** (0.00)
Model 2	Modified Phillips-Perron t	−6.08 *** (0.00)	−8.02 *** (0.00)	−6.33 *** (0.00)
	Phillips-Perron t	−11.01 *** (0.00)	−10.87 *** (0.00)	−3.01 *** (0.00)
	Augmented Dickey-Fuller t	−8.36 *** (0.00)	−7.60 *** (0.00)	−6.05 *** (0.00)
Model 3	Modified Phillips-Perron t	−6.89 *** (0.00)	−5.10 *** (0.00)	−3.11 *** (0.00)
	Phillips-Perron t	−6.66 *** (0.00)	−4.25 *** (0.00)	−3.99 *** (0.00)
	Augmented Dickey-Fuller t	−6.54 *** (0.00)	−4.00 *** (0.00)	−4.76 *** (0.00)
Model 4	Modified Phillips-Perron t	−9.12 *** (0.00)	−7.11 *** (0.00)	−5.23 *** (0.00)
	Phillips-Perron t	−11.09 *** (0.00)	−8.22 *** (0.00)	−6.00 *** (0.00)
	Augmented Dickey-Fuller t	−9.33 *** (0.00)	−3.88 *** (0.00)	−8.55 *** (0.00)

Notes: The number of parentheses denote *p*-value. *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively.

4.3. Panel Granger Causality Test Results

This study estimated causal relationships in panel series by Dumitrescu and Hurlin [43] which provided an extended Granger causality test. Table 8 indicates the bidirectional test results of panel Granger causality by W-bar, Z-bar, and Z-bar tilde. In particular, Dumitrescu and Hurlin [43] mentioned that if N is large but T is small then the Z-bar tilde should be favored, and the Z-bar statistic is not suitable for unbalanced panels. Therefore, the causal relationship in the panel data of this study was determined according to the criteria of the Z-bar tilde.

In Table 12, the null hypotheses that GDPP, EC, and REEC do not Granger cause CO_2 emissions within total countries, and GDPP and REEC do not Granger cause CO_2 emissions within OECD countries are rejected by the Z-bar tilde at the 1% significance level. This implies that changes in economic growth and renewable energy consumption in OECD countries can contribute to CO_2 emissions. In addition, we find that economic growth is the main issue for most countries, but it may cause more environmental pollution at a given income level, as suggested by Salari et al. [6].

Table 13 illustrates the Granger cause results of CO_2 emissions embodied in international trade on economic growth and energy consumption. The null hypotheses that, in total and OECD countries, BEET does not Granger cause GDPP and that GDPP does not Granger cause BEET are rejected by the Z-bar tilde at the 1% significance level. This indicates that bidirectional causality exists in the relationship between economic growth and CO_2 emissions embodied in trade balance in the case of total and OECD countries. In addition, energy consumption (EC and REEC) of total and OECD countries can be the Granger cause of BEET. Therefore, CO_2 emissions embodied in trade and energy consumption (including economic growth) in total and OECD economies exist with feedback effects. Consequently, the overall results in Tables 12 and 13 support the EKC hypothesis, even if we consider the perspective of the CO_2 emissions generated by production, consumption, and distribution of traded goods and services.

Table 12. Panel Granger causality test result within Traditional EKC hypothesis model.

Null Hypothesis	Statistics	Total Countries	OECD	Non-OECD
CO_2 ⇏ GDPP	W-bar	1.81	1.99	1.45
	Z-bar	5.52 *** (0.00)	5.01 *** (0.00)	2.03 ** (0.04)
	Z-bar tilde	1.55 (0.12)	1.77 * (0.07)	0.31 (0.75)
GDPP ⇏ CO_2	W-bar	2.99	3.54	2.54
	Z-bar	10.01 *** (0.00)	12.06 *** (0.00)	5.32 *** (0.00)
	Z-bar tilde	5.22 *** (0.00)	4.99 *** (0.00)	2.55 *** (0.01)
CO_2 ⇏ EC	W-bar	13.20	1.83	28.96
	Z-bar	67.98 *** (0.00)	3.53 *** (0.00)	100.82 *** (0.00)
	Z-bar tilde	33.21 *** (0.00)	0.92 (0.35)	50.19 *** (0.00)
EC ⇏ CO_2	W-bar	1.76	1.93	1.51
	Z-bar	4.23 *** (0.00)	3.98 *** (0.00)	1.85 * (0.06)
	Z-bar tilde	3.01 *** (0.00)	1.15 (0.24)	0.20 (0.83)
CO_2 ⇏ REEC	W-bar	1.81	1.54	2.18
	Z-bar	4.51 *** (0.00)	2.29 ** (0.02)	4.27 *** (0.00)
	Z-bar tilde	1.15 (0.24)	0.30 (0.76)	1.42 (0.15)
REEC ⇏ CO_2	W-bar	4.33	6.50	1.34
	Z-bar	18.56 *** (0.00)	23.35 *** (0.00)	1.32 (0.21)
	Z-bar tilde	8.26 *** (0.00)	10.93 *** (0.00)	0.10 (0.91)

Notes: The number of parentheses denote *p*-value. *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. 'X ⇏ Y' means that X does not Granger cause Y.

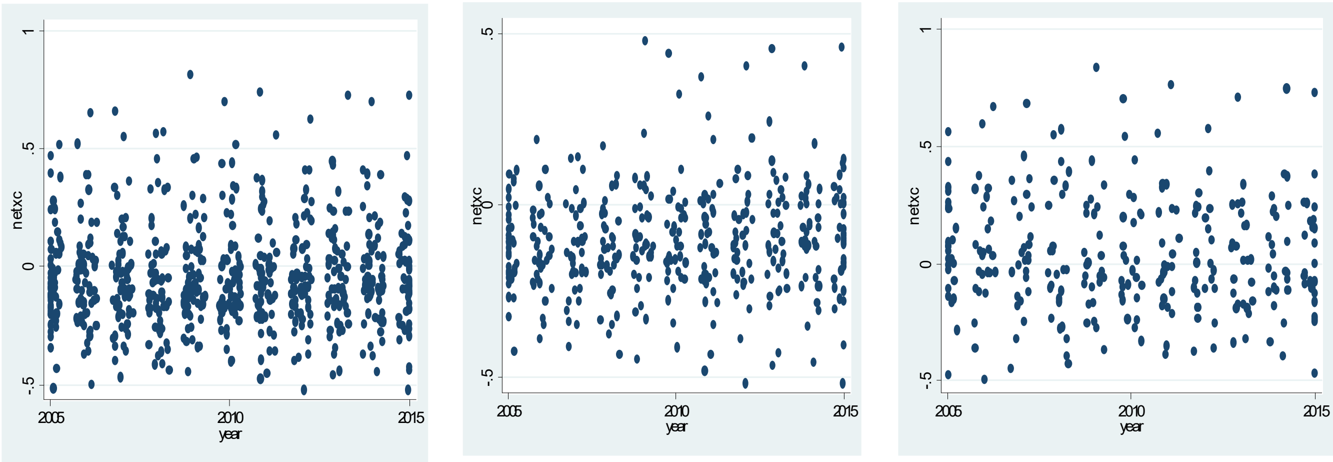
Table 13. Panel Granger causality test result within CO_2 emissions embodied in trade model.

Null Hypothesis	Statistics	Total Countries	OECD	Non-OECD
BEET ⇏ GDPP	W-bar	2.25	2.64	2.09
	Z-bar	7.23 *** (0.00)	6.83 *** (0.00)	4.01 *** (0.00)
	Z-bar tilde	2.99 *** (0.00)	3.03 *** (0.00)	2.11 ** (0.03)
GDPP ⇏ BEET	W-bar	3.66	4.03	3.45
	Z-bar	13.27 *** (0.00)	14.20 *** (0.00)	6.98 *** (0.00)
	Z-bar tilde	5.99 *** (0.00)	6.09 *** (0.00)	3.04 *** (0.00)
BEET ⇏ EC	W-bar	1.68	1.56	1.85
	Z-bar	3.81 *** (0.00)	2.40 ** (0.01)	3.06 *** (0.00)
	Z-bar tilde	0.80 (0.42)	0.35 (0.72)	0.82 (0.41)
EC ⇏ BEET	W-bar	3.24	4.42	1.61
	Z-bar	12.49 *** (0.00)	14.52 *** (0.00)	2.20 ** (0.02)
	Z-bar tilde	5.18 *** (0.00)	6.47 *** (0.00)	0.38 (0.70)
BEET ⇏ REEC	W-bar	1.98	2.21	1.67
	Z-bar	5.51 *** (0.00)	5.17 *** (0.00)	2.42 *** (0.01)
	Z-bar tilde	1.65 * (0.09)	1.75 * (0.07)	0.49 (0.61)
REEC ⇏ BEET	W-bar	2.94	3.69	1.91
	Z-bar	10.84 *** (0.00)	11.42 *** (0.00)	3.29 *** (0.00)
	Z-bar tilde	4.35 *** (0.00)	4.91 *** (0.00)	0.93 (0.34)

Notes: The number of parentheses denote *p*-value. *, **, and *** indicate the significant level of 10%, 5%, and 1%, respectively. 'X ⇏ Y' means that X does not Granger cause Y.

4.4. Pollution Haven Hypothesis Test Results

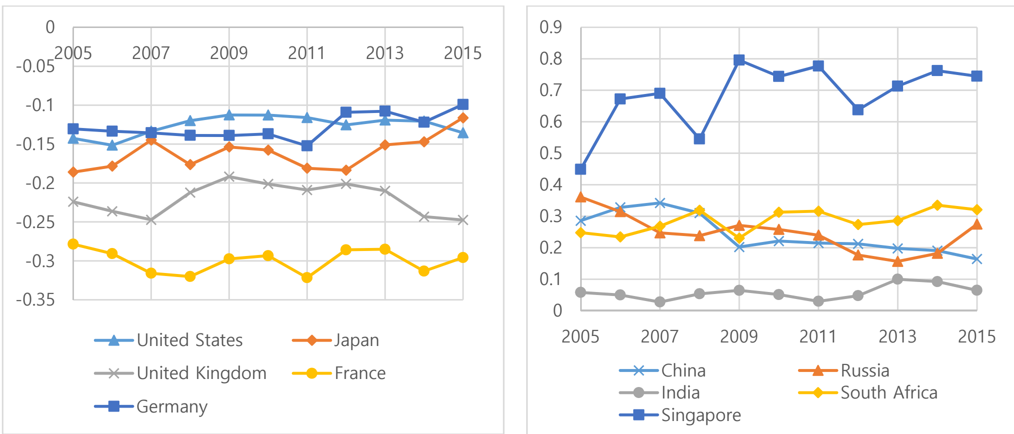
Figure 3 illustrates the distribution of the PHH results based on Equation (18). Figure 3a shows that all countries are well distributed for CO_2 emissions embodied in trade balance (CO_2NETXC) during the period of 2005 to 2015, while CO_2NETXC of most countries is located under zero. In addition, Figure 3b,c indicate CO_2NETXC distributions for OECD and non-OECD countries, respectively, and CO_2NETXT in the OECD countries are almost below zero but non-OECD countries are mostly above zero. This implies that the closer CO_2NETXC is to zero, the more CO_2 emissions occurring in exports and imports for a region decrease, and this country has more responsibility for CO_2 emissions in the process of international trade.



(**a**) (**b**) (**c**)

Figure 3. Pollution haven distributions from 2005 to 2015. (**a**) Total countries. (**b**) OECD countries. (**c**) Non-OECD countries.

More precisely, Figure 4 indicates the results for the top five countries based on CO_2NETXC. The results for the top five deficits and surpluses illustrate that most countries have experienced a constant pattern of CO_2NETXC from 2005 to 2015, and there appears to be support for the PHH, particularly for France, the United Kingdom, Singapore, and South Africa. Partially, Porter and van de Linde [23] suggested that environmental regulation spurs innovation, which can enhance the international competitiveness of a company and induce economic growth. Meanwhile, the evidence of PHH in this study indicated that pollution-intensive industries in developed countries move to developing or less-developed countries, with relatively weak environmental regulations, and, therefore, fewer pollution-intensive products are produced in developed countries are imported.



(**a**) (**b**)

Figure 4. Pollution haven patterns for the top five countries. (**a**) Top five countries for CO_2NETXC deficits. (**b**) Top five countries for CO_2NETXC surpluses.

5. Conclusions and Implications

This study investigated the relationship between CO_2 emissions and economic growth for OECD and non-OECD countries in accordance with the traditional EKC hypothesis. In addition, in the globalized era, this study analyzed the nexus between CO_2 emissions embodied in international trade and economic growth, including several procedures of panel regression analysis, Granger causality, and the PHH. These attempts have provided meaningful results, in which environmental pollution is reflected in international trade, unlike many previous studies demonstrating a simple relationship between CO_2 and economic growth.

The main findings of this study are as follows. First, in the period of 2005 to 2015, there is evidence of an inverted-U shaped relationship between CO_2 emissions and economic growth, particularly for total and non-OECD countries. In addition, the relationship between CO_2 emissions embodied in international trade and economic growth has the same result as the traditional EKC hypothesis model. This implies that in the early stages of economic development, the CO_2 emissions in trade balance increases, whereas it decreases beyond the income turning point. That is, we find that developed countries can be relatively net CO_2 emission importers with imports, including CO_2 emissions, that exceed exports, but developing or less developed countries can be relatively net CO_2 emission exporters.

Second, economic growth and renewable energy consumption can contribute to CO_2 emissions, and CO_2 emissions embodied in trade balances have bi-directional causality for economic growth and renewable energy consumption. This result implies that there is evidence for the existence the EKC hypothesis, and economic situation and renewable energy consumption are important factors affecting CO_2 emissions embodied in trade. Finally, partially upper countries among net exporters (or importers) of CO_2 embodied in trade balance support the PHH, in which products including environmental pollution in international trade can be more exported (or more imported) depending on the economic development situation of a country. Thus, some developed countries tend to be net importers of CO_2 emissions to avoid their own countries' environmental regulations, while some less-developed countries also tend to be net exporters of CO_2 emissions to improve their economic development.

Based on the results of this study, there are two important policy implications. According to accelerated greenhouse effects, we cannot avoid CO_2 emission problems, and shift responsibility for environmental pollution to other countries. It is, therefore, clear that international debate, in which environmental pollutants are produced and consumed by the degree of economic development, should be continued, and we need to recognize the corporate responsibility for environmental issues, especially in developed countries. In addition, due to the increase in the importance of international trade, we need to consider both externalities of environmental pollutants in the production process and CO_2 emissions embodied in international trade.

Unlike the age of self-sufficiency, we all have trade, and we cannot think of economic growth without trade. Although this study utilized the concept of CO_2 emissions embodied in trade and the PHH to overcome the shortcomings of the EKC hypothesis, this study did not consider the classification of industries within a country, and this limitation leaves room for further research.

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