4-26-2017

The Role of Trade and Renewables in the Nexus of Economic Growth and Environmental Degradation: Revisiting the Environmental Kuznets Curve (EKC)

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Recommended Citation

Nguyen Thi Ngoc Lan, "The Role of Trade and Renewables in the Nexus of Economic Growth and Environmental Degradation: Revisiting the Environmental Kuznets Curve (EKC)" (2017). *Undergraduate Research Awards*. 34.
https://digitalcommons.hollins.edu/researchawards/34

The Role of Trade and Renewables in the Nexus of Economic Growth and Environmental Degradation: Revisiting the Environmental Kuznets Curve (EKC)

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Submitted to Hollins University

Department of Economics and Business

In Partial Fulfillment of the Requirements for the B.A. Degree

DECEMBER 15, 2016

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Senior Thesis Fall 2016

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Abstract

Based on the Environmental Kuznets Curve (EKC) hypothesis, this study investigates whether there is a revised EKC relationship between economic growth and CO2 emissions under the presence of renewable energy and trade for a panel of 35 countries whose trade openness index have remained higher than average global trade index over the period 1980-2012. By addressing similar trade characteristics rather than income levels, this paper applies a panel analysis with random effects and fixed effects to test EKC hypothesis. We use the principal component analysis to explain why CO2 emissions stands as a critical indicator of environmental quality. The results from our random-effects and country-fixed effects models, including the impacts of trade and renewables, reveal evidence of the revised EKC hypothesis within our sample. Trade is found to have a positive association with the level of CO2 emissions, while renewable energy has a negative relationship with CO2 levels. As a policy implication, countries should strengthen environmental regulations of trade agreements and encourage investment in renewables to combat climate change.

I/ Introduction

The conflict between economic growth and environmental quality has played an important role in the discussion on the environmental effects of rising income over the last two decades. Yet, the debate on this topic is far from reaching a universal understanding on the subtleties behind the interaction between economic growth and environmental distress. Economic growth, measured as the increase in the real GDP per capita, creates an incessant throughput of energy and materials into the economy, releasing significant amount of pollution and by-product waste into the earth system. Since industrialization, the evidence of anthropogenic impacts on climate change has, obviously, become increasingly alarming. September 2016 marks a new record in the Earth's history with the increase in global CO2 emission levels over the threshold of 400 ppm (NASA Climate Change, 2016). For the first time in history, 197 countries convened in Paris to ratify the UNFCCC convention, The Paris Agreement, to mitigate climate change impacts caused by human activities. Yes, policymakers are still struggling to establish ratification actions and creating better assessment instruments, including better predictors gauging the impact of economic growth on environmental distress (UN Climate Change Conference, 2016).

According to the International Panel on Climate Change (IPCC)'s Climate Change 2014 Synthesis Report, an increasing number of climate change mitigation and adoption policies have not succeeded in slowing down the rate of environmental deterioration, especially the global greenhouse gas emissions (Pachauri et al., 2014). Among essential drivers of environmental crises, the growth of economic activities contributes the most to the increase in pollution levels, particularly CO2 emissions from fossil fuel combustion (Lorente and Alvarez-Herranz, 2016; Pachauri et al., 2014). Both developed and developing countries are facing trade-offs between economic growth and environmental quality, as they attempt to develop economic diversification strategies to enhance resilience and reduce emissions to combat climate change (Pachauri et al., 2014). As Stern (2007) pointed out, countries must take drastic actions to reduce global warming, because climate change impacts might trigger a future of reduced global GDP by as much as 25% with the pressure from increasing costs involved in coping with a looming possibility of environmental disasters.

Literature examining the relationship between economic growth and environmental degradation emerged in the late 20th century to provide better policy implications on how to address the ongoing interactions between economic activities and the environmental ecosystem. Among landmark analyses, a study conducted by Grossman and Krueger on the potential impacts of the North American Free Trade Agreement (henceforth NAFTA) on environmental quality in 1991, set a milestone helping introduce the environmental Kuznets Curve (EKC) by these two outstanding economists by 1995 (Grossman and Krueger, 1991). The EKC model hypothesizes an inverted-U association between economic growth and environmental degradation, which resembles the pioneering work of Simon Kuznets on the relationship between income inequality and economic growth (Kuznets, 1955). The EKC model suggests that in the beginning stages of economic growth, pollution, and waste increases until some level of income is met, at which the trend reverses. At higher income levels, the desire for better living standards, including access to a healthier or less-polluted environment, stimulates investment in technology to increase production efficiency and pollution cleanup, which improves the environmental quality (Grossman and Krueger, 1995).

Since then, a growing literature and discussions on this topic have emerged and introduced various interpretations of this relationship along with different versions of Grossman and Krueger's pioneering model. Proponents of the EKC, especially policymakers in developing countries, referred to this model to defend their economic growth priorities as a potential solution to environmental issues (Stern, 2004, Dasgupta et al., 2002). However, the inverse pattern of environmental degradation rduring the second half of the EKC may reflect the imports of pollution-intensive production processes from developed countries to developing countries (Andreoni and Levinson, 2001). Thus, many studies on the EKC are criticized by recent literature due to their possible lack of control variable biases or potential explanatory variable biases beside the simple income level, such as trade openness, political liberalization, financial development, and the introduction of renewable energy (Stern, 2004). Moreover, previous cross-country cross-sectional analyses based on the EKC model often chose a collection of countries by region or continent based on income groups across the world (Dinda 2004).

Besides the mainstream EKC explanation using scale, technological, and composition effects, recent literature on this problem has used international trade as an important variable to explain the results of EKC because trade activities can affect the environment both negatively and positively (Dinda 2004, Stern 2004, Andreoni and Levinson 2001). The Hecksher-Ohlin trade theory discussed by Arrow et al., (1995) and two trade-related hypotheses - Displacement Hypothesis and Pollution Haven Hypothesis – discerned by Dinda (2004) all contended that trade openness allowed developed countries to concentrate on clean services and human capital activities while developing countries with weaker environmental standards get all the dirty industries, as they specialize in pollution-intensive manufactures. On the other hand, international trade with increasing competitiveness and more stringent environmental regulations can stimulate technological progress and reforms in the energy sector through investment that potentially reduces pollution and improves the environment (Dinda 2004, Stern 2004). Since trade plays an important role in globalization and it is an important component of GDP for individual economies, this study will incorporate this factor into our EKC analysis.

Based on the latest approaches to the EKC hypothesis, this paper will examine whether there is an inverted-U relationship between environmental quality and economic growth under the effect of sustained adoption of renewables among 35 countries[1] whose trade openness index (the control variable) has remained consistently higher than the average global trade index from 1980 to the most recent data in 2012. By using trade as a control variable for selected countries, the first EKC contribution of this paper is to provide a new sampling method: looking at countries that have similar trade characteristics, rather than income levels. Secondly, the study will use the principal component analysis to explain why CO2 emissions is a standard indicator for environmental quality among major indicators like total greenhouse gas emission levels, water quality variables, deforestation, population density, electricity production from fossil fuels, and energy use. The paper will use a panel analysis with random effects, entity fixed effects, entity and time fixed effects to analyze time series and cross-sectional data from the World Bank and the US Energy Information Administration’s International Energy Statistics. The paper hypothesizes that there is a revised EKC relationship among these 35 selected countries as their economies rely on international trade, which might trigger the adoption of less pollution-intensive technologies, such as renewables, and reduce their negative impacts on environmental quality.

The rest of the paper is organized in the following structure. The second section of the paper reviews relevant literature pertaining to EKC case studies by defining the model and its evolution (results from earlier EKC studies), analyzing the strengths and weaknesses of those

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[1] Refer to Appendix VII/1.

theoretical models, and then discerning major criticisms behind the simple approach as well as more recent approaches to the EKC model with the addition of trade and renewable energy as explanatory variables. This will solidify the interactions among those variables in relation to economic growth and environmental quality, and justify the contributions of this study. The third section revolves around the data selection method, defining the regression models for our panel analysis using random effects, entity fixed effects, and entity and time fixed effects. It explains statistical methodologies to test the assumptions of the regression models. The fourth section discusses the empirical findings and interprets in light of our hypothesis. The last section offers final conclusions and limitations along with policy implications and suggestions on potential avenues for future research.

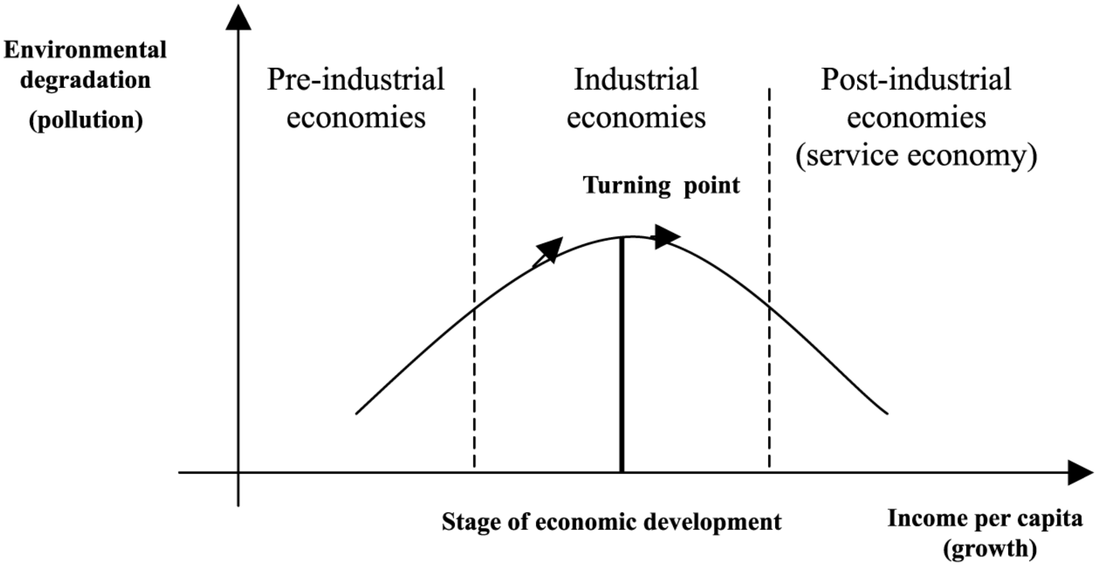
II/ Literature Review

Since the 1990s, the availability of data on different measured levels of environmental quality stimulated empirical studies of the nexus between economic growth and environmental degradation. Landmark articles (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993) laid the foundations for the Environmental Kuznets Curve (henceforth EKC) hypothesis after Kuznets (1955). Like the Kuznets Curve on income per capita and income inequality, the EKC suggests that the interaction between environmental degradation and economic growth displays a similar inverted-U-shaped relationship. While literature in the 20th century provides concrete theoretical underpinnings behind the EKC model, recent studies have revisited the model providing various extensions of the EKC with updated data, and additional variables and factors to examine the EKC hypothesis from more nuanced perspectives.

II.1/ Theoretical background of the EKC

The EKC hypothesis predicts a long-run development path for each individual economy as countries (or entities) experience economic growth through different stages. The first phase of the EKC, the path displaying a positive relationship (rising at a decreasing rate), reflects the first stages of economic development: Growth in per capita income is directly proportional to environmental degradation. During this phase, countries prioritize an increase in material output, employment, and levels of income and consumption –increased throughput- rather than clean air and water (Dasgupta et al., 2002). After the level of income of an economy reaches a threshold level, which ranges between $5000 to $8000 per capita, as early literature suggests, environmental quality begins to improve (Dasgupta et al., 2002). Thus, in the early stages of economic development, environmental quality declines faster than economic growth and slows down relative to the growth rate at higher income levels. From an empirical stance, a sample of cross-country cross-sectional data with different income groups can provide evidence of the EKC assuming all the selected countries in a meaningful sample each depict one inverted-U curve. At any given cross-section in time, in poor-income countries the relationship between economic growth and environmental degradation is expected to follow the initial stage of the EKC, while this association in developing countries reaches the peak of the EKC. Whereas, in high income countries the relationship becomes negative as the falling stage of the EKC suggests (Dinda, 2004). Graph 1 below provides an illustration of the EKC hypothesis.

Graph 1: Explanation of the EKC



Source: Panayotou (1993)

Several prominent scholars have developed theoretical models based on the EKC to interpret the results of earlier EKC studies and undertake appropriate policy recommendations. In general, the empirical evidence from EKC studies aims at identifying the scale, composition, and technological effects of economic growth on the environment (Dasgupta et al., 2002; Dinda, 2004; Stern, 2004). Ceteris paribus, the scale effect occurs when capital accumulation consumes a greater amount of pollution-intensive input and increases the throughput, which negatively affects the environment by increasing the pollution levels, depleting natural resources, and causing biodiversity loss (Antweiler et al., 2001; Cole and Elliott, 2003; Dinda, 2004; Stern, 2004). The EKC hypothesis conjectures that the scale effect will predominate during the initial stages of economic growth, explaining the positive association between per capita income and indicators of environmental degradation. Eventually the composition and technological effect will offset the scale effect to generate the negative relationship between economic growth and pollution (Dinda, 2004; Lorente and Alvarez-Herranz, 2016).

The composition effect may bring a mixture of positive and negative effects on the environmental quality, depending on whether a study looks at a specific country or a sample of countries. As income grows, the structure of the economy often changes, say, from a less pollution-intensive agrarian economy to more pollution-intensive growth in manufacturing and service industries. This conventional process of economic development comes along with the increase in environmental awareness, enforcement of environmental regulations, which eventually results in the improvement of environmental quality (Panayotou, 1993; Antweiler et al., 2001; Dinda, 2004; Stern, 2004). However, this positive gain in high-income countries can potentially induce a growth in the flows of dirty industries from developed countries to developing countries through international trade (Suri and Chapman, 1998; Dinda, 2004; Jayanthakumaran and Liu, 2012).

Income growth often gives an impulse to technological progress that increases efficiency and applies production methods beneficial to the environment (Antweiler et al., 2001; Andreoni and Levinson, 2001; Cole and Elliott, 2003; Sica and Susnik, 2014; Ben Jebli et al., 2015). Thus, once a country reaches a certain threshold level of income, the positive effects of cleaner technologies outweigh the negative sides of economic growth (Andreoni and Levinson, 2001;

Dinda, 2004). Coupled with international trade and enhanced international cooperation, technology transfers can help developing countries achieve economic growth while reducing the negative impacts of growth on the environment.

Pivotal theoretical models have been built to provide the foundations for the empirical findings of the EKC. The interaction of the Marginal Cost (MC) and Marginal Benefit (MB) schedules, under a decentralized market economy, can be used to explain the shape of the EKC. Selden and Song (1995) found that the optimal pollution[2] has an inverted-U relationship with capital stock; at the initial stages of economic development there is no optimal abatement until a given capital stock is obtained. Building on a similar theory behind increasing returns to pollution abatement, Andreoni and Levinson (2001) developed an EKC model based on the technological link between the consumption of a marketable good and the abatement of its unwanted byproduct. John and Pecchenino (1994) and McConnell (1997) derived the EKC from an overlapping-generations model, in which investment in environmental quality as a stock resource is initially zero and then increases with income. One common aspect behind these standard models is that most agree that at low levels of income, the marginal benefit of additional environmental quality is zero, as cleaner technologies can be implemented only after a certain threshold of income is achieved (Andreoni and Levinson, 2001).

Certain assumptions have been made to derive the concept of the EKC. As Dasgupta et al. (2012) mentioned, the marginal utility of consumption must stay constant or decline when the disutility of pollution, the marginal damage of pollution, and the marginal cost of reducing pollution are rising. Similarly, international trade must have no effect on environmental degradation, which means only the pollution externality at a local level is considered in the

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[2] The level at which the marginal cost of pollution abatement is the same as the marginal benefit of pollution abatement.

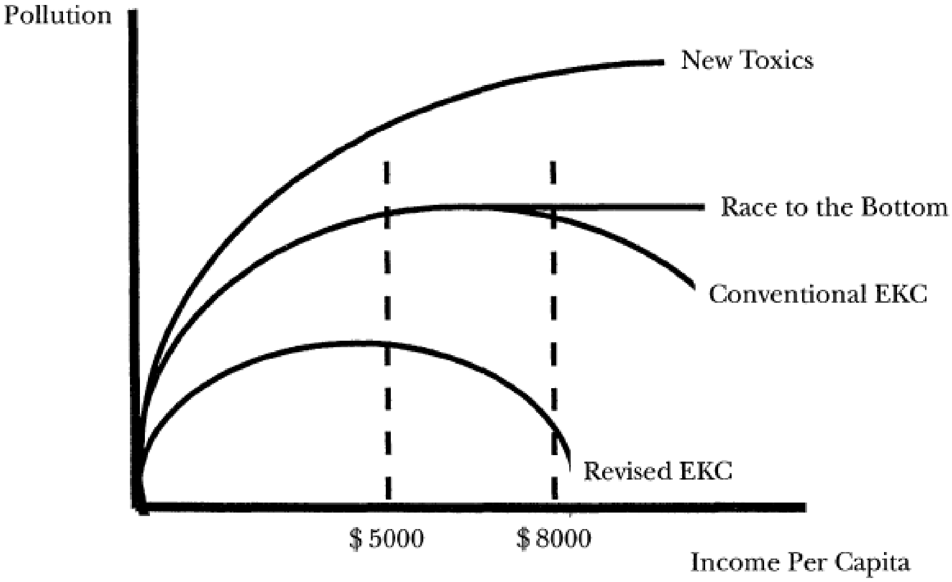
model (Dasgupta et al., 2012; Stern, 2004). Moreover, world per capita income is assumed to have a normal distribution (Stern, 2004). As the readers may surmise, major criticisms rise when some or most of these assumptions are violated in the real world.

The findings behind empirical case studies based on EKC models have, thus far, failed to reach never reached a consensus. Because economic conditions and historical characteristics differ from one country to another, the dynamic interaction between economic growth and environmental degradation cannot be generalized by a single model (Stern, 2004). If the EKC hypothesis and its assumptions hold, the possibility of a win-win solution for both environmental degradation and economic development is seemingly more attainable. Despite the inconclusive empirical evidence, some scholars still affirm that economic growth is required to improve the environmental quality (Beckerman, 1992; Panayotou 1993). Because the EKC evidence in high-income countries has led to conjectures that economic growth may be compatible with increased environmental quality, policymakers in developing countries set high priority for economic growth ahead of protecting natural resources in the economic production equation, only paying for the abatement costs at a later date (Dasgupta et al., 2002).

II.2/ Theoretical criticisms behind the EKC

The confounding findings of multiple EKC models cannot be used to censure the solid arguments proposed by Meadows et al. (1972) concerning the finite availability of natural resources, or Arrow et al. (1995) on the carrying capacity and ecosystem resilience on Earth. The EKC hypothesis neglects the complexity of the ecological systems on our planet. Furthermore, EKC models seldom have incorporated feedback loops of natural cycles and resource stocks, and they have failed at incorporating limits to the carrying capacity of the planet, and irreversible losses in ecosystem resilience (Arrow et al., 1995; Stern et al., 1996). Additionally, major literature surveys on the EKC conclude that the EKC models have never included all pollutants, or examined all the variables of environmental quality, which leads to a significant amount of conflicting arguments, interpretations, and criticisms among researchers and policy makers. (Stern et al., 1996; Dasgupta et al., 2002; Dinda, 2004; Stern, 2004)

Graph 2: Environmental Kuznets Curve: Different Scenarios



Source: Dasgupta et al., (2002)

Besides the conventional inverted-U shape, several EKC studies discern different development paths or shapes of the EKC (Refer to above Graph 2). Pessimistic critics discern two main hypotheses with the “Race to the Bottom” scenario and new toxic cases (Dasgupta et al., 2002). The “Race to the Bottom” scenario illustrates that the EKC flattens instead of falling after reaching its peak, as developed countries relax environmental standards to cease capital outflows after displacing the production of dirty industries to developing and poor-income countries through international trade (Dasgupta et al., 2002). Another pessimistic point of view delivers a warning on the release of potentially rising new toxics, which raises the EKC up to a higher level of pollution. Meanwhile, many pollutants and environmental impacts on natural ecosystems have not been considered. Emissions of most pollutants and aggregate waste have not declined; preeminent studies found a monotonically positive relationship between per capita incomes and the emission levels as well as flows of waste (Dinda, 2004; Stern, 2004).

Optimistic economists postulated that developing countries might follow a revised EKC under the impacts of environmental regulation, economic liberalization, better information, increasing pressures from market agents, and international assistance (Dasgupta et al., 2002). Many developing and emerging economies have learnt lessons about protecting the environment from the displacement of dirty industries from high-income economies, so they might experience a flatter and lower EKC than the conventional theories would prescribe. Dasgupta et al. (2002), Stern (2004), and Dinda (2004) have pointed out the critical role of technology transfers through international trade in providing sustainable solutions for both the environment and economic activities. These clean development mechanisms are worth further examination to identify how they affect the association between economic growth and environmental quality along with making the use of the EKC more applicable to current development paths.

III.3/ The role of international trade in relation to environmental degradation

The scale and composition effects of trade accelerate environmental pressures triggered by economic growth (Antweiler et al., 2001; Cole and Elliott, 2003). The EKC infers two critical hypotheses on the side effects of comparative advantage in pollution-intensive industries given international trade, namely: The Displacement Hypothesis and the Pollution Haven Hypothesis (Dinda, 2004). Both hypotheses deliver a common message based on the Hecksher-Ohlin trade theory that under free trade, less developed countries will become the producers and suppliers of labor and natural resource intensive goods that generate more pollution than human and service activities, which developed countries tend to specialize over time (Stern et al., 1996; Stern 2004; Dinda, 2004). The Displacement Hypothesis posits that the structural change in developed countries results from the displacement of pollution-intensive industries to the poor-income and developing countries (Stern et al., 1996; Dinda 2004). Thus, trade openness can cause the growth of dirty industries in poor countries and turn rich countries into net importers of pollution-intensive goods (Dinda, 2004). The Pollution Haven Hypothesis explains the case that dirty industries prefer to gravitate toward developing countries with low environmental standards to reduce abatement costs (Dinda, 2004).

In contrast, trade liberalization can induce environmental protection and reduce pollution through the adoption of market mechanisms (Dinda, 2004). Accordingly, as countries open to trade and more sectors are deregulated or privatized, the increase in energy efficiency and higher prices of pollution-intensive power reduce energy production and the release of pollutants. Market agents, such as global investors and multinational corporations, can play an important role in promoting clean production (Dasgupta et al., 2002; Dinda, 2004). As the news about the environmental damage of a firm's business activities can affect the firm's reputation and eventually its stock prices, shareholders and investors will create pressure to reduce environmental impacts of its production and encourage the adoption of cleaner technology (Dasgupta et al., 2002).

International trade in technology can generate positive impacts on both environmental quality and the growth of an economy (Antweiler et al., 2001; Cole and Elliott, 2003; Al-Mulali et al., 2015; Jayanthakumaran and Liu, 2012). The trade-induced diffusion of technology through foreign direct investment from developed countries allows economic latecomers to grow in more sustainable ways than older industrialized economies experienced in the past (Stern, 2014).

Along with technology acquisition, developing countries can reduce the levels of environmental degradation with adequate trade regulations and capital controls to sustainably produce output without stripping the resiliency of the ecosystem (Suri and Chapman, 1998; Antweiler et al., 2001). Depending on different conditions, conclusions on the effects of trade on pollution and economic growth must be taken with caution.

III.4/ The role of renewable energy in relation to income and pollution

The adoption of new technology may stimulate the consumption and generation of renewable energy, one of the major solutions to reduce fossil fuel dependence. Since renewable energy plays a vital role in reducing emissions, several leading case studies have examined the impact of the energy sector, especially renewable energy production, in relation to output growth and pollution levels (Ang, 2007; Lopez-Menedez et al., 2014). The introduction of renewable energy as one of the additional control variable in the EKC literature is important in light of the evidence of an EKC hypothesis for countries with high renewable energy resource intensity (Lopez-Menedez et al., 2014).

Renewable energy consumption is found to have a positive and statistically significant association with the increase in per capita income (Sadorsky, 2009). Indeed, the empirical evidence from a panel of emerging economies illustrates that fluctuations in income have a larger impact on increasing renewable energy consumption than fossil fuel electricity consumption (Sadorsky, 2009). Renewable energy consumption also has a long-run causality to trade and income growth (Ben Jebli et al., 2015), while in the short run, it has a causal association with CO2 emissions (Salim and Rafiq, 2012). Regarding policy implications, countries must set up energy regulations to promote renewable energy generation and increase efficiency through the expansion of trade exchanges to combat the environmental challenges while striving to meet economic priorities (Ben Jebli et al., 2015; Al-Mulali et al., 2015; Lorente and Alvarez-Herranz, 2016).

A vast amount of recent literature revisiting the EKC has introduced upgrades in econometric methods and has included additional explanatory variables. While the early literature utilizes cross-country analyses to test the evidence of the EKC, early methodology contains several shortcomings given the empirical results and policy implications (Stern, 2004; Dinda, 2004). Time-series analyses with various econometric models, including the autoregressive distributed lag techniques (ARDL) (Al-Mulali et al., 2015) and panel cointegration techniques (Ben Jebli et al., 2015) have introduced newer empirical evidence in support of the EKC. Studies conducting the Granger causality test have made a significant contribution to the literature of EKC, as evidence opens room for economic theory to explain the dynamic relationship between environmental degradation and economic growth (Shahbaz et al., 2014).

Because of the important role of trade and renewable energy in relation to economic growth and environmental degradation, this study incorporates trade openness and renewable energy consumption as two additional explanatory variables. While recent literature has started to incorporate these two factors into the EKC models, none of the previous studies have selected a sample of countries that share similar characteristics in relation to trade. This paper provides a new sampling methodology to overcome this shortcoming and expand the EKC’s interpretation and policy implications.

III/ Methods

III.1/ Data

To analyze the role of trade and renewable energy in the EKC model, this study collects a cross-country time series panel of 35 countries[3] whose trade openness indices have generally remained above the average world trade openness level from 1980 until 2012. As trade is an important component of GDP, we look at countries whose values of imports and exports expressed as a percentage of GDP remains relatively high. This means that the selected countries are all open economies, highly dependent on their foreign sectors. This selection method allows us to control the effects of trade and examine the role of renewable energy consumption in the EKC model. We will use trade as the control effect to reason how the variations in the adoption of renewable energy consumption, among selected countries, leads to changes in the nexus between per capita real GDP and CO2 levels. This selection criterion intends to overcome earlier criticisms on the findings of previous cross-country EKC studies that look at a sample of countries in the same region or across different income groups. We use the level of CO2 emissions (CO2) (in kilotons) as the indicator for environmental degradation - the response variable of the EKC model[4]. The independent variables include per capita real GDP (realGDPPC) in constant 2010 U.S. dollars, square of per capita real GDP (sqrealGDPPC), trade openness index (trade) measured by the sum of exports and imports expressed as a percentage of GDP, and the share of electricity generated from renewable sources (REGofEG). All data were

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[3] Refer to Appendix VII/1 for the list of selected countries.

[4] A principal component analysis (PCA) was conducted among indicators for environmental degradation to choose the variable that explains the most variance in the selected sample of data. Besides the level of CO2 emissions, other important indicators for environmental degradation include capture fisheries production, total fisheries production, total greenhouse gas emissions, and other greenhouse gas emissions. Refer to Appendix VII/4 for the detailed PCA results. We also took similar patches of regressions using those variables as dependent variables instead of CO2 emission levels. Refer to Appendix VII/5 for detailed results.

retrieved from the World Bank's World Development Indicators (2016) except for the statistics on renewable electricity generation, which are featured under the U.S. Energy Information Administration's International Energy Statistics (2016). Natural log transformations and panel analysis are conducted using RStudio 0.99.903 software. Descriptive statistics of the raw and transformed data are shown in Table 2 (Refer to Appendix VII/2)

III.2/ Model

Following the model of Lopez-Menendez et al. (2014), our empirical case study compares two EKC models. First, the standard EKC regression model with CO2 emissions levels (CO2) as a quadratic function of the per capita real GDP (realGDPPC) and, secondly, the standard model that includes the trade openness index (trade) and renewable electricity generation (REGofEG) as two additional explanatory variables. Following are the equations of two models:

$$lnCO2_{it} = \alpha_i + \gamma_t + \beta_1 lnrealGDP + \beta_2 (lnrealGDP)^2 + \varepsilon_{it}, \qquad (1)$$

$$\begin{aligned} lnCO2_{it} = \alpha_i + \gamma_t + \beta_1 lnrealGDP + \beta_2 (lnrealGDP)^2 \\ + \beta_3 lntrade + \beta_4 lnREGofEG + \varepsilon_{it}, \qquad (2) \end{aligned}$$

where i = 1,..,35 and t = 1980,...,2012[5] indicate the country and time series, respectively, and ln refers to the natural logarithm transformation of observation for each variable to restrict the negative and zero values of selected variables. α_i and γ_t denote the country and time fixed effects. The expected outcome would be for the country and time fixed effects to fluctuate depending on the conditions of individual countries. The turning point in income is defined as the maximum level of CO2 emissions: $\tau = e^{(-\beta_1/(2\beta_2))}$, which we obtain by determining the

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[5] Refer to Appendix VII/3 for the illustration of the dimension of the data

first order conditions for each equation, solving the first derivative of the dependent variable in each equation with respect to $lnrealGDP$ and then setting it equal to 0:

$$lnCO2'_{it} \quad = \beta_1 + 2\beta_2 lnrealGDP = 0$$

$$lnrealGDP = \frac{-\beta_1}{2\beta_2}$$

$$realGDP \quad = \tau = e^{(-\beta_1/(2\beta_2))}$$

Once a country reaches this threshold level of income, an increase in every unit of income will correspond to a decrease in the level of CO2. The above equations assume that though each considered country may have different EKC shapes and turning points, at a given income level all the countries have the same income elasticity. The two models capture several relationships between per capita real GDP and CO2 emissions depending on the coeffi88cients $\beta_1$and β_2 (see Appendix VII/4). Our empirical findings are consistent with an EKC when estimated coefficient $\beta_1 > 0$ and estimated coefficient $\beta_2 < 0$, meaning there is an inverted-U relationship between income and the level of CO2. Concerning equation (2), this study hypothesizes that the sign of the third estimated parameter may take a positive or negative sign, depending on whether sample countries are releasing heavier shares of CO2 emissions; whereas, the sign of the fourth estimated parameter should be negative if the share of renewable sources in electricity generation is significant and countries experience a consistent growth rate. Based on the empirical results from the study by Chiu and Chang (2009), renewable energy can help mitigate CO2 emissions when its supply makes up for around 8.39% of the total energy supply. Given the role of renewable energy and trade in potentially reducing emissions without halting economic growth, this study expects the turning point of the equation (2) to arise at lower levels of CO2 emissions compared to the one pertaining to the first regressions equation (equation (1)), which suggests a revised EKC hypothesis.

III.3/ Econometric techniques

This study estimates both the random and fixed effects (country and time specific) for each of the regression models above. In the fixed-effects models, α_i and γ_t are treated as regression parameters; meanwhile, in the random-effects models, they represent components of random disturbance term (Stern, 2004). If and when the explanatory variables are correlated, the random-effects model cannot be estimated consistently, meaning the fixed-effects model is preferred over the random-effects model. If the error terms are correlated, the random-effects, rather than the fixed-effects model, is more suitable to infer the regression results. The random-effects model assumes that the variation across entities is random and uncorrelated, which allows for time-invariant variables to influence the model as explanatory variables (Torres-Reyna, 2007). Oppositely, the fixed-effects model removes the effects of time-invariant characteristics that are unique to the individuals, so they do not influence the regression outcomes (Torres-Reyna, 2007). The results of the fixed-effects model, however, cannot be generalized to a population or another sample since the estimated parameters depend on the country-and time-effects in the selected sample (Stern, 2004).

Prior to running the regression equations (1) and (2), this study also examines the following tests to choose the most appropriate models:

(1) The Hausman test where the null hypothesis is that the preferred model is the random effects rather than the fixed effects model;

(2) The F test for time-fixed effects where the null hypothesis is that the coefficients for all years are jointly equal to zero or that there is no time fixed-effects model needed;

(3) The Breusch-Pagan Lagrange multiplier (B-P/LM) for random effects where the null hypothesis is that variances across entities are zero or that there is no need to consider random effects;

(4) The Breusch-Godfrey/Wooldridge test for serial correlation where the null hypothesis states that there is no serial correlation in the panel model;

(5) The Breusch-Pagan test for heteroskedasticity where the null hypothesis is that the panel data is homoscedastic, meaning the variance of the error term is constant for all levels of the explanatory variables. If there is evidence of heteroskedasticity and serial correlation, we will apply Arellano robust covariance errors for the regression results;

(6) The Dickey-Fuller test for unit roots/stationarity where the null hypothesis states that the time series data of the sample has a unit root, meaning the statistical properties like mean and variance are not constant over time. If there is evidence of a unit root in the data, we will analyze the models using the first difference of the variables.

IV/ Empirical Analysis

Followed by the abovementioned steps under Section III, the two EKC models in this study are estimated and compared with the effects of trade openness and renewable electricity generation. The result of the Hausman test provides small p-values for both two equations, which rejects the null hypothesis of preferring random effects and indicates that fixed-effects models should be used (Refer to below Table 1). According to the F-test with p-values approximately equal to 0, the null hypothesis is rejected, meaning the coefficients across years are different and, hence, the time-fixed effects model should be considered (Table 1). The Breusch-Pagan Lagrange multiplier (B-P/LM) also produces very small p-values, very close to 0, which shows that the random-effects model should be conducted rather than the pooling ordinary least square (POLS) model (Table 1).

Table 1: Summary of statistical tests for panel data – fixed effects model

	Equation (1): LnCO2 ~ LnrealGDPPC + sqLnrealGDPPC	Equation (2): LnCO2 ~ LnrealGDPPC + sqLnrealGDPPC + Lntrade + LnREGofEG
Hausman test	chisq = 7.2515, df = 2, p-value = 0.02663	chisq = 10.993, df = 4, p-value = 0.02664
F test for time-fixed effects	F = 8.7229, df1 = 32, df2 = 1086, p-value < 2.2e-16	F = 6.0492, df1 = 32, df2 = 1062, p-value < 2.2e-16
Breusch-Pagan Lagrange multiplier (B-P/LM) for random effects	chisq = 17189, df = 1, p-value < 2.2e-16	chisq = 14590, df = 1, p-value < 2.2e-16
Breusch-Godfrey/Wooldridge test for serial correlation	chisq = 903.22, df = 33, p-value < 2.2e-16	chisq = 810.24, df = 33, p-value < 2.2e-16
Breusch-Pagan test for heteroskedasticity	BP = 844.92, df = 36, p-value < 2.2e-16	BP = 1108.9, df = 38, p-value < 2.2e-16
Augmented Dickey-Fuller Test	Dickey-Fuller = -4.8343, Lag order = 10, p-value = 0.01	

The results of the regression models for random effects, fixed effects, and fixed and time effects suggest that there is statistically significant evidence of an inverted-U shape of the EKC for the selected sample of data at 1% level of significance (Table 2). Under the random-effects model, the adjusted R-square of the regression equation (2) that includes trade and renewables is 0.6387, which is larger than the one of the regression equation (1) (Table 2). This outcome indicates that the addition of trade and renewables as explanatory variables helps the regression equation (2) explain a higher percentage of the variability in the sample, meaning the regression model in equation (2) is a better fit for our selected data.

Table 2: EKC and the roles of Trade and Renewables

Use robust covariance matrix estimation (sandwich estimator)

	Dependent variable: LnCO2 (Robust standard errors)					
	Random effects		Entity fixed effects		Entity & time fixed effects	
	(1)	(2)	(1)	(2)	(1)	(2)
LnrealGDPPC	4.1278***	3.4402***	4.1261***	3.4915***	4.6205***	3.9434***
	(0.7683)	(0.7035)	(0.7722)	(0.7158)	(0.6954)	(0.7283)
sqLnrealGDPPC	-0.1755***	-0.1508***	-0.1748***	-0.1529***	-0.2283***	-0.1933***
	(0.0397)	(0.0381)	(0.0399)	(0.0387)	(0.0411)	(0.0425)
Lntrade		0.3196**		0.3209**		0.1422
		(0.1544)		(0.1557)		(0.1311)
LnREGofEG		-0.3196***		-0.3040***		-0.2571***
		(0.0770)		(0.0792)		(0.0805)
Constant	-12.2179***	-8.3869**				
	(3.6609)	(3.7347)				
Turning point	$128,042.04	$89,904.09	$133,565.27	$90,907.08	$24,818.89	$26,908.75
Observations	1,155	1,155	1,155	1,155	1,155	1,155
R2	0.5561	0.6414	0.5639	0.6490	0.3997	0.4671
Adjusted R2	0.5546	0.6387	0.5458	0.6271	0.3758	0.4384
F Statistic	721.5668***	514.3359***	722.7048***	515.9120***	361.4903***	237.5172***
Note:	***Significant at the 1 percent level of significance; **Significant at the 5 percent level of significance; *Significant at the 10 percent level of significance. Standard errors are presented in parentheses.					

For each regression equation (1) and (2), the p-values of the three effects models and all the coefficients of explanatory variables are statistically significant at 1% and 5% levels of significance, except for trade under the entity and time fixed effects model (Table 2). The coefficients of trade in three cases are positive, which illustrates that as each individual country's trade openness index increases, the level of CO2 emissions increases (Table 2). While under the random and entity fixed effects models, the coefficients for trade are statistically significant at 5% level. The coefficient for trade under the entity and time fixed effect model is not significant. This outcome implies that when the model includes the effects of time, there are time lags in which the trade openness index of each individual country in the sample may fall under the average world index. The coefficients of renewable electricity generation have negative signs, meaning the increase in the share of renewable sources in the generation of electricity is associated with a decrease in CO2 emissions (Table 2). As the turning points are calculated for each regression equation, regression equation (2), with the inclusion of trade and renewable electricity generation, has the turning points lower than the standard EKC (1) under the random effects and country-fixed effects models (Table 2). When considering the effects of trade openness and renewables, the result of random effects models and country-fixed effects models confirm the hypothesis of a potential revised EKC among the selected sample of data. Under the country and time fixed effects model, the turning point is higher for equation (2) (Table 2). This result might reflect the time lags in the rate of adoption of renewable energy in developing countries.

V/ Policy Implications, Limitations, and Potential Avenues for Future Research

This study has found evidence of the inverted-U relationship between economic growth and CO2 emissions as well as the revised EKC hypothesis under random effects and country-fixed effects models when accounting for impacts of trade and renewables within the selected sample of data. Since an increase in trade openness is associated with the rise in CO2 emissions, this sample exemplifies the negative impact of trade on the environment, as proposed by the Displacement Hypothesis and Pollution Haven Hypothesis (Dinda, 2004). This outcome implies that under the current increasing rate of globalization, countries that are heavily dependent on trade must integrate strong environmental regulations with current and future trade agreements to promote sustainable development. This policy implication is essential for climate change mitigation actions, as it helps reduce the transboundary effects of pollution that the EKC literature has not yet captured.

The evidence of the negative relationship between renewable electricity generation and CO2 emissions in this study suggests that the adoption of renewable energy is a potential means to solve the risks of climate change impacts and volatile oil and natural gas supplies and prices, due to the depletion of fossil fuel resources (Menyah and Wolde-Rufael, 2010). The mean proportion of electricity generation from renewables in this sample is approximately 47.55%, which affirms the empirical findings of Chiu and Chang (2009) on the required share of renewables for pollution reduction. Thus, countries should diversify their investments in the energy sector by expanding the share of renewable energy since this important energy source absolves those countries from their heavy reliance on fossil fuels, reducing greenhouse gas emissions (Apergis et al., 2010). Governments must undertake effective strategies to stimulate investment in renewable energy innovations and mitigation actions to combat climate change.

While revisiting the EKC hypothesis, we acknowledge difficulties in finding a variable serving as a proxy for the adoption of renewable energy. Data unavailability for certain variables in some countries affects our sample size, which might explain the insignificance of the parameter for trade and a higher turning point for the EKC with the inclusion of trade and renewables under entity and time fixed effects. Since this study has not yet considered the structural effects of individual countries. We are unable to tell which economic sectors are bound to experience the heaviest impacts of trade and the adoption of renewable energy.

Future research should also investigate the existence of a long-run equilibrium relationship through panel cointegration techniques and explore whether there is evidence of causality through Granger tests among CO2 emissions, real GDP per capita, trade, and renewables for open economies. Additional variables such as political institutions, structural changes, and financial development should be included to help increase R-square and explain other omitted biases behind the EKC. However, caution regarding heteroskedasticity and interaction mechanisms should be carefully examined when adding explanatory variables. Finally, the EKC hypothesis can also be examined through a micro-perspective by using local environmental indicators such as land use changes. As reported by World Bank, the level of CO2 emissions is estimated directly from the burning of fossil fuels and the manufacture process. Even though this variable is mostly used as the response variable for EKC studies, this variable does not take into account transboundary effects over time. Similar to other greenhouse gases, CO2 has no political boundary.

VI/ Reference

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VII/ Appendix

VII.1/ Table 1: List of selected countries in the sample

Country List	Code	Income Group	Region
Austria	AUT	High income	Europe & Central Asia
Canada	CAN	High income	North America
Chile	CHL	High income	Latin America & Caribbean
Finland	FIN	High income	Europe & Central Asia
French	FRA	High income	Europe & Central Asia
Iceland	ISL	High income	Europe & Central Asia
Ireland	IRL	High income	Europe & Central Asia
Korea, Republic	KOR	High income	East Asia & Pacific
New Zealand	NZL	High income	East Asia & Pacific
Norway	NOR	High income	Europe & Central Asia
Portugal	PRT	High income	Europe & Central Asia
Sweden	SWE	High income	Europe & Central Asia
Switzerland	CHE	High income	Europe & Central Asia
United Kingdom	GBR	High income	Europe & Central Asia
Albania	ALB	Upper middle income	Europe & Central Asia
Bulgaria	BGR	Upper middle income	Europe & Central Asia
Costa	CRI	Upper middle income	Latin America & Caribbean
Dominican	DOM	Upper middle income	Latin America & Caribbean
Gabon	GAB	Upper middle income	Sub-Saharan Africa
Malaysia	MYS	Upper middle income	East Asia & Pacific
Panama	PAN	Upper middle income	Latin America & Caribbean
South Africa	ZAF	Upper middle income	Sub-Saharan Africa
Thailand	THA	Upper middle income	East Asia & Pacific
Bolivia	BOL	Lower middle income	Latin America & Caribbean
Cote d'Ivoire	CIV	Lower middle income	Sub-Saharan Africa
El Salvador	SLV	Lower middle income	Latin America & Caribbean
Guatemala	GTM	Lower middle income	Latin America & Caribbean
Honduras	HND	Lower middle income	Latin America & Caribbean
Indonesia	IDN	Lower middle income	East Asia & Pacific
Kenya	KEN	Lower middle income	Sub-Saharan Africa
Morocco	MAR	Lower middle income	Middle East & North Africa
Nicaragua	NIC	Lower middle income	Latin America & Caribbean
Philippines	PHL	Lower middle income	East Asia & Pacific
Sri Lanka	LKA	Lower middle income	South Asia
Zimbabwe	ZWE	Low income	Sub-Saharan Africa

VII.2/ Table 2: Descriptive statistics of raw and transformed data

```
===========================================================================================
Statistic       N        Mean            St. Dev.          Min         Median          Max
-------------------------------------------------------------------------------------------
CO2           1,155   94,470.56       151,684.80      1,477.80     32,386.94       599,539.80
realGDPPC     1,155   16,096.11        19,563.29        591.47      5,241.79        91,593.63
sqrealGDPPC   1,155 641,475,767.00 1,268,509,873.00 349,831.70 27,476,343.00 8,389,393,100.00
trade         1,155     74.83            30.74          24.93         67.60          220.41
REGofEG       1,155     47.55            31.96           0.06         50.00          100.00

LnCO2         1,155     10.22             1.65           7.30         10.39           13.30
LnrealGDPPC   1,155      8.83             1.38           6.38         8.56            11.43
sqLnrealGDPPC 1,155     79.93            24.76          40.74         73.35          130.53
Lntrade       1,155      4.25             0.35           3.22         4.21             5.40
LnREGofEG     1,133      1.15             0.58          -3.65         1.36             1.53
-------------------------------------------------------------------------------------------
```

Notes: Data was collected from the World Bank's World Development Indicators (2016) and the U.S. Energy Information Administration's International Energy Statistics (2016). Calculations are undertaken using RStudio.

VII.3/ Table 3: Dimension of the data

Country	Year	CO2	realGDPPC	….
Albania	1980			
	…			
	2012			
Austria	1980			
	…			
	2012			

VII.4/ Table 3: Quadratic EKC patterns with different coefficients

Inverted-U shape	U shape	Monotonically increasing	Monotonically decreasing	Level
$\beta_1 > 0$	$\beta_1 < 0$	$\beta_1 > 0$	$\beta_1 < 0$	$\beta_1 = \beta_2 = 0$
$\beta_2 < 0$	$\beta_2 > 0$	$\beta_2 = 0$	$\beta_2 = 0$	

Source: Lopez-Menendez et al. (2014)

VII.5/ Table 4: Results of the Principal Component Analysis among 24 indicators for environmental quality

Environmental variables	**Code**	**PC 1**	**PC 2**	**PC 3**
Alternative and nuclear energy (% of total energy use)	ANE	-0.01684	-0.30086	0.25466
Arable land (% of land area)	AL	-0.00699	0.082184	-0.10982
Capture fisheries production (metric tons)	CFP	0.49369	-0.27567	-0.38346
CO2 emissions (kt)	CO2	0.33261	0.029123	0.10514
CO2 emissions (kg per 2010 US$ of GDP)	CO2PGDP	0.025298	0.11065	-0.07106
CO2 emissions (metric tons per capita)	CO2PC	0.1402	-0.20592	0.27515
CO2 intensity (kg per kg of oil equivalent energy use)	CO2I	0.032711	0.01949	0.010149
Coal rents (% of GDP)	CR	0.008594	0.011407	-0.00076
Electric power consumption (kWh per capita)	EPC	0.13944	-0.3949	0.38101
Electric power transmission and distribution losses (% of output)	EPTDL	-0.04092	0.079029	-0.06282
Electricity production from oil, gas and coal sources (% of total)	EPFOGC	0.075232	0.27669	-0.21443
Energy use (kg of oil equivalent per capita)	EU	0.10749	-0.22541	0.265
Forest rents (% of GDP)	FR	-0.03666	0.099419	-0.05703
Fossil fuel energy consumption (% of total)	FFEC	0.042029	0.00603	0.015163
Methane emissions (kt of CO2 equivalent)	Mekt	0.25023	0.21423	-0.03403
Mineral rents (% of GDP)	MR	0.017237	0.030348	-0.04387

Natural gas rents (% of GDP)	NGR	0.047082	0.058681	0.035858
Nitrous oxide emissions (thousand metric tons of CO2 equivalent)	NO2mt	0.24375	0.18222	0.010322
Oil rents (% of GDP)	OR	0.043246	0.079989	0.072714
Other greenhouse gas emissions, HFC, PFC and SF6 (thousand metric tons of CO2 equivalent)	OGGEmt	0.36352	0.49571	0.48783
Population density (people per sq. km of land area)	PD	-0.01845	0.12153	-0.20623
Total fisheries production (metric tons)	TFP	0.48445	-0.25823	-0.33493
Total greenhouse gas emissions (kt of CO2 equivalent)	TGHGEkt	0.29691	0.17044	0.1125
Total natural resources rents (% of GDP)	TNRR	0.025946	0.15863	-0.01473

Notes: Data was collected from the World Bank's World Development Indicators. The results of the principal component analysis show that the first principal component, which captures the most variation of the data, is mostly explained by these variables: capture fisheries production (metric tons), total fisheries production (metric tons), other greenhouse gas emissions (thousand metric tons of CO2 equivalent), total greenhouse gas emissions (kt of CO2 equivalent), and CO2 emissions (kt).

VII.6/ Results of the similar regression models explained in section III/3 with other response variables

VII.6-a/ Using capture fisheries production as the response variable

```
===============================================================================
                  Dependent variable: LnCFP (log of capture fisheries production)
              -----------------------------------------------------------------
               Random effects      Entity fixed effects   Entity & time fixed effects
                 (1)         (2)         (1)         (2)         (1)         (2)
-------------------------------------------------------------------------------
LnrealGDPPC   3.4163***   3.2017***    3.4112      3.2149     3.7008***   3.5275***
               (0.8773)    (0.9930)                            (1.0370)    (1.1182)

sqLnrealGDPPC -0.1820***  -0.1746***  -0.1819     -0.1757     -0.2096***  -0.2006***
               (0.0501)    (0.0576)                            (0.0667)    (0.0702)

Lntrade                    0.1160                  0.1223                  0.0560
                          (0.2279)                                        (0.1710)

LnREGofEG                 -0.1020                 -0.0960                 -0.0647
                          (0.0862)                                        (0.0981)

Constant       -3.8282     -2.6683
               (3.9388)    (4.8549)
Turning      $11,913.64  $9,591.87  $11,808.57  $9,403.46  $6,824.29  $6,583.84
points
-------------------------------------------------------------------------------
Observations    1,155       1,155       1,155       1,155       1,155       1,155
R2              0.0834      0.0921      0.0845      0.0930      0.0882      0.0907
Adjusted R2     0.0819      0.0889      0.0550      0.0621      0.0311      0.0320
F Statistic   52.4411*** 29.1570*** 51.6066*** 28.6109*** 52.5108*** 27.0295***
===============================================================================
Note: ***Significant at the 1 percent level of significance;
       **Significant at the 5 percent level of significance;
        *Significant at the 10 percent level of significance.
         Standard errors are presented in parentheses.
```

VII.6-b/ Using total fisheries production as the response variable

```
==============================================================================
                         Dependent variable: LnTFP (total fisheries production)
              ----------------------------------------------------------------
                Random effects      Entity fixed effects   Entity & time fixed effects
                 (1)        (2)        (1)        (2)        (1)        (2)
------------------------------------------------------------------------------
LnrealGDPPC   3.5490***  3.3286***   3.5411     3.3458    4.0880***  3.8673***
               (0.9041)   (1.0299)                         (1.0924)   (1.1800)

sqLnrealGDPPC -0.1751*** -0.1729***  -0.1746    -0.1741   -0.2324*** -0.2210***
               (0.0498)   (0.0588)                         (0.0704)   (0.0735)

Lntrade                   0.3531                0.3586                0.1902
                          (0.2508)                                    (0.1849)

LnREGofEG                 -0.1230               -0.1156               -0.0755
                          (0.0993)                                    (0.1050)

Constant       -5.3479    -4.6545
               (4.1308)   (5.1423)
Turning      $25,190.17 $15,150.60  $25,351.85  $14,895.96 $6,602.35 $6,307.83
points

------------------------------------------------------------------------------
Observations    1,155      1,155      1,155      1,155      1,155      1,155
R2              0.1282     0.1596     0.1298     0.1615     0.1029     0.1112
Adjusted R2     0.1267     0.1567     0.1018     0.1329     0.0468     0.0538
F Statistic   84.7269*** 54.6114*** 83.3848*** 53.7243*** 62.2978*** 33.9085***
==============================================================================
Note: ***Significant at the 1 percent level of significance;
       **Significant at the 5 percent level of significance;
        *Significant at the 10 percent level of significance.
        Standard errors are presented in parentheses.
```

VII.6-c/ Using total greenhouse gas emissions as the response variable

```
================================================================================
                  Dependent variable LnTGHGEkt: total greenhouse gas emissions
              -------------------------------------------------------------------
                Random effects      Entity fixed effects   Entity & time fixed effects
                  (1)        (2)          (1)        (2)         (1)        (2)
--------------------------------------------------------------------------------
LnrealGDPPC      1.8720*     1.5170     1.8814      1.6068     2.0776**   1.7582*
                (1.0972)    (1.1234)                          (0.9746)   (1.0458)

sqLnrealGDPPC   -0.0789     -0.0661    -0.0789     -0.0705    -0.1011*   -0.0846
                (0.0611)    (0.0599)                          (0.0527)   (0.0541)

Lntrade                      0.1759                 0.1848                0.1221
                            (0.1739)                                     (0.1238)

LnREGofEG                   -0.1598                -0.1355               -0.1181
                            (0.1011)                                     (0.1055)

Constant         0.8359      2.7494
                (4.9334)    (5.1226)
Turning       $141,934.06 $96,282.11  $150,645.84  $88,942.43 $28,997.80 $32,573.45
points

--------------------------------------------------------------------------------
Observations      1,155       1,155       1,155       1,155       1,155       1,155
R2               0.1541      0.1830     0.1574      0.1837      0.0735      0.0885
Adjusted R2      0.1527      0.1801     0.1302      0.1559      0.0155      0.0296
F Statistic   104.9474*** 64.3897*** 104.4021*** 62.8034*** 43.0826*** 26.3068***
================================================================================
Note: ***Significant at the 1 percent level of significance;
       **Significant at the 5 percent level of significance;
        *Significant at the 10 percent level of significance.
         Standard errors are presented in parentheses.
```

VII.6-d/ Using other greenhouse gas emissions as the response variable

```
======================================================================
                       Dependent variable: LnOGGE other greenhouse gas emissions
              --------------------------------------------------------
               Random effects     Entity fixed effects   Entity & time fixed effects
                 (1)       (2)      (1)      (2)        (1)       (2)
----------------------------------------------------------------------
LnrealGDPPC    0.2916    1.2046    0.5914   1.7836     0.5186   1.8209
              (4.7495)  (5.6349)                     (4.3179) (5.1024)

sqLnrealGDPPC  -0.0162  -0.0662  -0.0383  -0.1032    -0.0241   -0.0919
              (0.2623)  (0.2971)                     (0.2240) (0.2501)

Lntrade                  0.2676            0.3821              0.5765
                        (0.6911)                              (0.4793)

LnREGofEG                0.3432            0.4873              0.5441
                        (0.5662)                              (0.6217)

Constant       6.4815    0.1122
              (21.2005) (25.4874)
Turning      $8,103.08  $8,939.07 $2,254.37 $5,661.66 $47,067.41 $20,069.65
points

----------------------------------------------------------------------
Observations    1,155     1,155    1,155    1,155    1,155     1,155
R2             0.00005   0.0069   0.0005   0.0124    0.0003   0.0166
Adjusted R2    -0.0017   0.0034   -0.0317  -0.0213  -0.0623   -0.0469
F Statistic    0.0276    1.9891*  0.2561  3.4928***  0.1527  4.5756***
======================================================================
Note: ***Significant at the 1 percent level of significance;
      **Significant at the 5 percent level of significance;
       *Significant at the 10 percent level of significance.
        Standard errors are presented in parentheses.
```

The results of four cases generate evidence of the inverted-U association between real GDP per capita and CO2 emissions. However, most of the parameters are not statistically significant. The parameters for trade and renewables are not significant in all the models under the above four cases. The existence of the revised EKC hypothesis is found in most of the regression models, but we cannot make any conclusion based on these outcomes.